Work submitted for the award of
Doctor of Dental Science

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Specialisms and contributions of knowledge to the field

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None of the work submitted herewith has been submitted or is being submitted concurrently in candidature for any other degree.

R. J. Williams

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INTRODUCTION

During my undergraduate and postgraduate education my studies crossed several academic boundaries. This broad educational experience has been critical in the achievement of applying developing technologies within engineering to my chosen field of dental technology. Indications of my standing within my own field are that I am appointed by the General Dental Council as an Inspector of Courses and also as a General Dental Council Assessment Panel Member to consider applications for statutory registration from abroad. Since September, 2010, for example, I have inspected 2 programme proposals. I attend Assessment Panels about 6 -8 times per year. I am also currently an External Examiner to the Fd Sc Dental Technology programme validated by De Montfort University and franchised to Lambeth College, London; Castle College, Nottingham; Matthew Boulton College, Birmingham; and Liverpool Community College.

In recent years I have attracted 3 full time research students (2 Ph Ds and an M Phil), sponsored by the governments of the students, and acted as Director of Studies to these students. Two of these have already successfully completed and the third is continuing satisfactorily. I have been an Editor of a well respected journal of the profession (Journal of the British Institute of Dental and Surgical Technologists), 1992 to 2001, I have been an external examiner to dental technology degrees at Manchester Metropolitan University, to a Ph D submission to Sheffield Dental School. In March, 2010 I was guest of honour and launched a multi-million Computer Assisted Design/Computer Assisted Manufacture/Rapid Manufacture (CAD/CAM/RM) machine constituting a major investment by Renishaw – an international firm marketing RM products in dentistry based in Gloucester:

In addition, recently (2nd - 7th April, 2011) I visited Ghana being a partner in a successful joint bid between UWIC and the Ghana Health Authority for funding from the Welsh Assembly Government’s International Health Links Funding Scheme – Start up Award. The project was to explore the possibilities of enhancing dental public health in the Kadjebi region of Ghana. As a result of a successful visit, a confident bid for further funding has been submitted for £15K to improve dental public health in Ghana.

The accompanying list of publications and presentations indicate a long standing successful discipline-specific interest in the application of CAD/CAM/Rapid Manufacturing (RM) and of applying IT to dental technology learning and teaching.

APPLICATION OF CAD/CAM/ RAPID MANUFACTURE TO DENTISTRY

Developments in this field have been amongst the most recent and perhaps the most exciting focus of my activity. The developments I have pioneered are likely to eventually supersede conventional techniques in the field of removable partial denture (RPD) alloy framework fabrication which is currently labour intensive. Renishaw have recently initiated trials with the applications developed at UWIC. Traditionally, unique, patient-specific, alloy frameworks have been constructed using the ‘lost wax’ process. This procedure is used throughout dentistry but over the past fifteen years or so, IT techniques have been widely introduced in the field of crown and bridge technology where the crown or bridge is milled from a solid block and controlled by IT. Digital technologies however failed to make any progress in the area of RPD alloy framework fabrication until the completion of research began over recent years in UWIC which I led. RPD framework shapes are far too complicated to be milled from a block. The research I initiated and have continued with in
collaboration with colleagues from the Product Design and Research Centre has culminated in the direct building of alloy frameworks by the use of RM technology.

To make progress in this area initially several physical processes needed to be mimicked in a virtual world. For example, electronic surveying and virtual ‘wax’ patterning were developed and achieved at UWIC. Initially plastic patterns were produced and used in the casting process. However, in 2006 a world first was achieved by the team at Llandaff in collaboration with a consultant clinician whereby an RPD alloy framework was successfully fitted to a patient without the use of a physical wax or plastic pattern and without casting. A paper describing this step forward – that of producing direct metal builds – was published in 2006 (Williams, Bibb, Eggbeer et al - see ‘Publications’). Case studies of patients fitted with CAD/CAM/RM frameworks are planned, capitalising on and consolidating the advantages the technique offers.

Following research at UWIC, utilising digital scanning techniques, an electronic sculpting environment and RM processes, there is potential for current traditional techniques to become obsolete and the method of fabrication to be revolutionised. For the paper mentioned above, clinical colleagues assisted the team at UWIC to achieve the world first in trial fitting a removable partial denture framework to a patient. Currently a few other groups have begun to apply such techniques in this way but the UWIC team remains ahead. Adoption of the new digital technologies enables fundamental stages such as metal alloy casting and wax pattern production to be entirely omitted. Recent findings indicate that the alloy framework produced by RM has better mechanical and biocompatible properties than cast alloys, perhaps due to the control and standardisation digital technology offers. Casting can be
imprecise and operator dependent. The ground-breaking achievements noted above arise from UWIC’s CAD/CAM/RM research and mark the proof of concept stage.

A funding award, the UWIC Research Opportunity Fund, enabled some of the above development to take place.

The results achieved so far have only been able to be assessed by a trial fitting, i.e. the framework was left in the oral cavity for a brief period, a matter of minutes. Further studies were needed to ensure that the alloy used in the RM process was biocompatible. For the development of this aspect it was possible to interest an international clinical partner, Dr Danimir Jevremovic, University of Privredna Akademija, School of Dentistry, Pančevo, Serbia. The last few papers cited in the list of publications will show that the relationship is beginning to bear fruit. One collaborative cytotoxicity study has shown that the RM alloy compared well to an alloy already in dental use. In addition, the results of a UWIC M Phil study of which I am Director of Studies, recently completed, has shown that the ion release of over 90% of the constituents of an RM alloy is safe and in fact again performed better than an alloy already in use. The study conformed to an International Standard. Publications are planned arising from the research degree, one has been submitted. Developments are reaching the stage where long term case studies can be undertaken and an agreement will be sought between UWIC, the University in Serbia and Renishaw, to move quickly towards case studies in the near future. Such a partnership is rife for EU funding applications and Renishaw are interested in offering RM produced RPD alloy frameworks. If this occurs, the knowledge transfer will be very significant indeed on a world scale.
APPLICATION OF IT TO DENTAL TECHNOLOGY EDUCATION

A second major thrust of my research has been in the field of learning and teaching. Initial research which culminated in a BT Academic Award obtained with a partner institution. Manchester Metropolitan University joined with UWIC on a project taking place between 1997-1999. Many useful learning aids were produced as a result and increased resources were added to the dental technology suite. Two other UWIC Learning and Teaching Funded Awards (Calls 2 and 4) were also gained with the result that the dental laboratories in UWIC were transformed and greatly enhanced with new educational technologies. Within the specialised laboratories, there are now networked computers with large screens available to students in the labs, at the point of learning, a demonstrator’s bench housing a PC, large monitor, a VCR, a wide-angle camera and a mini camera. This has resulted in practical demonstrations of events on a scale of a few millimetres being visible to class sizes of above 20, whereas previously only a few students at a time could realistically see a live demonstration. The facility also allows the creation of high quality learning support materials. The result has been a much more efficient and student-centred delivery with student waiting time virtually eliminated. One laboratory is also equipped with video conferencing equipment so that all images created by the cameras mentioned above, along with presentations (e.g. PowerPoint) can be sent over the web and images received in the lab.

The above established a basis for more recent developments in the use of web based video conferencing to deliver dental technology related subjects to students at a distance. I have been instrumental in the development of the application of relevant packages, which have become routine within the Dental Technology Unit at UWIC but which are at the forefront of dental educational progress. Publications are planned.
DEVELOPMENT OF DENTAL PUBLIC HEALTH

I have been active in the initiation of participation by the Dental Technology Unit in the Africa Partnership Initiative (API), an initiative that was developed by Design Wales and the Cardiff School of Health Sciences (CSHS) at UWIC. The aim of the API is to provide opportunity, through collaboration, to further develop the use of appropriate and relevant technology and community resources as a basis to promote and develop projects in Africa. API is also a member of Wales for Africa Health Links Network.

During the initial fact finding visit of the team at UWIC of which I was a part, it became clear that there were a number of dental and environmental health issues which required attention in the district. My role in the delegation was to be in charge of dental technology training activities. The aim of the visit was to develop an activity plan aimed at capacity building and to determine priority areas in dental and environmental health. There is no doubt that the team at UWIC is in an excellent position to obtain further substantial funding for the next phase of the activity.

CONCLUSION

The foregoing indicates an interest and energy directed towards several areas of dentistry. The lines of enquiry indicated by the above continue to be pursued with vigour and enthusiasm.
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PUBLICATIONS AND PRESENTATIONS TO LEARNED SOCIETIES
(In reverse chronological order.)


26) **Williams, R J** (1993) 'Dentist/Technician Communication', Presentation to the General Dental Practitioners Post-graduate Diploma, Prince Charles Hospital, Mid Glamorgan, April.


29) **Williams, R J** (1989) The Use of Computers in Dental Technology Education, Denny Award, British Institute of Surgical Technologists, Sevenoaks

30) **Williams, R J** (1989) Computers in Dental Technology, Proceedings of the Society of University Dental Instructors, University of Bristol, March/April


34) **Williams, R J** (1987) A Perspective on Teaching, Dental Laboratory, Nottingham, July


A selective laser melted Co–Cr alloy used for the rapid manufacture of removable partial denture frameworks – initial screening of biocompatibility

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Abstract: The aim of this study was to determine the cytotoxicity of a Co–Cr alloy used for the rapid manufacture of removable partial denture frameworks using murine fibroblasts L929 cell lines and three test methods: the MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide, a yellow tetrazole) assay, the agar diffusion test (ADT) and the dye exclusion test (DET). Two groups of disc specimens (5 mm diameter, 1 mm thick) were fabricated. The first group was cast using a conventional method (CM) in a Nautilus CC casting. The second group was fabricated using selective laser melting (SLM) in SLM Realiser. The total cell number and viability of cells pre-incubated with CM and SLM alloys were comparable to the control sample. Differences between the growth inhibitory effects of the CM and SLM alloys in the MTT assay were below 30%. Results of two independent agar diffusion tests with CM and SLM alloys showed neither detectable discoloration around or under the discs nor a detectable difference in staining intensity. As the cell response for both CM and SLM alloys was 0/0, the discs can be rated as non-cytotoxic. The results suggested that the F75 Co–Cr alloy used for the SLM process did not release harmful material that could cause acute effects against L929 cells under the given experimental conditions.

Keywords: dental alloys; selective laser melting; cytotoxicity; removable partial dentures.

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INTRODUCTION

Over the last decade, there has been a rapid increase in the employment of computer-aided design (CAD) and computer-aided manufacture (CAM) in dental applications. The majority of currently used CAD/CAM systems are based on a milling procedure, whereby requested forms, such as frameworks or full anatomical crowns, are fabricated by milling material from a block. Additive manufacturing (AM), on the other hand, uses a revolutionary layering additive technique, enabling the production of complex customized shapes, such as removable partial denture (RPD) frameworks.

In recent years, the term "additive manufacture" (AM) has been used to describe the fabrication of functional, end use components in a layer-by-layer manner. AM enables the fabrication of geometries unsuitable for alternative methods and can be ideal for low volume or one off production, especially in medical applications. In dental technology, research has shown that a combination of CAD and AM may be used to replace laboratory crafting techniques. Furthermore, the AM process, selective laser melting (SLM, Realiser GmbH/MTT-Group) has been used to fabricate RPD frameworks.

The potential advantages of such a process over conventional laboratory techniques can be summarized as reduced manufacture time, inherent repeatability and elimination of inter-operator variation. In addition, CAD could provide some automation of dental processes (for example, cast analysis, undercut elimination and path of insertion identification).

The first steps towards clinical trials have been completed. A RPD framework was made by means of scanning a patient's cast followed by virtual surveying and framework design using CAD, and then CAM production using SLM technology. Conventional finishing and polishing procedures were used to complete the RPD framework. The conclusions of the pilot study were that CAD/SLM produced frameworks that were comparable to conventional frameworks in terms of accuracy, quality of fit and function. However, this conclusion was based on a single study and no long-term results are available since there is no known data about the biocompatibility of the specific cobalt-chromium alloy used for the SLM process. Though the basic chemical elements generally match those of the conventional casting alloy, it has been stated that alterations in the composition and pre-treatment can greatly influence the cytotoxicity of an alloy. Cell culture studies are the usual starting point when evaluating biocompatibility, providing an investigation of toxicity in a simplified system that minimizes the effect of confounding variables. By using cells from the murine fibroblast cell line, the cytotoxicity of various dental materials, including dental alloys, can be determined. This study used murine fibroblasts (L929) in accordance with the requirements of the ISO standard 7405 (ISO 2008). The aim was to determine the cytotoxicity of the Co–Cr alloy used for the fabrication of
LASER MELTED Co-Cr ALLOY BiOCOMPATIBILITY

an SLM RPD framework by using L 929 cell line and three test methods: the MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide, a yellow tetrazole) assay, the agar diffusion test (ADT) and the dye exclusion test (DET). To the best of our knowledge, there are no reports about the cytotoxicity of the selected laser melted Co–Cr alloy used for the rapid manufacture of RPD frameworks.

EXPERIMENTAL

Sample preparation

a) Conventional method (CM) samples. The composition of the commercially available alloy Remanium GM380+ (Dentaurum, Ispringen, Germany) used in this study is presented in Table I.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Co</th>
<th>Cr</th>
<th>Mo</th>
<th>Si</th>
<th>Mn</th>
<th>N</th>
<th>C</th>
<th>Fe</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remanium 380+</td>
<td>64.6</td>
<td>29</td>
<td>4.5</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandvik Ospreys F75</td>
<td>Balance</td>
<td>27–30</td>
<td>5–7</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td></td>
<td>&lt;0.35</td>
<td>&lt;0.75</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

The alloy is a non-precious Co–Cr alloy containing no Ni, Be or Fe, which is widely used as a cast partial denture alloy. Five disc specimens (5 mm diameter, 1 mm thick) were obtained from wax patterns that were invested and cast according to the manufacturer’s instructions. The investment used was Rema dynamic (Dentaurum, Ispringen, Germany), and vacuum casting was performed using a Nautilus CC (Bego, Bremen, Germany). After casting, the discs were divested and blasted with 100 μm aluminium oxide particles, then polished with silicon carbide papers in the sequence 320, 400, 600, 1200, 1500, and 2000. Final polishing was performed using oxide pastes.

b) Selective laser melting (SLM) samples. Five disc specimens (5 mm diameter, 1 mm thick) were first built in a virtual environment (Magics, Materialise, Belgium). The physical specimens were produced using an SLM Realiser (MTT-Group, UK). The powdered alloy used in the process was a Co–Cr type alloy, the composition of which contained a maximum of 0.5 % Ni (F75 alloy, Sandvik Osprey Ltd., UK, Table I). After the build, the supporting structures were removed, and then the samples were prepared as described above for the cast samples.

Cell lines

L-929 cells were grown in a suitable culture medium, supplemented with antibiotics to prevent the growth of opportunistic microorganisms. The cell population was divided twice a week and placed in fresh media to stimulate growth and development. The tissue was broken into a suspension of single cells by enzymatic digestion in the presence of a chelating agent. The cell lines were cultured in 25 cm² flasks at 37 °C in 100 % humidity and 95 % air, 5 % CO₂. Only cells in the rapid or exponential growth phase of development were used for the assays. The cell number and percentage of viable cells were determined by a dye exclusion test (DET) with Trypan Blue. The viability of the cells used in the assay was over 90 %.

Cytotoxicity tests

The cytotoxicity was measured as a percentage of cell growth inhibition using the three tests described below.
a) **Dye exclusion test (DET).** Petri dishes (50 mm; Falcon, Becton Dickinson and Comp., Franklin Lakes, NJ, USA) containing CM or SLM alloy discs were plated with viable mouse cells and incubated for 24 h at 37 °C in 95 % air and 5 % CO₂. Control samples were also incubated but contained no alloy discs. After incubation, a single cell suspension was obtained by trypsinization. Cell number and viability were assayed by Trypan Blue staining in a counting chamber.\(^5\) (Dead cells take up Trypan Blue whilst living cells do not.) Over 90 % of the cultured cells were viable (i.e., no uptake of Trypan Blue) when assayed.

b) **MTT assay.** Growth inhibition was also evaluated by the tetrazolium colorimetric MTT assay (ISO 2009).\(^1\) The assay depends on the cleavage of the tetrazolium salt MTT to purple formazan crystals by mitochondrial dehydrogenases in viable cells.

Cells (L929) were cultured in Petri dishes containing CM or SLM alloy discs and incubated for 24 h at 37 °C, in air containing 5 % CO₂. The control samples contained no discs. After incubation, the cells were detached from the alloy discs using enzymatic digestion, and counted in a counting chamber using Trypan Blue stain. New cells were cultured for 48, 72 or 96 h at 37 °C in 95 % air and 5 % CO₂. These cells were then cultured for 3 h with yellow MTT solution and the purple formazan product was isolated and dissolved in 100 μl of 0.04 M hydrochloric acid in 2-propanol. The cytotoxicity was expressed as the percentage growth inhibition.

c) **Agar diffusion test (ADT).** L-929 cells were incubated for 24 h at 37 °C in 95 % air and 5 % CO₂ after plating on Petri dishes (10 mm). The concentration of cells was 10 ml; 2.5×10⁵ cells ml⁻¹. Sterile agar was heated and a nutrient medium added. The mouse cells were combined with the agar-nutrient mixture and allowed to solidify over 30 min. The cells were stained with a neutral red solution (or toluidine red, Basic Red 5, or C.I. 50040; IUPAC name: toluidine red) and kept in the dark for 15 min. Two samples of CM or SLM discs were placed into each Petri dish and the dishes incubated for 24 h at 37 °C in 95 % air and 5 % CO₂.

Any interaction between the metal and the cells, causing the cells to die and lose the red dye, was noted using an inverted microscope, Reichert-Jung, Biostar, model 1820E. It is well known that living cells retain the red dye. Thus, the decolourised zones of dead cells were measured using a ruler and analysed according to ISO standards (2008).\(^1\) The results were evaluated according to the zone and lyses index and rated for the severity of the cytotoxicity, as described previously.\(^1\) Each product was tested in quadruplicate and the experiment was repeated twice.

Statistical analysis was realised using the Statgraphics Centurion program. The data were statistically evaluated by the Student’s t-test. A value of *p* < 0.05 was considered statistically significant.

**RESULTS**

Rounded, disc-shaped experimental samples are shown in Figs. 1 and 2 (CM and SLM samples, respectively). The unpolished SLM samples exhibited very fine surface roughness, caused by the transition of the laser beam during the manufacturing process. The polished samples correspond to the state of the final alloy under oral environmental conditions.
Fig. 1. CM Samples (left – cast and sandblasted, right – polished).

Fig. 2. F75 SLM Samples (left – untreated, right - polished). Note the fine surface roughness of the untreated sample caused by the laser beam.

The L929 fibroblasts were pre-incubated in culture medium with CM or SLM alloys for 24 h and then the survival rates of the pre-treated cells were evaluated by the standard procedure for the DET or MTT assay. The results of the DET and MTT assays are presented in Figs. 3 and 4, respectively.

Fig. 3. Dye exclusion test (DET). Recovery of L929 cells pre-incubated with CM and SLM alloys for 24 h. The results show the relative cell number obtained from two independent experiments completed in triplicate. Data are shown as the mean and the bar indicates the standard deviation ($p > 0.05$).

The variation in the cell numbers of pre-incubated cells compared to the control sample was small: 8 percent below and 15 percent above the control value for both the CM and SLM alloys, respectively. The viability of each sample was 99%.
The cell number steadily increased during the recovery period for both CM and SLM alloys (48–96 h), which indicated that no cytotoxic effects were registered in the several cell generations. There were no statistical significant differences between treatments regardless of the recovery period.

In the MTT assay during the same recovery period, no cytotoxic effects of the CM or SLM alloys against L929 cells were detected (Fig. 4). Differences between the growth inhibitory effects of CM and SLM alloys were found but the growth inhibition level was not statistically significant ($p > 0.05$). Therefore, both alloys can be rated as non-cytotoxic.

![Fig. 4. MTT Assay. Survival of L929 cells pre-incubated with CM and SLM alloys for 24 h.](image)

The results represent the relative absorbance of the pre-treated cells obtained from two independent experiments, completed in quadruplicate. The data are shown as the mean and the bar indicates the standard deviation ($p > 0.05$).

The results of two independent ADT with CM and SLM alloys showed a detectable discoloration neither around nor under the discs, or a detectable difference in the staining intensity. As the cell response to both the CM and SLM alloys was 0/0, the discs can be rated as non-cytotoxic.

**DISCUSSION**

Super-alloys, such as Co–Cr, are suited to the SLM process as the material properties facilitate the process physics, such as melt-pool and temperature gradient control. However, alloys available for AM processes, such as SLM, routinely include nickel. When the specifications for these alloys were developed, there were allowable levels of various elements, which permitted recyclers more flexibility in making low-cost alloys. The alloy used for the tests reported herein contained a maximum of 0.5 % nickel. AM alloys containing a maximum of 0.1 % nickel can be obtained but this adds considerably to the cost.
Among other elements, the use of nickel in dental alloys has often been attacked because of its potential side effects. Severely cytotoxic Co–Cr alloys contained high amounts of Ni, although no general correlation between the overall alloy composition and cytotoxicity was detected. While Co and Cr undergo redox-cycling reactions, the primary Ni route is depletion of glutathione and bonding to sulph-hydryl groups of proteins. However, it can be stated that Ni showed a negative effect in combination with certain other metals and, therefore, does not necessarily contribute to a toxic or allergenic potential. Generally, element release is not simply proportional to its abundance in the bulk alloy, but is also highly dependent on the inter-ionic interactions within the alloy.

Cytotoxicity tests can implement several cellular parameters, such as cell viability, DNA/RNA/protein synthesis, membrane integrity, etc. In this study, cytotoxicity was assessed by three methods, addressed to different ends, i.e., viability and cell survival. Viability was determined by short-term (24 h) ADT and DET assays, and cell survival, after cell pre-treatment with the alloys, by DET and MTT assays. Although only the ADT assay has been prescribed as an ISO standard (ISO 2008), the use of different test methods is highly advisable. While the DET and ADT methods rely on the breakdown of membrane integrity, the MTT method focuses mainly on the mitochondrial function (dehydrogenase activity). Although the last test showed a slightly worse outcome for the SLM alloy, cellular proliferation in the subsequent period (48, 72 and 96 h), which covered several cell cycles i.e., cell generations, showed no significant damage to the cell function. Replication during an extended contact period with potential toxic substances, however, showed good biocompatible properties of the chosen SLM alloy. Furthermore, membrane lyses was not detected in the ADT or DET assay when L929 fibroblasts were exposed to the examined alloys. The negative effect decreased with time for both examined substances.

The results suggested that the alloys did not release harmful material that could cause acute effects against L929 cells under the given experimental conditions.

In an oral environment, the intimate contact between the alloy and tissues can create microspaces with a high concentration of released metal ions. Alloy surface properties can be of decisive importance in such situations; a point supported by findings suggesting less biocompatibility in under as-cast alloy conditions compared to its highly polished state. Enhanced contact might lead to local adverse tissue reaction. Ensuring that cast or AM-produced frameworks are appropriately finished and that their porosity is low remains dependent on human subjectivity.

The murine L929 fibroblast assays represent sufficient screening models for an investigation of the in vitro toxicity of metal cations. They exhibit a similar
response with gingival fibroblasts; hence, it can be assumed that the SLM alloy also does not have cytotoxic effect on gingival tissue.\textsuperscript{20,22,23} Generally, corrosion is characterized by electrochemical phase boundary reactions which cause the liberation of metal ions.\textsuperscript{14} The amount and nature of released cations varied depending upon the type of alloy and other parameters, \textit{e.g.}, type of corrosion, composition and chemical characteristics of the corrosive solution such as pH and ionic composition, artificial saliva, cell culture medium, serum, \textit{etc.}\textsuperscript{24-27} In one study, ion release from cast and SLM Co–Cr alloy was compared.\textsuperscript{28} The main ion released was cobalt, as, due to the passivating behaviour or chrome, only a small amount of chromium and molybdenum was detected. Due to the low releases of ions, the corrosion was influenced almost completely by the surface. The SLM test specimens showed lower emissions than the cast specimens did because the laser molten material is more homogeneous, contains fewer pores and has a finer microstructure. However, almost no difference was detected after two weeks between the different variants examined, having concentrations below the detection limit of the analyzing method.

However, oral mucosa could present only an increased resistance towards the leakage of cytotoxic agents, as it becomes keratinised and has a protective mucin layer. On the other hand, it should be emphasized that the oral environment includes severe biological factors, plus interactions such as saliva composition, pH status, \textit{etc.} Nevertheless, based on the obtained data, the SLM alloy shows promising potential to withstand environmental conditions and have a life span comparable to the currently used cast alloy when biocompatible properties are concerned.

Although the lost wax procedure has been a central technique in RPD framework production for a very long time, AM with its link to information technology might be of great interest in dentistry in general.\textsuperscript{24} Linking intra-oral scanning to CAD and AM has the potential to remove laborious laboratory techniques and improve accuracy and repeatability.

Future research on the mechanical properties, as well as \textit{in vivo} tests of the SLM or other AM produced dentures are necessary to show whether in reality a revolution is at hand, as it appears.

**CONCLUSIONS**

Based on the results of the MTT, ADT and DET tests employed in this study, it can be concluded that the Co–Cr alloy routinely in use in AM technologies such as SLM, does not exhibit cytotoxic potential. Further clinical trials should be performed to show the \textit{in vivo} behaviour of this alloy under oral environmental conditions.
ИЗВОД

СЕЛЕКТИВНО ЈАСЕРСКОТОПЉЈЕЊЕ CO–Cr ЛЕГУРЕ ЗА СКЕЛЕТИРАНЕ ПРОТЕЗЕ – ИНИЦИЈАЛНА ПРОЧЕНА БИОКОМПАТИБИЛНОСТИ

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Циљ студије је да одржи цитотоксичност F75 Co–Cr легура, која се употребљава током компјутерског процеса производње скелетираних протеза, коришћењем L929 ћелијског линије мишијих фиброобласта и три методе: MTT теста, агар дифузионог теста (ADT) и теста губиљења боје (DET). Направљене су две групе узора (5 пута пречника, 1 пук делбилија). Празна група је изложена од легура кобалт-хром конвенционалном методом (СМ) у пени за лиоени Nautilus CC. Друга група је направљена коришћењем методе селективног топљења лазером (SLM) у апарату SLM Realiser. Укупан број ћелија, преилигираних са CM и SLM легуrom, као и њихова одрживост узора не су било од урмених узора. Разлике у инхибаторном ефекту на раст CM и SLM легура у MTT тесту биле су мање од 30 %. Резултати два независна агар-дифузионог теста са CM и SLM легуrom не показују асоцијацију обезбожавање око или испод дискова, нити приметну разлику у интензитету пребојавања. Касно ћелијски одговор за CM и SLM легуру био 0/0, дискови се могу окарактерисати као не-цитотоксични. Резултати сугеришу да F75 Co–Cr легура, која се користи у SLM процесу добија скелетираних протеза не открива штетне материје, које могу проузроковати акутне ефекти на ћелију L929 ћелија, и под условима високог кисеоника.

(Примешено 6. априла, ревизирано 28. јуна 2010)

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THE USE OF STEREOLITHOGRAPHIC DATA FOR THREE DIMENSIONAL FINITE ELEMENT ANALYSIS MODEL GENERATION

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Abstract

Introduction. Computerized simulations, such as Finite Element Analysis (FEA), can be useful for research and even replace expensive and time-consuming procedures that are associated with 'in-vitro' studies. Virtual model generation can be advantageously applied to the most important and most intricate areas of inquiry.

Materials and methods. In this study a three-dimensional scanner (Steinbichler Optotechnik) was used. Scan data was utilized to develop a stereolithographic data file using appropriate software (InnovMetric PolyWorks IMAlign, and Alias Wavefront's 'Spider'). Conversion of the .stl file into a volume model suitable for FEA analysis was generated using Catia software.

Results. For the model description, 155355 nodes and 104491 elements have been used. Elements were tetrahedral, second class. The generated model can be further manipulated, meaning different variants suitable for further analysis can be achieved.

Conclusions. Using such a methodology, a precise model of irregular form, for example a tooth form, can be achieved. Although there is a cost in terms of time and money, once the model is achieved a gate towards simple and efficient FEA analysis is opened.

Key words: finite element analysis, stereolithography

Introduction

Scientific conclusions are usually based on objective data, gained by controlling variables in experimental conditions. It is often presumed that real experimental tests yield the most accurate results. However, there are often many...
for the implementation of physical experiments. For example, complexity, duration and the number of variables involved, as well as time and cost, are factors which can prohibit progress. Furthermore, some conceivable experiments are impossible to implement practically.

In order to overcome the above mentioned problems, computerized simulations which replicate actual conditions have become a part of science over the previous four decades and dentistry has been included in this development. The combination of different materials, as well as complex morphology makes a tooth very hard to subject to a stress and strain analysis, for example. Simulations on a computerized model can also include the possibility of checking the interaction of different variables. Therefore, finite element analysis (FEA) has become one of the leading techniques for the analysis of physical phenomenon in the field of structural, solid body and fluid mechanics.

FEA is a mathematical method which transforms a real object into a virtual model. The method consists of defining the object in a finite number of constituents. Model variables are approximated with defined mathematical functions. Each small constituent, called an ‘element’, is assigned with a specific mathematical function, enabling individual deformation to be more precisely calculated than if the structure was taken as a whole. The function assigns physical properties to each specific element but the union of the parts allows the behavior of the entire virtual model to be studied.

FEA finds its application in different industrial fields. In biomechanics, FEA also has advantages both as an investigative and a teaching tool. The method is very useful since it can offer analyses which would be impossible by other methods. However, several limitations of FEA application have surfaced over time. Its introduction in dentistry was in 1972, with articles by Breckelmans, et al., and today it can be found more or less in all branches: dental materials, oral and maxillofacial surgery, orthodontics, endodontics and conservative dentistry, implantology and, of course, prosthodontics.2-7

Today, the use of FEA, especially in combination with real experiments, sets a standard for many investigations that are considered contemporary. Use of FEA models enables a reduc-
Danas, upotreba MKE metode, naročito u kombinaciji sa realnim eksperimentom, standard je mnogih istraživanja koja sebe smatraju savremenim.8 Ona omogućuju smanjenje troškova i vremena od idejne zamisliti do realizacije željene ideje, kao i povećanje poverenja u odabrani dizajn virtualnim testovima pod velikim brojem različitih uslova.

Najvažniji deo MKE studije je, svakako, MKE model. Njegove karakteristike imaju ogroman uticaj na kvalitet i validnost dobijenih rezultata. Stoga je generacija MKE modela jedan od ključnih faktora virtualne analize. Najvažniji nosi epitet MKE Prosežan i ogroman phodnost egzaktnih morfoloških značajki, gde njihov veći deo izlazi po realnoj tehnici, veoma obiljem sličnosti realnih deo objektova.

Metod rada

a) skener

Tromensionalno skeniranje je metod dobijanja podataka o nepoznatoj tromensionalnoj površini koji se može upotretiti gde god postoji potreba za skladenštenjem i/ili reproducirbilišću kompleksnih oblika (Renishaw10). Na tržištu postoje različite vrste skenera (npr. optički, laserski, pipalica) od kojih svaki ima svoje za i protiv argumente.11-12 U ovoj studiji korišćen je optički skener Comet 250 (Steinbichler Optotechnik GmbH, Neubeuern, Germany, sl. 1.).

tion in cost and time from an initial idea to its final realization. There is also increased trust in a developed model which was tested under many conditions in the virtual environment.

The most important aspect of any FEA study is the FEA model. Its characteristics have a great effect on the quality and validity of results. Therefore, FEA model generation is one of the crucial factors in virtual analysis. This most important factor can also be the most difficult, since the FEA model is anything but easy to construct. An average tooth model can have several thousand elements and nodes 4-7, bearing in mind that the greater number of these, the greater the accuracy of the study. Positioning and defining a great number of elements can take months or even years if done manually, where even a single error influences output data. It should furthermore be remembered that in the case of a tooth, precise morphological measurements are required that can only be gathered by sectioning. In addition, finding an incorrect element amongst so many similar elements can be a very hard task. Such intensive work was normal procedure until new, more efficient techniques for creating 3D model generation were developed.

Obtaining the virtual model is the most demanding task for any researcher. The aim of this research is to present a simple, precise and efficient method to generate 3D FEA models. The technique involves scanning, processing and transforming the scanned data into a three-dimensional virtual model.

Materials and methods

a) Scanning

3D scanning is a method of gaining data relating to a 3D surface that can be used wherever there is a need for defining complex shapes (Renishaw10). Various scanner types can be found on the market (e.g. optical, laser, touch-probe) each having certain advantages and disadvantages.11-12 A Comet 250 (Steinbichler Optotechnik GmbH, Neubeuern, Germany, fig. 1) optical scanner was used in this study.

For this research, morphological characteristics were gathered from an extensive literature search13. Based on this data, average tooth dimensions as well as shape were determined.
Tooth roots were modeled based on mesio-distal and bucco-mesial dimensions taken from the literature (fig. 2). For this case, the upper left quadrant was chosen and the most common occurrence assumed—the loss of the first molar (fig. 3). Teeth were first modeled in wax, after which a gnathological jaw model was created by the process described above.

In general, a 3D optical scanner uses regular white light for gathering data about the scanned model geometry, as well as surrounding structures. A scanner consists of a projector that emits striped white light on the object and a digital camera that registers the pattern (see fig. 1). When lines are emitted, they are horizontal and parallel until they contact a surface angled towards the projection path. Distortion and bending of the lines can be detected, if viewed from different angles (fig. 4). Captured patterns are automatically processed in the computer. If linear light transmissions are considered, it is clear that in a single scan dark zones can be found (shadow area, fig. 5). Hence multiple scans are required to achieve an undisturbed geometry. Correlation of single shots is possible based on several positions that form a so-called cloud of points which represent rough data of the scanned surface.
A software package, InnovMetric Polyworks IMAlign (InnovMetric Software Inc. Quebec), is used to position and assimilate single shots. A detailed description of this process is beyond the scope of the current article but in short, identification of the corresponding points, special tools (e.g. N-point pairs alignment) and function (Select Unique data) are required (fig. 6). Finally, the cloud of points is imported into Alias Wavefront’s Spider software (Alias Wavefront Inc., Toronto, Ontario). This programme is used to join single parts from the point cloud into a polygonal network (fig. 7). Recognition of the scanned structure from a view of the point cloud alone is almost impossible. However, if in the virtual world a cloth, as it were, was thrown over the points, a clearly visible structure would appear. This process in its final form generates the so-called .stl (standard triangulation file), that can be easily recognized\(^14\).

b) \textit{FEA model generation}\

Once generated, the cloud of points format can be imported into specific programmes that recognize .stl file extensions, a surface created, and then a volume (solid) model achieved. The whole procedure is possible from modeling
izbora globalne finoće podele pomeranj klizača na skali, čime se definije ukupan broj elemenata i čvorova. Program, korišćen u ovom istraživanju, je softverski paket Catia (Dassault Systemes, France).

Za definisanje osobina materijala modela, neophodni su podaci o modulu elastičnosti, granici tečenja i Poasonovom koeficijentu. Elastično oslanjanje oslonih zuba je definisano primenom materijala sa malim modulom elastičnosti na sve konačne elemente koji se nalaze u zoni modela koja opisuje okosnicu zuba. Vrednosti koeficijenata date su u tabeli 1.

### Tabela 1. Vrednosti modula elastičnosti i Poasonovog koeficijenta za odabrane materijale

<table>
<thead>
<tr>
<th>Materijal (material)</th>
<th>Modul elastičnosti (GPa) (modulus of elasticity (GPa))</th>
<th>Poasonov koeficijent (+) (Poisson’s ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kost (bone)</td>
<td>14.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Cirkoniium (zirconium)</td>
<td>205.0</td>
<td>0.22</td>
</tr>
<tr>
<td>Periodontálni ligament (periodontal ligament)</td>
<td>0.27</td>
<td>0.45</td>
</tr>
<tr>
<td>Cementni film (cement)</td>
<td>5</td>
<td>---</td>
</tr>
</tbody>
</table>

### Rezultati

Konačni izgled modela posle dorade niza skeniranih površina je prikazan na slici 8. Trodimenzionalni model prepariranih zuba (25 i 27) i mosta sa zubnom nadogradnjom (26) dobijen je skeniranjem modela zuba i obliku stereolitografskog zapisa, koji je preveden u za-preminski model u programskom paketu Ansys Inventor.

Na slici 9 prikazan je spoljni izgled mreže konačnih elemenata iz dve tačke pogleda. Mreža se vidi samo na površini modela, ali postoji u nizu slojeva i unutar modela.

Za opisivanje modela je korišćeno ukupno 155355 čvorova i 104491 elemenata u obliku tetraedra. Izgled elementa u obliku tetraedra drugog ređa.

Kod predmeta koji nemaju pravilan geometrijski oblik, već imaju oblik tzv. slobodne forme, uglavnom je neophodna primena velikog broja elemenata i vrlo fine podele, da bi se obuhvatala svaka značajnija zakrivenost

### Results

The final model after refining the scanned surfaces is shown in the fig. 8. In fig. 9, a finite element network has been shown from different viewpoints. The network is visible on the model surface but it also exists within the body of the model.

For model description 155355 nods and 104491 tetraedral elements have been used. The elements can be classified as second class elements.

Objects having an irregular shape, or a ‘free form’, usually need a huge number of elements and fine graduation in order to specify all curves of the object. Tooth form is representative of this group and therefore a very fine graduation and a huge number of elements and nods are used for the description. For free form type objects, tetrahedral elements are the most appropriate description modality, since triangu-
u obliku predmeta. Oblik zuba je tipičan predstavnik ove grupe predmeta, zato se kod analize njegove nosivosti primenjuju izuzetno fine podele sa velikim brojem elemenata i čvorova. Za ovakav oblik površina (oblik slobodne forme) najpogodnija je primena elemenata u obliku tetraedra jer on sa površinama u obliku trougla može najverovatnije opisati promenu krivine spoljne površine zuba.

Pored boljeg opisa geometrije, finija podele omogućava i zadovoljene ravnoteže sila između većeg broja pojedinih konačnih elemenata u tačkama koje se međusobno nalaze na manjem rastojanju. Sve ovo dovodi to tačnijeg rešenja numeričke simulacije ponašanja noseće strukture pod zadatim opterećenjem.

Na slici 10 je prikazano polje opterećenja, za slučaj delovanja kose sile pod uglom od 45° (simulacija uobičajenih mastikatornih pokreta).

Primenom navedenih znanja i softverskih paketa, moguće je kreirati varijante virtualnih modela. Slika 10 pokazuje izgled virtualne lar forms can precisely define curve variations of the outer surface.

Besides providing a better description, a finer graduation enables force equilibrium between a greater number of single elements in points that are close to one another. This leads to a more accurate equation of the numerical simulation of model behavior under given conditions.

In fig. 10 force field application has been shown, in the case of the 45° force (simulation of the usual masticatory movements).

Using the mentioned skills and software packages, it is possible to create model variations. Fig. 10 shows virtual preparation in the form of a class II inlay. Therefore, surveillance of the influence of different variables is possible, decreasing time and investment compared with real tests.
Discussion

FEA modeling is a very interesting and progressive way of gathering data about various physical characteristics of tissue, dental structures, dental materials and other bioactive structures. Though there is an obvious presence in foreign literature, domestic articles have only recently begun to implement this technique. From the author’s own experience and many contacts with other authors, it can be concluded that 3D model generation is the main limiting factor preventing wider uptake of FEA at home.

Anyone who has dealt with FEA element by element or node by node generation of 3D models, knows how hard and inefficient this method can be. Though automatic generation of simple geometric forms, such as cubes, balls, or cylinders is not difficult, such simplicity obviously cannot be applied to shapes such as tooth morphology, which must be one of the most irregular shapes. Therefore every method offering faster, simpler and more precise 3D FEA model generation is worth exploring.

Generally, when applying the FEA method, the greatest and most common errors are in numerical analysis, in the so-called border zones; for example the transition regions and force application points. Therefore, all suppliers for finite element methods and other similar numerical programs (finite values, finite volumes), in the introductory part of the instructions for use put the attention on the necessity of brainstorming when reading data. Manufacturers find this necessary with regards to legal prosecution in construction failure cases that have been previously verified by the method. Real experience is the best method of estimating construction quality. Numerical tools only enable faster data prediction but have imperfections and the possibility of software malfunctions.

The future of FEA application in dentistry, especially its wide use, depends mostly on its availability. Furthermore, the presence of the .STL files stimulates its use in the dental field. Rapid Prototyping, recently applicable in industrial branches only, slowly but surely finds its way towards the dental profession. So articles not only about scanning but also about denture fabrication can now be found.
je nedostatka softvera i numeričkih metoda, lakše i brže dođe do parametara neophodnih za ocenu.

Budućnost primene MKE metodologije u stomatologiji, pogotovo opsežnost njene primene definitivno zavise od primenjivosti i dostupnosti gore navedene ili njoj sličnih metoda. Staviše, primenjivost i sve veća rasprostranjenost .STL fajlova obećava njihovu široku primenu kada su u pitanju stomatološke nauke. Rapid prototyping, do skora primenjivan u industrijske svrhe, polako ali sigurno počeo je da krši svoj put ka zubnoj delatnosti tako da se sada mogu naći radovi o primeni .STL fajlova

rane koriste nadoknadu. Elizaciju, sada vrste rena dobivši model dinstven fikacije, olakšavajući medusobno poredenje. Dobiti interakcije podaci pokazuju kome u ovoj studiji deli kvalitet dobijenih ma jalnih pomoći bi. Radaju po In
daju

krzi stomatologiji, pogotovo morfološki Vražajući fajlova, materijala, prototyping, do iz različitih firmi. Interesantno sto je, kakav skener ima veoma dobre karakteristike, posebno vezano za kvalitet dobijenih podataka.11,12 Skener oписan u ovoj studiji deli te karakteristike, no je sigurno da mogu naći i njegov naslednici, npr. Oni sa automatskim snimanjem multiplih sima, iz različitih uglova (kakav je Comet 5), pomoću pokretnog stočića ili glave skenera, što bi narančno omogućilo još jednostavnije dobijanje podataka. Interesan to je na ovom mestu konstatovati da se na našem tržištu može naći relativno veliki broj skenera prilagođenih upravno dentalnim potrebama, a u vezi sa razvojem CAD/CAM tehnologije. Ovi skeneri variraju po osobinama i karakteristikama (Sirona In Eos, Procera, Wieland itd.) ali se gotovo redovno ne mogu koristiti za 3D modelovanje u tematski različitim softverima, kakav je CATIA. Ovo stoga, što su podaci koje ovi skeneri daju mahom kodirani, što, naravno, odgovara marketinškoj poziciji i zaštiću interesa komercijalnih firmi.

The main advantages, when using .STL files include the very sophisticated possibilities of visual presentation (visualization tools, cuts, etc.). Furthermore, single scan interaction is possible. Thus, some models can be joined or cut, creating parts out of the full model, or, vice versa. The root and crown structures can be taken away from the tooth, etc. For example, three morphologically identical fillings can be completed with three different materials, since they can be created by cutting an area from the original tooth which is then redefined as a filling material. Thus mutual comparison is greatly simplified. When working with .STL files, easy modifications to input and output data are also features connected with FEA modeling. It can be said with confidence that stereolithography is a topic set to enter dentistry in the coming years.

To return to the topic of FEA modeling using .STL files, further simplifications are also expected. Information in the literature shows that optical scanners give very good data quality 11,12. The scanner described in this study shares those qualities. However, its antecessors can still be found, e.g. those with automated scanning from different angles by a rotation scanner head (such as the Comet 5). This has further simplified the procedure. It is interesting to note that the dental market now offers a variety of scanners adapted specifically for use in dentistry, in CAD/CAM technology. There are scanners which vary according to the features and specifications required (Sirona In Eos, Procera, Wieland etc.), but commonly they cannot be used for 3D modeling in software such as CATIA. This is because scanned data are usually coded, enabling data protection which is necessary in the light of the commercial position of a firm in the market.

Further improvements demand the use of in-depth scanners, since the ones described above gain only surface object data. The latter are the most difficult to gain, bearing in mind the complicated tooth structure, but manual data input relating to the enamel, pulp and dentin thickness is obligatory. First attempts with CT and MRI data are promising, showing possible use in the scans of hard-to-reach areas, such as inner organs. It is to be noted, however, that the
Dalja poboljšanja zahvala bi mogućnost primene dubinskih skanova, s obzirom da se dosad navedenim tipovima skenera mogu dobiti podaci jedino o karakteristikama površine. Ovi poslednji jesu, doduše, najvažniji i najteži za dobijanje, imajući u vidu veoma komplikovanu zubnu morfologiju, ali zahtevaju manuelno dodavanje podataka o debljini gledi, dentina i pulpnog tkiva. Prvi pokušaji rađeni u vidu CT i MRI snimaka su obećavajući, a njihova prvenstveno posebno je interesantna zbog mogućnosti direktnih modelacija inače površinskom skeniranju teško dostupnih struktura, kakve su npr. unutrašnji organi. Treba, međutim, napomenuti da se princip rada ovih uređaja ne razlikuje od onog ovde prikazanog, osim nešto izmjenjenog input-a, odnosno vrednosti ulaznih podataka. Nastavak puta do 3D MKE modela nadalje ide stopama opisanim u ovom članku.

Metoda konačnih elemenata, uz sve svoje prednosti i mane, koje danas dobro poznajemo, sadašnjost je i budućnost ispitivanja i naučnih delatnosti u mnogim granama stomatologije. Stoga je više nego bitno izučiti i primeniti nove, savremene i usavršene metode, kao što je princip opisan u ovoj studiji, pomoću kojih se mogu postići efikasni, precizni i kvalitetni rezultati. Ovaj rad takođe je osnova za dalja istraživanja, jer MKE metoda može dati podatke koji se ne mogu postići drugim metodama. Ipak, za sada se čini da na našim prostornima ovakav pristup još uvuk daje skromni doprinos naučno-istraživačkom radu. Zato je tehniološko napredak upravo faktor koji bi na ovom polju mogao doneti značajne izmene.

principle does not differ from the one described here, besides input data variation. The way to achieve 3D FEA models, even if internal data is gathered, follows the steps described in this article.

Finite element analysis, with its advantages and disadvantages that are very well known today, can be considered to have a presence and be expected to occur in the future of many dental research fields. It is, therefore, necessary to study and implement new, contemporary and improved methods, such as those described in this study, which enable precise and efficient results to be achieved. This article also forms the basis for further research, since FEA can gain data unobtainable by other methods. Still, it can be stated that this approach is not yet fully developed. Technological developments might just be one factor allowing significant improvements.

**Conclusion**

With the use of appropriate methodology, that uses an adequate scanner, as well as programs for scanned data calculation, their conversion and input into appropriate FEA software, generation of the most complex, high quality and precise FEA models, such as irregular tooth forms, is possible.


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**KLINIČKA EVALUACIJA INLEJ-RETINIRANIH ADHEZIVNIH MOSTOVA TOKOM DVOGODIŠNJEG OPSERVACIONOG PERIODA**

**A CLINICAL EVALUATION OF INLAY-RETAINED FIXED PARTIAL DENTURES AFTER A TWO-YEAR OBSERVATION PERIOD**

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**ABSTRACT**

*Introduction.* Inlay retained adhesive restorations present a conservative approach when a single tooth is missing in the posterior region. *Material and Methods.* Twenty-five restorations were included in the clinical study. Patient selection, preparation technique as well as denture fabrication followed current principles in this area. Patients were examined every 6 months over a 2 year examination period. Results were statistically analyzed. *Results.* The success rate for the first year comes to 91.1%, while cumulative success probability during the second year (24 months) was 86.6%. Furthermore, colour, texture and marginal staining were satisfactory during the observation period. *Conclusion.* Fibre-reinforced composite adhesive dentures are a tooth preserving, minimally invasive, aesthetic and reliable treatment option for single tooth replacement in the posterior area.

*Key Words:* inlay-retained bridges, adhesive bridges

**Uvod**

Kliničke situacije, u kojima se zapaža nedostatak pojedinačnog zuba postaju sve češće u stomatološkoj praksi. Između različitih varijanti tretmana, nedostajući zub može se nadokonaciti pomoću inlej-retiniranih adhezivnih mostova, u kombinaciji sa adhezivnom tehnikom cementiranja.1,2,3 Generalno, metoda...
podržava konzervativni pristup, naročito ukoliko agonisti imaju postojeće ispuni ili kariозne lezije.4 Metal-keramika nije mogla da obezbedi dugotraj an uspeh delimičnih nadoknada, stoga su kompozitni sistemi ojačani vlaknima predloženi za navedenu indikaciju.5,6 U prvom mahu, javljala se se pucanja i rascementiranjanja, dajući kumulativnu stopu uspeha od 73% nakon 5 godina vezano za pucanje i 96% vezano za rascementiranjanje.6 Dodatno, dugotrajni estetski rezultati nisu bili zadovoljavajući, sa odlanjanjem, prebojavanjem i diskoloracijom fašetirajućeg komposita.

U tom kontekstu, predložene su modificacije vlaknima ojačane osnove.7,8 Nadalje, predstavljena je nova generacija fašetirajućih komposita, sa modifikovanim sadržajem mikropunioča (SR Adoro, Ivoclar Vivadent; Gradia InDirect, GC; Symphony, 3M itd.). Pomenuti sistemi, kako je navedeno, trebalo bi da omoguče odlično poliranje, sa dugotrajnom rezistencijom na plak i diskoloraciju.

Nekoliko in-vitro studija podržalo je ideju, da se modificovana osnova ojačana vlaknima može odpreti mastikatornim silama u bočnoj regiji.9,10 Nadalje, potencijalne prednosti kompozitnog sistema vezane su za niži modulis elastičnosti staklenih vlakana u poređenju sa drugim materijalima, što bi modalo da redukuje vrednosti napona na prelazu Zub-nadoknada, smanjujući verovatnoću rascementiranjanja.11 Dakle, u kombinaciji sa odgovarajućim materijalom za fašetiranje, sistem bi mogao da omogući dobijanje dugotrajnih pozitivnih rezultata kod terapije minimalne krezubosti adheživnim nadoknadama.

Cilj

Cilj ove studije je da oceni kliničke parametre kompozitnih adheživnih mostova, koji se koriste za nadoknadu pojedinačnog nedostajućeg zuba u bočnoj regiji denticije, tokom dvogodišnjeg perioda pračenja.

Materijal i metod

a) Odabir pacijenata
U ovoj studiji, urađeno je 25 nadoknada pacijentima, kojima nedostaje drugi premolar ili prvi molar. Starost pacijenata je 19 do 47

The purpose of this study was to evaluate clinical parameters of composite iFPDs, used for replacement of a single tooth in the posterior region during a two-year observation period.
godina. Studija je odobrena od strane Etičkog komiteta fakulteta. Specifični kriterijumi izbora su:
- dobra oralna higijena,
- stepen labavljenja zuba je nula,
- oba nosača su vitalni zubi,
- minimalni ili bez znakova mobilnosti ago-
nista ili antagonista,
- okluzo-gingivalna aksijalna dimenzija mini-
imum 3 mm,
- bezubo palje maksimalno 12 mm,
- očnjako vođenje,
- bez znakova parafunkcionalnih aktivnosti.

b) Preparacija zuba nosača

Preparacija je urađena prema principima, koji se mogu naći u literaturi:3,5,6,11,12
- dubina kaviteta okluzalno minimum 2 mm,
- širina istmusa 1.5 - 2 mm za premolare i
  2.5 - 3 mm za molare,
- proksimalno sanduče minimum 1.5 mm,
- divergencija aksijalnih zidova oko 6 ste-
peni,
- tretman glednih prizmi.

Za preparaciju su korišćena standardna inlej
svrdla (Komet Brasseler, Germany), a za tretman
glednih prizmi korišćen je poseban ultrazvučni
set (SonicSYS, KaVo, Biberach, Germany). U
slučaju podminiranih zona, korišćena je adhe-
zivna tehnika postavljanja ispuna (Tetric EvoC-
eram, Ivoclar Vivadent, Schaan, Liechtenstein).
Otisci su uzeti A silikonom (Virtual, Ivoclar
Vivadent, Schaan, Liechtenstein), uz upotrebu
retrakcionog konca broj 0 (Ultrapak, Ultradent,
USA).

c) Laboratorijska procedura

Kompozitni sistem ojačan vlaknima korišćen
je prema uputstvima proizvođača. Fiber osnova
(Vectris, Ivoclar Vivadent, Schaan, Liechten-
stein) je napravljenja na osnovu anatomskih
technike7,8 i zatim fastirana estetskim dvojno
vezujućim kompozitom (Adoro, Ivoclar Viva-
dent, Schaan, Liechtenstein). Završno poliranje
urađeno je ekstra finim polirerima i dijamans-
kim pastama.

d) Adhezivno cementiranje

Kod gotovih nadoknada, proveno je mar-
ginalno zaptivanje, okluzija i estetske kar-
akteristike. Nadoknade su, zatim, adhezivno
cementirane pomoću visokoestetskog kompoz-

Ethical Committee. Specific criteria for patient
selection were:
- good oral hygiene,
- zero degree of loosening,
- both abutments vital,
- minimal or no signs of abutment or antago-
nist mobility,
- occluso-gingival axial dimension at least 3
  mm,
- edentulous area up to 12 mm maximum,
- canine guidance,
- no signs of parafunctional activities.

b) Abutment preparation

Preparation was completed according to the
guidelines suggested in the literature:3,5,8,11,12
- occlusal cavity 2 mm deep at least,
- isthmus width 1.5-2 mm for premolars and
  2.5-3 mm for molars,
- proximal box 1.5 mm at least,
- taper of the axial walls approx. 6 degrees,
- enamel prism treatment.

Standard inlay burs were used for the prepa-
ration (Komet Brasseler, Germany), while
a specific ultrasonic set was used for enamel
treatment (SonicSYS, KaVo, Biberach, Ger-
many). The adhesive technique with Tetric EvoCe-
ram (Ivoclar Vivadent, Schaan, Liechtenstein)
was used for cusp reinforcement, if weakened
by caries removal. Impressions were taken with
A silicone (Virtual, Ivoclar Vivadent, Schaan,
Liechtenstein), with no. 0 retraction cord (Ul-
trapak, Ultradent, USA).

c) Laboratory procedure

A fibre-reinforced composite system was
used according to the manufacturer’s instruc-
tions. A fibre frame (Vectris, Ivoclar Vivadent,
Schaan, Liechtenstein) was fabricated accord-
ing to the anatomical technique7,8 and then
covered with esthetic dual-curing composite
(Adoro, Ivoclar Vivadent, Schaan, Liechten-
stein). Final polishing was done using extra fine
polishers and diamond pastes.

d) Adhesive placement

The restorations were tried for fit, occlu-
sion and aesthetic appearance. Subsequently,
adhesive cementation was performed using
high aesthetic composite cement (Variolink
II, Ivoclar Vivadent, Schaan, Liechtenstein).
itnog cementa (Variolink II, Ivoclar Vivadent, Schaan, Liechtenstein). Površine inleja si-
lanizirane su pomoću Monobond S, tokom 60 s.
Gledne površine tretirane su 37% fosfornom kiselinom (Total Etch), nakon čega je nanešen
Syntac Primer i Adhesive (15 s i 10 s, respet-
tivno). Tanak sloj bonda (Heliobond) je po-
tom nanešen i prosvojet 20 s. Odnos mešanja
bafe i katalizatora iznosi 1:1, u željenoj boji, uz
upotrebu katalizatora niske viskoznosti. Cement
je nanešen na unutrašnje površine nadoknade,
nakon čega je nadoknada postavljena in situ, uz
upotrebu konstantnog pritiska u trajanju od ma-
kar 15 s. Višak je uklonjen pomoću standardnog
dentalnog konca, a cement je zatim prosvojet
tokom 40 s sa svake strane (Bluephase, Ivoclar
Vivadent, Schaan, Liechtenstein). Glicerinski
gel je aplikovan pre definitivne polimerizacije,
ucilju sprečavanje kiseonične inhibicije.

Po cementiranju, uvrađene su završne do-
rade, sa veoma finim dijamantima i silikon-
karbidićnim diskovima i četkicama (Astrobrush,
Ivoclar Vivadent, Schaan, Liechtenstein).

e) Parametri praćenja

Procena uspešnosti izvedena je po cementi-
ranju, a zatim 6, 12, 18 i 24 meseca po tret-
manu. Procenu je vršio isti ispitivač, na osnovu
kriterijuma koje je predložio Walton:13
1. Uspešan – bez potrebe za bilo kakvom
intervencijom,
2. U funkciji – pacijent nije dostupan di-
rektnom pregledu, ali je potvrdio uspešnost
tretmana preko telefona,
3. Nepoznat – kontakt sa pacijentom nije
mogao da bude uspostavljen,
4. Repariran – nadoknada je u funkciji, ali
postoji potreba za većom intervencijom,
5. Neuspešan – rascementiranje
nadoknade, fraktura osnove ili nosača.

Dalja analiza urađena je na kategorijama
uspešan, repariran ili neuspešan, prema modi-
fikovanoj USPHS klasifikaciji.14 Kriterijumi
praćenja bili su:
- za nosače: fraktura, veza, marginalno pre-
bojavanje, sekundarni karijes, postopera-
tivna osetljivost,
- za adhezivne nadoknade: fraktura osnove,
fraktra fasete, tekstura, boja.

The inlay fitting surfaces were silanized with
Monobond S for 60 s. Enamel finish lines were
reated with 37% phosphoric acid (Total Etch),
after which Syntac Primer and Adhesive were
plied (15 s and 10 s, respectively). A thin lay-
er of the bonding agent (Heliobond) was then
plied and light cured for 20 s. Base-catalysts
were mixed in a 1:1 ratio in the desired colour,
low viscosity syringes were used. The cement
was applied to the inner iFPD surfaces, after
which the restoration was inserted and con-
stant pressure applied for at least 15 s. Excess
was removed using regular dental floss, after
which the restoration was light cured for 40 s
on the each side (Bluephase, Ivoclar Vivadent,
Schaan, Liechtenstein). A glycerine gel was ap-
pied prior to polymerization in order to prevent
oxygen inhibition.

Final adjustments were completed accord-
ingly, with extra fine diamond burs and silicone-
carbide discs and brushes (Astrobrush, Ivoclar
Vivadent, Schaan, Liechtenstein).

e) Examination

Examination was performed at baseline, 6,
12, 18 and 24 months after treatment. It was
formed by one examiner according to the
criteria suggested by Walton:13
1. Successful – no need for any kind of in-
tervention
2. In function – the patient could not be
examined directly, but confirmed no need for
re-treatment via phone
3. Unknown. Contact with the patient
could not be established.
4. Repaired. The restoration was in func-
tion, but there was a need for major correction.
5. Failed. Restoration lost retention, the
frame or abutments exhibited fracture.

Further analysis was performed for catego-
ries successful, repaired or failed according to
the modified USPHS classification.14 The ex-
amination criteria were:
- for abutments: fracture, bonding, marginal
discoloration, secondary caries, postopera-
tive sensitivity;
- for iFPD: framework fracture, veneer frac-
ture, texture, colour.
Korišćen je a - d sistem ocenjivanja, gde je:

a – odličan,
b – prihvatljiv,
c – popravljiv,
d – nepopravljiv.

f) Statistička analiza

Statistička analiza urađena je u SPSS programskom paketu verzija 12.0 (SPSS, Chicago, IL, USA). Izračunati su srednja vrednost, standardna devijacija i koeficijent varijacije, nakon čega je primenjena univarianatna Kaplan – Meier-ova analiza.

Rezultati

Primer uspešne nadoknade prikazan je na slici 1. Ukupna uspešnost ahezivnih nadoknada prikaza je u tabeli 1. Jedna restauracija nalazi se u kategoriji 'neuspešan' u trećem mesecu, usled fraktura osnove. Detaljna analiza pokazuje da su dimenzije osnove bile neadekvatne, što bi se moglo smatrati glavnim uzrokom neuspeha. Druga nadoknada u ovoj kategoriji našla se u devetom mesecu po cementiranju, a u pitanju je rascementiranje na oba konektora. Kako

The ranking system used was a-d, where;

a – excellent,
b – acceptable,
c – repairable,
d – irreparable.

f) Statistical analysis

Statistical analysis was carried out using the SPSS software package ver. 12.0. (SPSS, Chicago, IL, USA). The mean value, standard deviation and variation coefficient were calculated. In addition, an univariate Kaplan – Meier estimation was performed.

Results

A successful restoration is shown in picture 1. Overall success of the iFPDs is shown in the fig.1. One restoration failed due to framework failure in the third month. The patient was a male, 43 years old, with a metal-ceramic FPD as antagonist. Detailed analysis has shown that framework dimensions were insufficient, which can be claimed to be the main factor responsible. The second failure occurred 9 months after insertion and this was due to debonding, both on
šestomesečni izvještaj o ovom pacijentu nije dostupan (‘nepoznat’ u tabeli 1), ne može se sa sigurnošću tvrditi, da li je delimično rascem
mentiranje prethodilo potpunom ispadu iz
funkcije. Prema komentaru pacijenta, prevremeni kontakt se može smatrati uzrokod odva
janja mosta od zuba nosača.

Detaljna klasifikacija data je u tabeli 2. Kod jedne nadoknade, može se naći reparabilna
fraktura fasete, bez većih ispadu iz funkcije. Ni jedan nosač nije pretpro frakturnu tokom
funkcije, takođe, nema znakova problema sa
vitalitetom tokom perioda praćenja. Postoper
rativna senzitivnost javila se u dva slučaja,
trajala je oko 4 meseca i može biti povezana
sa najvećom površinom zuba tretiranom kiseli
nom. U oba slučaja, u pitanju su mladi pacijenti
(23 i 25 godina). Jedan slučaj bio je sumnjiv
na sekundarni karijes, međutim, radiografsko
ispitivanje nije potvrdilo prisustvo destrukcije.
Kod jedne nadoknade, javila se inflamacija gin
give u predelu distalnog dela MOD konektora,
razlog je, međutim, može naći u lomu plombe
susednog zuba, koji je izazvao irritaciju papile.

Vrednosti Kaplan – Meier-ove verovatnoće
dati su na grafikonu 1. Uspešnost nadoknada
u prvoj godini iznosi 91.1% (isključene kate
gorije ‘nepozнат’), dok kumulativna uspešnost
tokom druge godine (24 mesece) iznosi 86.6%.

Marginalno prebojavanje prikazano je u
tabeli 2, kao i tekstura i boja. Vezano za pre
bojavanje, nakon 24 mesece 78,1% nadoka
anda ocenjeno je sa A, 18,8% sa B dok se 3,1%
nadoknada nalazi u kategoriji C. Prebojav
je se moglo ukloniti sa polirerima, u nekim slučajevima. Boja je pokazala dobre rezultate
kako inicijalno, tako i nakon 2 godine funkcije.

Pacijenti su, generalno, zadovoljni preduze
tim tretmanom. Čak i oni, kod kojih se javio
problem i neuspešan rad, bili su spremni na
ponavljanje tretmana pre nego na opciju punih
čuvarstv retiner.

Diskusija

Adhezivne delimične nadoknade, kakvi su
inlej-retinirani mostovi, veoma su interesan
tan modalitet tretmana, koji podržava pe
verzaciju tvrdih zubnih tkiva. Pored minimal
inavazivnosti, oni takođe predstavljaju brz, ef
kišan i jeftin način tretmana.1,2,3,4,5,6,8,12

Vezano za druge mogućnosti, puni čuvarst
retineri imaju uspešnost od 92% nakon 10
mesal i distal retainer. Since details from a
6 month recall were unavailable (unknown in
fig. 1), it cannot be ascertained whether par
ial debonding appeared to total failure.
According to the patient statement, premature
contact can be considered as the reason for
debonding.

A detailed classification is shown in fig. 2. One restoration exhibited a reparable veneer
fracture with no major consequences. No abut
ment showed fracture during function and there
were no signs of vitality problems during the
examination period. Postoperative hypersen
sitivity appeared in two cases, it lasted for 4
months and can be linked with the area having
the greatest degree of etching. Both cases ap
peared in younger patients (23 and 25 years of
age). One case was susceptible to secondary car
ries, however radiographic investigation showed
no signs of caries destruction. One restoration
showed gingival inflammation next to the dis
tal part of the MOD connector. However, the
reason for the inflammation was due to a filling
failure in a neighbouring tooth, which was the
cause of subsequent irritation, rather than any
problems with the restoration under study.

The Kaplan- Meier probability is shown
in graph. 1. The success rate for the first year
comes to 91.1% (unknown statement excluded),
while the cumulative success probability
during the second year (24 months) was 86.6%.
Marginal discoloration is shown in table 2,
as well as colour match and texture. Regarding
staining, after 24 months 78,1% were ranked A,
18,8% were B whilst 3,1% were rated C. Dis
coloration could be removed with polishers in
some cases. Colour match has shown good re
sults both initially and after a 2 year period of
function.

Patients are generally satisfied with the
treatment. Even those exhibiting fatal failure
showed interest in re-treatment rather than a
full crown FPDs restoration.

Discussion

Adhesive partial restorations, such as iFPDs,
are a very interesting way towards hard dental
tissue preservation. Besides minimal invasive
ness, they also provide a quick, efficient and
cost effective restorative option.1,2,3,4,5,6,8,12

Among other treatment modalities, full
crown FPDs express survival rates of 92% over
**Slika 1. Primer restauracije iz kategorije 'uspěšan'(0,6,12,18,24 meseca)**
*Picture 1. Example restoration from the 'successful' category (0,6,12,18,24 months)*

**Tabela 1. Klasifikacija uspešnosti radova prema Walton-u**
*Table 1. Survival rates according to Walton*

<table>
<thead>
<tr>
<th></th>
<th>nulti pregleąd Basic examination</th>
<th>6 meseci</th>
<th>1 godina</th>
<th>1.5 godina</th>
<th>2 godine</th>
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<tr>
<td></td>
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<td>n=25</td>
<td>n=24</td>
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<td>Uspěšan/Successful</td>
<td>25</td>
<td>23</td>
<td>20</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>U funkciji/In function</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>4</td>
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<tr>
<td>Nepoznat/Unknown</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Repariran/Repaired</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Neuspešan/Unsuccessful</td>
<td>0</td>
<td>1</td>
<td>1</td>
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</tr>
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</table>

**Tabela 2. Rezultati prema modifikovanim USPHS kriterijumima (a-odličan, b-prihvatljiv, c-popravljiv, d-nepopravljiv)**
*Table 2. Results according to the modified USPHS criterie (a - excellent, b - acceptable, c - repairable, d - irreparable)*

<table>
<thead>
<tr>
<th></th>
<th>nulti pregleąd Basic examination</th>
<th>6 meseci</th>
<th>1 godina</th>
<th>1.5 godina</th>
<th>2 godine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=50</td>
<td>n=46/48</td>
<td>n=40/42</td>
<td>n=42</td>
<td>n=32</td>
</tr>
<tr>
<td>Nosaði (n:50)/Retainers</td>
<td>50A</td>
<td>46A</td>
<td>40A</td>
<td>42A</td>
<td>32A</td>
</tr>
<tr>
<td>Fraktura (zub)/Fracture</td>
<td>50A</td>
<td>46A</td>
<td>40A,2D</td>
<td>42A</td>
<td>32A</td>
</tr>
<tr>
<td>Veza/Connection</td>
<td>50A</td>
<td>44A, 2B</td>
<td>35A, 5B</td>
<td>36A,5B,1C</td>
<td>25A,6B,1C</td>
</tr>
<tr>
<td>Marginalno prebojavanje Marginal discoloration</td>
<td>50A</td>
<td>46A</td>
<td>40A</td>
<td>42A</td>
<td>32A</td>
</tr>
<tr>
<td>Sekundarni karijes Secondary caries</td>
<td>50A</td>
<td>46A</td>
<td>40A</td>
<td>42A</td>
<td>32A</td>
</tr>
<tr>
<td>Postop. oštetljivost Postoperative sensitivity</td>
<td>48A,2B</td>
<td>46A</td>
<td>40A</td>
<td>42A</td>
<td>32A</td>
</tr>
<tr>
<td>Mostovi (n:25)/Bridges</td>
<td>n=25</td>
<td>n=23/24</td>
<td>n=20/21</td>
<td>n=21</td>
<td>n=16</td>
</tr>
<tr>
<td>Fraktura (osnova) Fracture (base)</td>
<td>25A</td>
<td>23A,1D</td>
<td>20A</td>
<td>21A</td>
<td>16A</td>
</tr>
<tr>
<td>Fraktura (delaminacija) Fracture (delamination)</td>
<td>25A</td>
<td>23A</td>
<td>20A</td>
<td>20A,1C</td>
<td>16A</td>
</tr>
<tr>
<td>Tekstura/Texture</td>
<td>22A,3B</td>
<td>20A,3B</td>
<td>16A,4B</td>
<td>17A,4B</td>
<td>15A,1B</td>
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<tr>
<td>Boja/Color</td>
<td>21A,4B</td>
<td>19A,4B</td>
<td>16A,4B</td>
<td>17A,4B</td>
<td>15A,1B</td>
</tr>
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</table>

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godina i 74% nakon 15 godina.\textsuperscript{15} Uobičajeni problemi, vezano za nosače, su karijes (18%) i potreba za endodontskim tretmanom (11%). Očigledno je, da se uzroci neuspeha punih i delimičnih retinera veoma razlikuju, što pokažuje ova studija. Pucanje i rascemtwiranje mogu se povezati sa redukovanim geometrijom adhezivnih mostova, čime se minimizira kako bonding zona, tako i dimenzije osnove. Zahvaljujući adhezivnom cementiranju i vidljivim marginama, pojava sekundarnog karijesa nije tako uobičajena. U ovoj studiji, nisu se javili endodonski problemi, što podržava ideju da je šteta nanešena pulpnom tkivu manja kod delimičnih u poređenju sa punim čaurastim retineraima.\textsuperscript{16}

Neke studije pokušale su da poboljšaju otpornost fiber osnove. Članak Song i sar.\textsuperscript{17} poredi dva načina preparacije zuba nosača, koji se razlikuju u dimenzijama, odnosno ekstenzivnosti proksimalnog sandučeta. Iako drugi način obezbjeđuje veću prezervaciju zubnih tkiva, pokazao se značajno slabijim u poređenju sa klasičnim sandučastim dizajnom. Ova studija, takođe, ukazuje na značaj vertikalne dimenzije konekторa, pre nego na njegovu širinu, čineći višinu najznačajnijim faktorom vezano za odluku o postavljanju adhezivne delimične nadoknade. Poboljšanje osnove dovodi do razlika u tipu neuspeha, u poređenju sa prvom generacijom kompozitnih adhezivnih mostova. Kako je prikazano u literaturi,\textsuperscript{8} uspešnost od 71% nakon 5 godina uglavnom se može vezati za delaminaciju fasete. Sa jednim izuzetkom, ovakvo previdanje ne može se izvesti, na osnovu rezultata ove studije. Navedeni primer može se, međutim, oceniti kao 'reparabilan', a klinička procedura reparačije čini se da je jednostavna i efikasna.

Rascemtwiranje je, prema literaturi, češće primeteno u mandibuli u poređenju sa gornjom vilicom.\textsuperscript{18} Uzroci se mogu povezati sa specifičnom ulogom donje vilice u mastikatornim pokretima. Takođe se češće može očekivati na premolari, usled manje površine veze. Rascemtwiranje se, i u ovoj studiji, dogodilo u donjoj vilici, mada se ono može vezati za prevremeni kontakt, koji nije uklonjen usled nedostupnosti pacijenta. U poređenju sa metal-kermičkim delimičnim nadoknadama, kompozitne restauracije pokazuju manju tendenciju ka rascemtwiranju.\textsuperscript{16} Razlozi se mogu povezati sa većom jačinom veze između gledi 10 years and 74% over 15 years.\textsuperscript{15} The most common problems with abutment teeth of conventional FPDs are caries (18%) and the need for endodontic treatment (11%). It is obvious, compared to the results of this study, that failure rates greatly differ between full and partly retained FPDs. Both debonding and fractures can be related to the reduced geometry of iFPDs, which minimizes the bonding area as well as framework dimensions. Due to the adhesive cementation and visible margins, secondary caries is less likely to occur. This study also did not indicate any endodontic problems, supporting a thesis that damage to the pulp tissues is much lower with iFPD restorations compared to full retainers.\textsuperscript{16}

Some studies tried to improve fracture resistance of the fibre framework. An article by Song et al\textsuperscript{17} compared two abutment preparation designs, which differ in proximal box dimensions and extension. Though a tube-shaped design provided maximal tissue preservation, it appeared to be significantly weaker compared to the box-shaped design. This study showed the importance of the connector dimensions in the vertical plane, rather than in the width, making the height the most decisive factor when deciding pro et contra iFPDs.

Framework improvements lead to a difference in the failure type, compared to the first generation of composite iFPDs. As reported in the literature,\textsuperscript{6} survival rate of 71% after five years has been mainly related to veneer delamination. This is not an expectation arising from the results of this study, given the observation of only one such occurrence. The mentioned case, however, can be classified as repairable and clinical procedure seems to be simple, efficient and long-lasting.

Debonding is reported to be more likely in mandibular restorations rather than those in the upper jaw.\textsuperscript{18} The reasons could be related to specific lower jaw movements during mastication. It is also rather expected on premolars, due to a reduction in the bonding surface. Debonding in this study appeared to occur in the lower jaw but can be related to a premature contact, which was not treated because of the patient’s unavailability. Compared to the cast metal ceramic iFPDs, composite restorations are less likely to debond.\textsuperscript{16} The main reason for this is the enhanced bonding strength between enamel and the composite iFPD, compared to
sa jedne, i kompozitne nadoknade, sa druge strane, u poređenju sa gled-metal vezom. Drugi razlog može se tražiti u razlici elastičnih modulusa, gde se kompozitni približava dentinskome. Za povećanje jačine veze predložene su modifikacije dizajna.\textsuperscript{19} Ipak, ove modifikacije, usled svoje komplikovanosti, verovatno se pre mogu izvesti ukoliko se, kao građivni materijal, koriste keramički materijali.

Boja, tekstura i diskoloracije značajno su uticale na rezultate prve generacije fasetirajućeg kompozita.\textsuperscript{5,6,12} Promene u sadržaju punioca, kao i poboljšana, dvojna svetlosno – toplotna polimerizacije vode značajno boljem ishodu, kakav se zapaža u ovoj studiji. Kod pomenutih članaka, mogu se naći izveštaji o akumulaciji plaka, koji sledstveno vode gingivalnim problemima. Slični nalazi ne mogu se naći u ovom istraživanju. Način slaganja slojeva u principu se ne razlikuje od onog, primenjenog kod keramičkih materijala, osim jednostavnosti izrade, koja potiče od nepostojanja potrebe za predimenzioniranjem nadoknade. Prema rezultatima ove studije, boja može biti adekvatna čak i u najzahtevnijim zonama, kakve su prelazi zub – nadoknada.

Ova studija bazirana je na nedostatku zuba u bočnoj regiji, a u literaturi se mogu naći i primjeri anteriornih ili čak višečlanih nadoknada.\textsuperscript{20} Iako inicijalni rezultati deluju ohrabrujuće, generalno se višečlan nadoknade ne mogu uspešno uraditi adhezivnom tehnikom. To je i razlog fokusiranosti ove studije na mostove manjeg raspona. Eventualna dalja poboljšanja mogla bi dovesti do probaja adhezivnih nadoknada i u ovom indikacionom polju.

**Zaključak**

Kompozitne nadoknade ojačane vlaknmama su minimalno invazivni, estetski i pouzdan način tretmana minimalne krezubosti bočnog segmenta denticije. U kliničkoj praksi, za postizanje dugotrajnih rezultata pažnju treba obratiti na izbor pacijenata, okluzo – gingivalnu dimenziju nosača, modelovanje osnove i adhezivnu tehniku cementiranja. The enamel-metal bond. A second factor could be due to a difference in the elasticity modulus. The modulus of composite closely matches that of dentin. For bonding improvement a modified design has been suggested.\textsuperscript{19} However, it has to be noted that the latter is more likely to be achieved with high-strength ceramic frameworks, due to its complexity.

Colour match, texture and discoloration greatly influenced a positive outcome of the first generation of veneering composite.\textsuperscript{5,6,12} Changes in the filler content, as well as improved dual light-heat polymerization led to a significantly better outcome in this study. The above articles reported plaque accumulation, which lead to subsequent gingival problems. However, those findings can not be confirmed by the present investigation. The composite layering technique basically does not differ from those used for ceramic restorations but it is more convenient since there is no shrinkage of the material. From the results seen in this study, colour can be achieved and matched even in the most demanding areas, such as tooth-restoration transition.

While this study is based on posterior single-tooth replacements, others were focused on anterior or even long-span composite iFPDs.\textsuperscript{20} Though initial results were encouraging, in general multiple tooth restorations can not be supported by the adhesive technique. For this reason this study focused on short-span iFPDs. However, eventually, further improvements could provide a breakthrough in multiple composite restorations.

**Conclusions**

Fibre-reinforced composite iFPDs are a tooth preserving, minimally invasive, aesthetic and reliable treatment option for single tooth replacement in the posterior area. In clinical practice, attention should be paid to patient selection, abutment height, framework modelling and adhesive cementation in order to achieve long-lasting results.
LITERATURA / REFERENCES


An Electronic Method for Measuring the Fit of Removable Partial Denture Frameworks to Dental Casts

Robert J Williams*, Tahseen Rafik and Zeid Al-Hourani

Abstract: It is well established that the Removable Partial Denture (RPD) is an effective treatment prosthesis. The objectives of a successful RPD are: to preserve the health of remaining oral structure, restore function and restore esthetics. To achieve these objectives, an RPD framework must fit accurately to the supporting structures. This paper presents a method for measuring the gaps or spaces present between the RPD framework and supporting structures which will enable the dentist and the dental technician to evaluate the accuracy of fitting of the prosthesis before it is delivered to the patient. The method used in this research is based on the principle of electric capacitance and uses a specially designed prototype measurement system.

Keywords: Dental technology, Capacitance transducers, Small gap measurement

Introduction

It is widely acknowledged that in order for a removable partial denture (RPD) framework to achieve maximum retention, create pleasing aesthetics and remain biocompatible, accuracy of fit must be optimized (Sykora, 1997; Ivik, et al. 1992 and Stern, et al. 1985). RPD frameworks are fabricated from high-shrinkage metal alloys, and are often soldered or tinned to cast metal cores. frameworks are fabricated from high-shrinkage metal alloys, and are often soldered or tinned to cast metal cores. In order to determine how to hone fabrication processes so that accuracy can be maximised, a careful examination of the size of gaps between frameworks and supporting structures is necessary. Several researchers have studied such gaps in a research context. For example, elastomeric impression materials are used to take impressions of the dentition and cast and then encase in resin the space to reveal gaps between the framework and cast, accurately maintained by the resin (Fritell, et al. 1985). Both the latter studies used photographs of sections taken across spaces, which were enlarged by projecting transparencies onto screens to increase accuracy of measurement. Other researchers have shown that a framework may appear to fit 'in vivo' but with the use of, for example, custom made feeler gauges under retentive clasp ends, that there are gaps not seen with the naked eye (Murray, et al. 1988). The present study suggests that subjective judgments of fit based on the use of the naked eye or experience may be flawed (Calverley, et al. 1987 and Rantanen, et al. 1986).

The above studies, although very suggestive, are unable to show that the fit of a framework on a cast may be in a distorted state (Ali, et al. 1997). Whilst acknowledging that a framework may be distorted when fitted to a cast or indeed for that matter the oral cavity, objectively assessing and measuring spaces between a framework and a cast is an important first step in quality assurance.

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This paper reports on a method of objectively assessing framework fit, which is comparatively fast and efficient and promises to allow accurate measurements of spaces to be made outside the research context on a routine basis.

2. Methods for Gaps Measurements

There are three main methods for measuring small gaps. These are X-rays, Ultrasonic and capacitive transducers. The theory of operation of each of these methods is presented below.

2.1 X-Ray

When a material is subjected to x-ray bombardment, some of its electrons will gain energy and leave the atom, creating a void in the vacated shell, thereby releasing a photon of x-ray energy known as x-ray fluorescence.

The energy level or wavelength of fluorescent x-rays is proportional to the atomic number and is characteristic for a particular material. The quantity of energy released will be dependent upon the thickness of the material being measured.

Basically, the x-ray fluorescence unit consists of an x-ray tube and a proportional counter. Emitted photons ionize the gas in the counter tube proportional to their energy, permitting spectrum analysis for determination of the material and thickness.

X-ray fluorescence is the most precise measurement method, especially for small-diameter parts, or dual coatings such as gold and nickel over copper.

2.2 Ultrasonic

Ultrasonic thickness gauging is a widely used non-destructive test technique for measuring the thickness of a material from one side.

The ultrasonic method uses the pulse reflection principle and is based on the amount of time it takes for ultrasonic waves to pass through and return from inside the object. This is explained below with reference to Fig. 1.

The measurement process starts by transmitting a pulsed ultrasound energy from the ultrasonic probe through the framework. The ultrasonic pulse will travel through the framework medium until it reaches the interface between the framework and the cast. Because of the difference in the medium, part of the ultrasonic energy will be reflected back to the probe (first reflection) and the majority of the energy will continue travelling through the gap. When the wave reached the end of the gap and hits the cast, another reflection occurs (second reflection). The time between the two reflections depends on the depth of the gap and the sound speed in the medium of the gap.

\[
\text{Gap Depth} = (12 - t1) \times \text{Speed of Sound in the gap}
\]

The resolution of the above ultrasonic method depends on the pulse width (the narrower the pulse, the higher the resolution). Another constraint is the Quality Factor of the ultrasonic probe (minimum number of cycles in the pulse). Typical ultrasonic transducers have a Q-Factor of 10. That means we need to have a minimum of 10 cycles per pulse. To achieve a resolution of 0.1 mm, a very narrow pulse is needed with 10 cycles in it. This means a very high frequency ultrasonic wave is needed (around 100MHz). The probes that are capable of working at this frequency are usually expensive and very delicate.

A disadvantage of radiation methods is the use of X-ray or gamma radiation that requires special safety measures for protection of the users against the radiation. The equipments used are also relatively expensive.

There were two main limitations for the use of ultrasonic non-destructive testing in this study. These limitations can be summarized as:

1. To achieve a resolution of 0.1 mm with an ultrasound probe it should have a high frequency. This high frequency depends on the speed of the sound traveling in the material (in this case the Cobalt Chromium RPD framework). The resolution is related to the shortened pulse length that can be produced, which is very difficult to achieve. A demonstration held in the Dental Technology Centre at UWIC was promising but proved very expensive. The technique was excluded due to the high expense of instrumentation needed.

2. An X-ray technique can be used to measure a gap between an RPD framework and a cast. However, about 4 images are needed for each framework and these need to be digitalized before the measurement can be taken. This technique is time consuming.
Because of the above-mentioned difficulties and disadvantages, an alternative method was sought. Initially it was proposed that the electronic principle of capacitance might be applicable to the problem in hand.

3 Capacitive Transducers

A capacitor in its simplest form consists of two conducting plates separated by an insulating layer called a dielectric. When a capacitor is connected in a circuit across a voltage source, the voltage forces electrons onto the surface of one plate and pulls electrons off the surface of the other plate resulting in a potential difference between the plates.

The capacitance of a capacitor is proportional to the quantity of charge that can be stored in it for each volt difference in potential between its plates. Mathematically, this relationship is written as:

\[ C = \frac{Q}{V} \]

(1)

where \( C \) is capacitance in farads, \( Q \) is the quantity of stored electrical charge in coulombs and \( V \) is the difference in potential in volts.

The difference in potential or voltage of the capacitor can be calculated using the formula:

\[ V = \frac{Q}{C} \]

(2)

The capacitance of a capacitor is affected by three factors:

1. The area of the plates.
2. The distance between the plates.
3. The dielectric constant of the material between the plates.

Larger plates provide greater capacity to store electric charge. Therefore, as the area of the plates increases, capacitance increases.

Capacitance is directly proportional to the electrostatic force field between the plates. This field is stronger when the plates are closer together. Therefore, as the distance between the plates decreases, capacitance increases.

The ability of the dielectric to support electrostatic forces is directly proportional to the dielectric constant. Therefore, as the dielectric constant increases, capacitance increases.

Taking into account each of the above three factors, the capacitance of a capacitor with two parallel plates can be calculated using the formula:

\[ C = \frac{8.855 \times 10^{-12} K A}{d} \]

(3)

where \( K \) is the dielectric constant;
\( A \) is the area of the plate;
\( d \) is the distance between the plates and 
\( 8.855 \times 10^{-12} \) is the absolute permittivity of free air space.

Substituting the value of \( C \) described by Eq. 3 in Eq. 2 will result in:

\[ V = \frac{d \times (Q / K \times A \times 8.855 \times 10^{-12})}{d} \]

(4)

Equation 4 shows that if \( Q, K \) and \( A \) are kept constant, then the value of the voltage across the two plates is directly and linearly related to the distance between the two plates.

The above principle was used to develop a method of measuring the fit of RPD frameworks to dental casts. The denture is usually made from conductive material and forms one end of a capacitor. The other plate of the capacitor is formed by sticking a small sensor (0.01 mm thick) made from conductive foil on the cast. By connecting the ends of these two plates to a high-precision current source and measuring the voltage across the two terminals, since the voltage will be directly related to the gap between the denture and the cast, the distance between the RPD framework and the cast can be determined.

3. Experimental Set-up and Measurements

Figure 2 show the experimental set-up used in this project. It is based on a high precision current source developed by Sensatech Research Ltd (Sensatech Research Ltd, Unit 6 Level 3 North, New England House, New England Street Brighton, UK. BN1 4GH, www.sensatech.com). This device is used to maintain constant current (constant \( Q \)) in the capacitor, irrespective of its value. The device is powered by 20V DC power source and the voltage across the capacitor is measured by a digital voltmeter. The voltage should be directly related to the gap between the capacitor's plates.

![Figure 2. Basic experimental set-up](Image)

It was necessary to calibrate the system and find the voltages for different known gaps and for different sensor sizes. To do this, a simple setup was built using a micrometer where one plate of the capacitor was mounted on the fixed end of the micrometer while the other end (the sensor) was fixed on the moving end as shown in Fig. 3.

The gap between the two plates was varied in 0.1 mm steps using the micrometer dial and for each gap value the voltage was measured. The results were tabulated in a look-up table and plotted in Fig. 4.

The decision was taken to use one sensor size (5x5 mm) to carry out the evaluation process. This decision was taken because it has the best straight line and all the RPD components were almost the same size (rest, guide plates,
terminus third of clasp retentive arms, and the reciprocal clasp arms).

and the size of any gaps determined by using the above graphs.

The size of gaps measured by capacitance were then verified using radiography (Fig. 6) and by measuring the thickness of acrylic resin usually used for crown and bridge modelling (Palavit®G, Heraeus Kulzer GmbH, Philipp-Reis-Straße, Germany) material which was allowed to flow into gaps. This technique has been used before to evaluate the accuracy of fitting of RPD framework (Figs. 7a and 7b). The Palavit G resin were placed on the area of concern of the gypsum cast, the framework were then placed to full seating applying sufficient figure pressure allowing the resin to polymerise. The thickness of the resin layer was then measured using digital micrometer calibre. The average of three for each component was then recorded in Table 1. All three methods of measurement yielded results that coincided to a large degree in Table 1. Thus confirmation of the accuracy of the electronic method of measurement described above was provided.
4. Results

The graph represents the measurements of known gaps. It is shown that the voltage increases as the gap size increases. Area, as well as gap size, affects the capacitance measurement. Thus each line refers to a given area.

The results were verified firstly using X-Rays. A radiograph of gaps between the model and the alloy framework were measured. Secondly a resin (Palavit G) was flowed into gaps, allowed to set and the thickness (corresponding to the gap size) measured.

Table 1 shows measurement of gaps using X-Ray, Palavit G, and capacitance measurements. This was achieved by placing the x-ray on a light table, and using the Graticule Magnifier (Lensel Optics Pvt Ltd. 662/D2, MIDC, Chinchwad, Pune 411 019, India) with Scale range 0.1mm-22mm, touching the x-ray image the gap between the metal framework and the cast was measured. Three readings were recorded for each component and the average is shown in Table 1.

Table 1. Comparison of results of measuring the gap between some components of the RPD framework and the supporting cast

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<tr>
<td>Gap on X-Ray</td>
<td>&lt;0.1 mm</td>
<td>0.2 mm</td>
<td>0.3 mm</td>
<td>0.1 mm</td>
<td>&lt;0.1 mm</td>
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<tr>
<td>Capa.</td>
<td>0.0 mm</td>
<td>0.2 mm</td>
<td>0.3 mm</td>
<td>0.1 mm</td>
<td>0.0 mm</td>
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<tr>
<td>Palavit G</td>
<td>&lt;0.1 mm</td>
<td>0.15 mm</td>
<td>0.27 mm</td>
<td>0.95 mm</td>
<td>&lt;0.1 mm</td>
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5. Discussions

Many clasps engage only a 0.25 mm undercut. If the terminus of an active clasp presents a gap between itself and the cast of only 0.1 mm, for example, the retentive function of that clasp will be greatly reduced. Similarly, occlusal supports functioning as indirect retainers would not need to move a great distance towards the surface of the underlying tissue to cause lifting of the prosthesis.

The objective measurement of such spaces is an important first step in assessing the function of an RPD. The method described above offers this facility conveniently. Although there is a thickness of sensor and adhesive used in the method described above, this is only 0.16% of a 0.25 mm gap, for example. Further, if the sensor is adapted along the whole length of a clasp, it is likely that the clasp will be distorted so as to maintain a similar gap at the active end which would be evident without the sensor. The same is true of occlusal rests if the foil is adapted over the whole rest seat.

The electronic device described above offers a method of simply, accurately and objectively assessing the fit of a framework to a cast in crucial areas, which is readily available and not limited to a research setting. Not only can spaces under important areas of the framework be detected but they can be accurately measured. With the use of the device described, frameworks thought to be satisfactory based on subjective assessment may well be deemed to be unsatisfactory, and vice versa.

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Technology applicable to the digital production of removable partial denture frameworks is developing quickly. Previous reports have described how sacrificial patterns can be produced by rapid manufacture machines and trial fitted to patients. However, recently a case was reported whereby a rapid manufacture machine was used to build a chromium cobalt framework directly, omitting the casting process. This paper reviews progress to date, outlines possible developments and indicates the need for future research.

CAD/CAM; rapid manufacture; removable partial dentures; selective laser melt

Robert J Williams, Dominic Eggbeer, Richard Bibb

The principles of computer aided design and manufacture (CAD/CAM) and rapid manufacture (RM) technologies have been applied to the fabrication of removable partial denture frameworks (RPDs). Already the potential advantages are clear and have been discussed. Developments achieved so far have included electronic surveying of a three-dimensionally scanned dental cast and the production of successful castings from plastic patterns produced by digital rapid manufacturing (RM) technology, one of which was satisfactorily trial fitted to a patient. A recent paper reports on a satisfactory trial fitting to a patient of an RPD framework which was built in Cr/Co alloy by an RM machine, avoiding both the duplicating and casting processes. In the future, it could be possible to employ RM machines on a large scale that can directly build frameworks in metal alloys, thus avoiding the casting stage. In other words, RPD frameworks would routinely be produced without wax and without casting.
Materials and Methods

The procedure described in several publications\textsuperscript{3\textendash}6 begins with three-dimensional scanning of a cast, usually the whole arch. The illustrations of casts in Fig 1 show firstly a lower cast undergoing scanning with a structured white light digitiser (Comet 250, Steinbichler Optotechnik, Am Bauhof 4, 83115 Neubeuern, Germany) and secondly a point cloud representing an upper cast after scanning. In principle, any suitable method of scanning could be used, like structured light, laser or touch probe. However, it should be ensured that the latter gives a suitable depth of undercut.

For the publications cited above, the scan data came in the form of a 'point cloud' where the cast was represented by thousands of points in three dimensions. Software is used to produce this surface definition from the point cloud and a Standard Triangulation Language (STL) file is produced (Fig 2).

A commercially available software package (FreeForm\textsuperscript{6}, FreeForm\textsuperscript{2} Software, SensAble Technologies, Curiestrasse 2, D-70563 Stuttgart, Germany) has been used to enable electronic surveying and patterning to be completed\textsuperscript{2\textendash}6. FreeForm has been well described as a virtual sculpting environment\textsuperscript{2}. It also offers functions that enable virtual structures to be produced in defined and precise dimensions as required by the operator. An STL file can be imported into this environment and Fig 3 shows such a file in FreeForm. The computer model of a cast may be turned and tilted in the virtual environment. There are functions within FreeForm that have a direct dental application. For example, the 'parting line function' shows the areas of undercut, again as shown in Fig 3. The effect is rather similar to shining parallel light onto a cast from a vertical direction. The undercut areas are effectively in shadow.

The junction of the two colours in Fig 3 is in the exact position of a survey line if drawn using a physical surveyor\textsuperscript{2}. The direction of the parting line function may be changed, emulating the effect of tilting a model on a surveyor and hence re-defining undercut areas. Thus a suitable path of insertion may be chosen from at least the same number of options as those offered by a physical surveyor.

Once the path of insertion is chosen, another function in FreeForm known as 'extrude to plane' can be used to eliminate undercuts. Vertical extrusions from the survey line are
added by the package instantaneously (Fig 4). It is also possible to select different colours that may perhaps make some operations clearer.

The depth of undercuts can be measured using the ‘ruler’ function that will give a value for the distance between the original scan and the extruded plane (Fig 5). For a clasp to enter an undercut, it can be positioned on the original scan without the undercuts removed and later ‘cut and pasted’ onto the build of the model with the planes extruded. This is a much simpler operation than it appears.

Cast preparation is completed by adding relief. The relief area can be defined by using a line to encircle where the relief is required and the software is instructed to raise this area of the surface of the model to the dimensions required. Fig 6 shows relief added to a cast where the relief has been raised by 1 mm. At this point virtual cast preparation is complete. The prepared cast shown in Fig 6 is a ‘buck’ file, which means that a file has
been saved in such a form that when the file is re-imported into FreeForm to enable the framework to be built, it cannot be altered inadvertently during that stage.

A build of a framework being undertaken in the virtual sculpting environment is shown in Figs 7 and 8. Shapes of the framework can be defined and the software will place these shapes on the model. For example, the requirement to place a 'D' shaped part in a certain position of the required dimensions in millimetres can be entered into the software. However, a library of parts is not needed. Shapes can be built up or carved in a free-hand manner, and modelling, blending and shaping can be carried out on the whole framework.

Once the software build is completed, supporting structures must be added in the virtual environment (Fig 9). This is a semi-automatic process.

Supports are necessary to conduct heat away from the physical build area. They also secure the part preventing movement during the build. If there is insufficient support,
heat can lead to part distortion that in turn can lead to build failure. Fortunately, supports are thin and easily removed after RM processing. Many of them will fracture on movement with the hand.

In Fig 10, the framework is shown as it emerges from the RM machine. The framework was produced in a chromium cobalt alloy. Prior to processing, the alloy is received in a powdered form. As an example of composition, one alloy specification (F75) supplied by Sandvik Osprey for an RM machine has the following composition: 27-30% Cr, 5-7% Mo, 1% max Si, 1% max Mn, 0.75% max Fe, 0.35% max C, 0.5% max Ni, balance Co. A comparison with a standard dental casting alloy would show considerable similarity.

Supports, and the framework itself, can be seen in Fig 10. Placing supports on the fitting surface has been avoided to keep this surface intact.

Illustrations of a selective laser melting (SLM) machine and the process taking place are shown in Figs 11a and 11b. Fig 12 shows an RPD framework built by rapid manufacture
A framework built by selective laser melt techniques trial fitted to a patient.

Figures 11a and 11b illustrate an SLM machine. Figure 11b shows a part in the early stages being built in layers on a bed by laser welding.

Techniques in situ. The fit and overall acceptability was judged to be good by both the patient and the clinician.

Before the built framework is obtained, however, the completed virtual image is layered by software. In other words, imagine that the computer takes a very thin horizontal slice through the image of the framework. If a view of this slice could be seen from above, the layer would show a shape or pattern that practically has only two dimensions. The chromium cobalt build is achieved through a computer controlled laser beam which is moved in a path conforming to the pattern of the first layer of the object. This welds powdered alloy together. Once one layer has been built, powder is added and the next layer is welded by the laser beam. This, and associated techniques, have been described in the literature.7–9

There are no quoted accuracy figures for the SLM process, but indications from studies at the University of Wales Institute, Cardiff, are that it builds within ±100 microns of the...
volume of an RPD framework. Scanning accuracy depends on the scanner used. As an example, the Renishaw (New Mills, Wotton-under-Edge, Gloucestershire, UK) 'Incise' touch probe scanner claims an accuracy parameter which is the maximum distance between any measured point on any scan and the true surface of the sphere used to scan, which is less than 20 microns.

The framework is finished by employing familiar dental techniques such as stoning, electro-brightening and polishing normally used after a casting has been sandblasted.

The constituents of cobalt chromium alloys available for RM techniques are very similar to many dental alloys. However, to date no tests related to the toxicity of the RM processed alloys have been carried out and so the case study illustrated above has only been trial fitted. In addition, no CE marks for intra-oral use have been obtained at this stage. Furthermore, there have been no long-term case studies or tests (including flexure tests) and these will be needed if the technology is to become embedded and used on a routine basis. It can be said, however, that good results could be expected relating to clasp flexure and other properties. Part densities produced by SLM technology are typically higher than 99.8% and show a suitable hardness and strength.10

Another barrier to using the new technology is the cost. It has been estimated that the cost of production using the techniques described in the section above could currently amount to £150-£175 per framework5. However, most of the cost is related to building the alloy in the RM machine. Since this is a comparatively new process, it can be expected that prices will drop radically as RM technologies in general become more established. However it is unlikely that any dental laboratory would own its own RM machine for many years. More likely the data could be sent electronically to a centre that would produce the framework, as is currently the case with manufacturers of several crown and bridge structures and substructures.

Another expected improvement is that the software could be developed to include dedicated dental functions. FreeForm has not had any facilities developed specifically relating to dental applications. It is theoretically possible, for instance, to have an array of icons of RPD components on screen that could be ‘dragged and dropped’ in place on the STL file of the cast. With such advances, the speed of ‘on screen’ builds of frameworks would be dramatically increased and become much faster than physical wax pattern production. Another potential benefit offered is that, for example, clasps could be made to enter the appropriate depth of undercut automatically. This could be programmed into the software. Likewise, other components could be placed according to textbook principles, thereby assuring and standardising quality. Electronic surveying already compares well with physical surveying in terms of speed. Undercuts are eliminated almost instantaneously, for instance. However, even this process could be semi-automated, with software producing suggestions in relation to the path of insertion for specific cases.

Other alloys apart from cobalt chromium are commercially available in powdered form for RM processing, for example titanium and stainless steel alloys. Unfortunately, the powdered titanium is extremely expensive and stainless steel alloys so far investigated have a modulus of elasticity too low to enable successful clasps to be produced.

Building frameworks in the virtual field is completed with the use of a ‘Phantom Arm’ connected to a personal computer. This allows three-dimensional movement of the cursor
or virtual tools on the screen and also provides force feedback sensations when the model or wax is contacted. This situation obviously requires the dental technologist to acquire new skills. Training would of course be required but gaining such skills is not beyond those who are already adept at the highly dexterous skills needed to manipulate wax ready for investing. In addition, all the knowledge relating to the positioning of removable partial denture components is as valid in the virtual environment as it is in the physical world.

It is probably necessary for all the developments mentioned above to occur before CAD/CAM/RM techniques become more widely used in RPD construction. However, the principle of fabricating satisfactory CAD/CAM/RM produced alloy frameworks has begun to be established. The work reviewed here begins that process and points to the potential advantages discussed above.

Further Research

The application of RM-produced alloy frameworks to dentistry is in the early stages. The technology on which the application is based has only fairly recently been developed. It is not surprising then that toxicological tests suggested above need to be completed. Also, other in vitro tests would be of interest, such as tensile and fatigue testing to compare dental cast alloys with RM produced alloys. In fact, any physical or chemical tests that compare the substrates produced by casting and RM building would establish the similarity or differences of the products of the two processes. The information provided by such tests could satisfy international standards allowing the new technology to be adopted more widely in dentistry. If it can be established that it is safe to allow RM processed alloys to be used for RPD frameworks, a number of long-term case studies would complete the evaluative process.

Conclusion

The lost wax process has been a central technique in dentistry for a very long time. Any possibility that alloy frameworks could be produced without wax and without casting is of great interest. Given this and the fact that RM processes are linked to information technology, a revolution for this branch of dentistry may be at hand. Developments are occurring in related fields at great speed. The scanning process, for example, is consistently becoming easier, cheaper and more widespread. Virtual patterning could be extremely fast with a ‘drag and drop’ system mentioned above. It has also been noted that quality assurance can, to some degree, be set into the software of on-screen builds. Finally, the positioning of supports for a direct metal alloy build has recently become semi-automated, which has already accelerated the process. These points indicate that the CAD/CAM/RM technologies described are set to become easier, faster and cheaper with time and may very well one day form an accepted method of RPD framework fabrication.

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While computer-assisted design/computer-assisted manufacturing (CAD/CAM) has become common in fixed partial denture construction, particularly when one is employing milling,\(^1,2\) the use of CAD/CAM for the fabrication of removable partial-denture (RPD) frameworks has only recently been developed.\(^3\) Unfortunately, milling an RPD framework from a solid block of alloy is impossible with current technology. The manufacturing stages of RPD development, therefore, may lie in techniques of rapid manufacturing (RM) rather than milling. Interestingly, there has been some previous application of RM technology to maxillofacial restoration.\(^6\) This presentation will outline the method of fabrication of an RPD framework without the use of a waxup or cast.

The CAD/CAM Procedure

A master cast, typically of the whole arch, is scanned. Any suitable scanner (e.g., structured light, laser, touch probe) may be used as long as the undercuts necessary for retention are accurately reproduced. The scan data for the work described herein came in the form of a "point cloud," with the data consisting of thousands of points representing the master cast in three dimensions. The computer-model surface is obtained from these points. A software package may be used to accomplish this, after which a standard triangulation language (STL) file is created. A commercially available software package (i.e., FreeForm, SensAble Technologies, Woburn, MA) is used to enable electronic surveying and patterning to be completed.\(^4,5\) This software package serves as a virtual sculpting environment,\(^7\) into which the STL file can be imported. The direction of the parting line can be changed, or the model tilted, again mimicking the principles of physical surveying (Figure 1).

After the path of insertion has been designated, a function known as "extrude to plane" can be used to eliminate undercuts. The depth of undercut can also be measured with FreeForm software (SensAble Technologies, Woburn, MA) using its ruler function, which measures the distance between the extruded plane and the original scanned cast. Relief can then be added by defining the required area on the scanned model and instructing the software to raise that area to a specific dimension (Figure 2). The electronically surveyed model

![Image](https://via.placeholder.com/150)
can be saved as a buck file. A buck file is a reference object which ensures that once the file is re-imported into the software, it cannot be inadvertently altered during the next stage of digitally building the framework.

The position and dimensions of various shapes can be defined, and the software will place the shapes on the model (Figure 3). Free-hand modeling, shaping, and blending can also be used. Once the pattern is completed, supporting structures must be added in the virtual environment. The computer then slices the STL file into horizontal layers. Each layer is built by a selective laser melting (SLM) rapid-manufacturing machine. A layer of powdered alloy is melted together by a fiber laser. This laser is controlled by the computer’s movements, which copy the layer of the virtual pattern, over the surface of the powder. Once one layer has been physically manufactured, fresh powder is deposited on top of the previous layer and is built in the same way until the entire framework is completed. Ultimately, a complete solid alloy framework is produced (Figure 4). Alloys that are currently available in a form suitable for an SLM RM machine include chromium cobalt, stainless steel, and titanium.

Conventional finishing and polishing methods can be used to fit and complete the framework (Figure 5).

The chromium cobalt alloys available for RM techniques have constituents very similar to many dental alloys. To date, however, no toxicological tests have been completed on the RM-built alloys. As a result, the case study illustrated herein has only been trial-fitted. Long-term studies will be needed if the technology is to become pervasive in daily practice. The process could also be significantly improved if specific dental functions, relating particularly to dental applications, are developed in the software. It is theoretically possible, for instance, to have an array of icons of RPD components on screen, which could be dragged and dropped in place on the STL file of the cast. With such software development,
the speed of on-screen framework builds would be dramatically increased and compare favorably with physical wax pattern production. Another potential advantage is the fact that the principles of RPD fabrication can be rooted in the software (ie, clasps will enter the appropriate depth of undercut), thus ensuring and standardizing quality. While electronic surveying already compares well with physical surveying, this process could be semi-automated with software. Although it is necessary for the aforementioned developments to occur before CAD/CAM/RM techniques become more widely used in RPD construction, the principles of fabricating satisfactory CAD/CAM/RM-produced alloy frameworks have begun to be established.

Not only is the application of RM-produced alloy frameworks in the early stages of development, the technology itself has only recently been developed. The aforementioned toxicological tests should be completed, as well as other in vitro tests (eg, tensile testing, fatigue testing), to compare dental cast alloys with RM-produced alloys. In general, any physical or chemical tests comparing the substrates produced by casting and RM building would help establish the similarities or differences between the two processes and provide information that may allow them to be adopted more widely. If it can be established that it is safe to proceed with RM-processed alloys, a number of long-term studies would complete the evaluation process.

Conclusion
Casting has become a critical aspect of dentistry, and since RM processes are linked to information technology, they could potentially revolutionize this branch of dentistry. Virtual patterning could be extremely fast with the aforementioned drag-and-drop system, and quality can be set into the software of on-screen builds. The positioning of supports for a direct metal-alloy build has also recently become semi-automated. These points indicate that the CAD/CAM/RM processes described herein are set to become more user-friendly and time efficient, and may very well one day be an accepted method of RPD-framework fabrication.

References

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Figure 5. Rapid-manufacturing-built framework finished, polished, and fitted to the cast.
Proper Bite Development:
Occlusal Considerations

David Fray, DDS

For restorative procedures, ensuring proper occlusion is essential to the aesthetic and functional outcome, as well as the durability of the treatment. It is important for patients to understand that the teeth, temporomandibular joints, and the muscles must work in a harmonious relationship in order to have a healthy bite. (Figure). If the teeth do not fit together properly, muscle tension or an unhealthy joint may result, reducing the patient's ability to open and close smoothly.

Patients should be aware that common signs of abnormal jaw function include joint popping or clicking, muscle fatigue, and pain during mastication. If these symptoms occur on a frequent basis, or if the patient experiences a sudden difficulty opening the mouth, he or she may have temporomandibular joint (TMJ) disorder, and his or her dentist should be notified immediately (Table). Patients who experience frequent headaches should also inform their dentist of this condition. When the muscles that surround the complex TMJ become strained, the circulation is cut off, thereby causing waste products released during metabolism to build up. As a result, tension headaches may occur.

Because less than one in four patients who suffer from headaches are not aware that their oral alignment may influence their discomfort, it is important for the clinician to educate the patient about the relationship between headaches and TMJ disorders. Not all causes of TMJ disorders are known. Among the potential contributing factors are an abnormal bite, trauma, low-level infections, genetics, and/or stress.

"If untreated, a misaligned bite may result in muscle or joint complications."

Treatment of TMJ disorders is often difficult, as many of the symptoms may also be caused by stress, sinus infections, decaying teeth, or facial neuralgia. Some patients may find that their symptoms improve over time, without treatment, while others continue to experience increased amounts of pain. Although most of the population will experience signs of TMJ disorders, only a small percentage will experience symptoms that will cause them to seek treatment. Patients who exhibit any of the minor symptoms on an infrequent basis should be informed that they have little cause for concern. The elimination of forward head posture will allow the patient to improve his or her posture, which will translate into increased physical strength, balance and endurance.
Use of CAD/CAM technology to fabricate a removable partial denture framework

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This article reports on the first patient-fitted chromium cobalt removable partial denture framework produced by computer-assisted design, computer-assisted manufacture and rapid prototype technologies. Once the dental cast was scanned, virtual surveying and design of the framework on a 3-dimensional computer model was accomplished. A rapid prototype machine was used for direct fabrication of the alloy framework. Traditional finishing techniques were applied, the framework was assessed by a clinician in a conventional manner, fitted to the patient, and judged to be satisfactory by both the patient and clinician. (J Prosthet Dent 2006;96:96-9.)

The introduction of computer-aided design and computer-assisted manufacturing (CAD/CAM) into crown, inlay, and fixed partial denture fabrication is well advanced.1,2 Furthermore, CAD/CAM and rapid prototyping (RP) have been used in areas of maxillofacial technology.3,4 Recent work has shown that, in principle, CAD/CAM/RP technologies can be successfully applied to the fabrication of removable partial denture (RPD) alloy frameworks.5,6 Within the latter field, electronic surveying and the production of sacrificial patterns through digital technologies have been achieved, but there have been no reports of direct RP alloy builds or of the application of these achievements to the treatment of patients. This article describes the further development of CAD/CAM/RP technologies in RPD framework fabrication whereby the casting stage is omitted. This article also describes how digital processes are verified by successfully fitting the RPD framework to a patient. In essence, an RPD alloy framework was produced without the use of wax and without casting through the application of new technologies.

CLINICAL REPORT

A 75-year-old woman, requiring a bilateral distal extension prosthesis, presented to the Royal Gwent Hospital, Newport, UK, for treatment. The design requirements necessitated a lingual plate, infraorbital clasps, appropriate support, and indirect retention. Figure 1 shows the unrestored condition of the patient. Dental casts were produced according to accepted principles.7 CAD/CAM/RP procedures were then undertaken as follows.

A 3-dimensional scan of the patient’s partially dentate cast was obtained using a structured white light digitizer (Comet 250; Steinbichler Optotechnik GmbH, Neubuern, Germany). Multiple overlapping scans were used to collect point cloud data that were aligned using software (PolyWorks; InnovMetric Software Inc, Quebec, Canada). Other software (Spider; Alias-Wavefront Inc, Ontario, Canada) was used to produce a polygon surface in the standard triangulation language (STL) file format.

The CAD package used in this study (FreeForm; SensAble Technologies, Inc, Woburn, Mass) was selected for its capability in the design of complex, well-defined shapes that are required when designing custom prosthesis devices that must fit human anatomy. In addition to this capability, several precise functions within the software allowed electronic surveying to be completed.6

The CAD package has tools analogous to those used in physical sculpting and enables a manner of working that mimics physical surveying and wax pattern fabrication. The software uses a haptic interface (Phantom Desktop haptic interface; SensAble Technologies Inc) that incorporates positioning in 3-dimensional (3-D) space and allows rotation and translation in all axes,
transferring hand movements into the virtual environment. It also allows the operator to feel the object being manipulated in the software. The combination of tools and force feedback sensations mimics working on a physical object and allows shapes to be designed and modified, sometimes by using the phantom arm in a freehand manner and at other times by precisely defining sizes, shapes, and positions. The software also allows the import of scan data to create reference objects or “bucks” onto which fitting objects may be designed. The RPD metal framework in this report used this CAD software, and the RPD framework design was built on a 3-D scan of the patient’s cast (Fig. 2). The computer-aided design of RPD frameworks using the CAD software has been previously described.5,6

In a previous study,6 the application of RP methods was investigated for the production of sacrificial patterns that were used to cast RPD frameworks in cobalt-chrome alloy. In the present study, direct manufacture was attempted with the aim of eliminating the time and material-consuming investment-casting process. The RP development of selective laser melting (SLM) technology due to its ability to produce complex-shaped objects in hard wearing and corrosion resistant metals and alloys directly from CAD data.

To build the RPD framework on an SLM machine (SLM Realizer 2; MCP-HEK, SLM Tech Center, Borchen, Germany), adequate supports had to be created using software (Magics Version 9.5; Materialise NV, Leuven, Belgium) (Fig. 3). The purpose of the supports is to provide a firm base for the part to be built onto while separating the part from the substrate plate. In addition, the supports conduct heat away from the material as it melts and solidifies during the build process. Inadequate support results in incomplete parts or heat-induced curl, which results in build failure. Because the supports need to be removed with tools, the part was oriented such that the supports avoided the fitting surface of the RPD, and thus, the resultant framework would not be affected or damaged by the supports or their removal. The chromium cobalt (Sandvik Osprey
DISCUSSION

Although the framework exhibited slight surface porosity in some small areas, this was not considered likely to prohibit normal function, and the RPD framework was positioned on the mandibular teeth and other denture bearing areas. The fit was subjectively judged to be excellent. The RPD framework produced using the SLM process in conjunction with cobalt-chrome alloy resulted in an RPD framework that is comparable in terms of accuracy, quality of fit, and function to those produced by existing methods commonly used in dentistry.

The current costs of using the CAD/CAM approach are high. For example, the cost of FreeForm software and a Phantom arm is approximately $30,000. A suitable scanner (Roland DGA Corp, Irvine, Calif) costs approximately $25,000, including the software to produce a surface. However, the majority of the cost is in the initial investment, and such costs are likely to decrease with further technical development. To produce a scanned model with a surface takes approximately 5 to 15 minutes of operator time and 1 hour of machine time. The time taken to virtually survey the 3-D cast is comparable to physical surveying or perhaps slightly faster. Building the framework on screen may take about 40 minutes, but it is likely that with practice, this time could be greatly reduced. In future, this process could be condensed dramatically if software were developed to allow components to be “dragged and dropped” from icons on the screen to position on the virtual cast. However, SLM machines are expensive, and it is likely that laboratories would send data to a center to obtain alloy frameworks. SLM production costs are currently high. For example, one firm (MCP Tooling Technologies, Stone, UK) charges approximately $269 per framework for a batch of 6 different RPD frameworks, plus the cost of the alloy. However, methods and equipment in the field are developing rapidly, and it is expected, for example, that positioning supports will be automated, reducing operator time. Once the alloy build has been completed, finishing times and methods are the same as finishing a framework in the “as cast” condition.

The method described offers potential advantages. For instance, in the future, it may be possible to virtually build a framework on a scanned cast using a “drag and drop” facility by means of RPD components displayed as icons on screen and dragged onto the electronically surveyed digital model. In such a situation, quality assurance could be built into the software. This would reduce interoperator variability, and increase speed and economy over traditional handcrafting and investment casting techniques. However, there is need for refinement and development of the software and equipment for dental requirements and for further studies in this area.

SUMMARY

The successful application of CAD/CAM/RP technologies for the fabrication of RPD alloy frameworks has been confirmed by this report. Electronic processes are in existence that can be applied to RPD fabrication. The framework showed an accuracy of fit judged to be at least comparable to the results obtained by traditional casting methods.

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Rapid manufacture of removable partial denture frameworks

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Rapid manufacture of removable partial denture frameworks

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Abstract
Purpose – The aim of this study was to explore the application of rapid manufacturing (RM) to the production of patient specific, custom-fitting removable partial denture (RPD) alloy frameworks. RPDs are metal frameworks designed to retain artificial replacement teeth in the oral cavity.
Design/methodology/approach – The study was undertaken by applied case study. An RPD was designed using computer-aided design software according to well-established dental technology design principles, based on a digitally scanned cast produced from an impression of the patient’s mouth. The RPD design was then exported as an STL file in preparation for direct manufacture using selective laser melting. Dimensionally accurate frameworks were manufactured in 316L stainless steel and chromium-cobalt alloy. These were assessed for accuracy of fit and function on the patient cast and on the patient in clinic.
Findings – This successful case study demonstrates that an RM approach can produce fully functional, precisely fitting RPD frameworks for specific individual patients.
Research limitations/implications – The study was based on a single design produced using two materials. Further studies are in progress to show that the results can be achieved on a regular and predictable basis.
Practical implications – This study provides some practical guidance for the application described and suggests that similar success may be achieved in related custom-fitting applications.
Originality/value – The paper demonstrates the successful application of a novel approach to the design and manufacture of custom-fitting dental devices.

Keywords Manufacturing systems, Computer aided design, Dentistry

Paper type Case study

Introduction
Over the last decade computer-aided design, computer-aided rapid prototyping (CAD/CAM/RP) techniques have been employed in dentistry, but predominantly to the manufacture of crowns and bridges (Willer et al., 1998; Van der Zel et al., 2001; Duret et al., 1996). However, there has been a little research into the use of such methods in the field of removable partial denture (RPD) framework fabrication. Whilst rapid prototyping and rapid manufacturing (RM) techniques have proved successful in other dental applications, the lack of suitable design software has restricted their application in producing RPD frameworks. Recent studies by Williams et al. (2004a,b) and Eggbeer et al. (2004, 2005) have established a valid approach to the computer-aided surveying of dental casts, framework design and the subsequent production of sacrificial patterns using RP technologies.

The potential advantages offered by the introduction of CAD in the field of RPD framework design include automatic determination of a suggested path of insertion, instant elimination of unwanted undercuts and the equally rapid identification of useful undercuts, which are all crucial in dental technology. The potential advantages of an RM approach are reduced manufacture time, inherent repeatability, and elimination of inter-operator variation.

Methodology
Step 1: 3D scanning
A three-dimensional scan of a partially dentate patient’s dental cast was obtained using a structured white light digitizer (Comet 250; Steinbichler Optotechnik GmbH, Neubeuern, www.steinbichler.de). Multiple overlapping scans were used to collect point cloud data that was aligned using Polyworks software (InnovMetric Software Inc., Quebec, www.innovmetric.com). Spider software (Alias-Wavefront Inc., Toronto, Ontario, www.alias.com) was used to produce a polygon surface in the STL file format (Manners, 1993).
Step 2: design of the RPD framework

The CAD package used in this study, called FreeForm®, was selected for its capability in the design of complex, arbitrary shapes that are required when designing custom appliances and devices that must fit human anatomy. The software has tools analogous to those used in physical sculpting and enables a manner of working that mimics that of the dental technician working in the laboratory (FreeForm®, SensAble Technologies, Inc., Woburn, MA, www.sensable.com). The software utilises a haptic interface (Phantom® desktop haptic interface; SensAble Technologies Inc.) that incorporates positioning in three-dimensional space and allows rotation and translation in all axes, transferring hand movements into the virtual environment. It also allows the operator to feel the object being worked on in the software. The combination of tools and force feedback sensations imitate working on a physical object and allows shapes to be designed and modified in a natural manner. The software also allows the import of scan data to create reference objects or “bucks” onto which fitting objects may be designed. The RPD metal frameworks used in this study were designed according to established principles in dental technology (Brudz-Jorgensen and Bochet, 1998) using this CAD software and based on a three-dimensional scan of a patient’s cast. The CAD of RPD frameworks using this software is fully described by Williams et al. (2004b) and Eggbeer et al. (2004, 2005). The finished design used in this case is shown on the screen capture shown in Figure 1.

Step 3: rapid manufacture

As a previous study (Eggbeer et al., 2005), the application of RP methods was investigated for the production of sacrificial patterns that were used to invest cast RPD frameworks of cobalt-chrome alloy. Four RP methods were compared: stereolithography (SL) (3D Systems Inc.), ThermoJet® (3D Systems Inc.), Solidscape® T66 (Solidscape Inc., Merrimack, NH, www.solidscape.com) and Perfactory® (Envisiontec GmbH, Elbestraße, www.envisiontec.de).

In this study, direct manufacture was attempted with the aim of eliminating the time and material consuming investment-casting process. The development of selective laser melting (SLM) technology showed potential application for dental technologies due to the ability to produce complex shaped objects in hard wearing and corrosion resistant metals and alloys directly from CAD data.

In order to successfully build the RPD framework on the SLM machine (SLM Realizer 2, ReaLizer GmbH, Paderborn, www.realizer-rp.de) adequate supports had to be created using Magics software (Version 9.5, Materialise N.V., Leuven, www.materialise.com). The purpose of the supports is to provide a firm base for the part to be built onto whilst separating the part from the substrate plate. In addition, the supports conduct heat away from the material as it melts and solidifies during the build process. Inadequate support results in incomplete parts or heat induced curl, which leads to build failure. As the supports need to be removed with tools, the part was oriented such that the supports avoided the fitting surface of the RPD, as shown in Figure 2. This meant that the most important surfaces of the resultant part would not be affected or damaged by the supports or their removal.

First experiment

The 316L stainless steel was selected for the first experiment for its excellent corrosion resistance making it suitable for dental applications. In addition, the SLM machine manufacturers have shown that the material is well suited to processing by SLM. The part and support files were sliced and hatched using the SLM realizer software with a layer thickness of 0.050 mm. The material used was 316L stainless steel spherical powder with a maximum particle size of 0.045 mm (particle size range 0.005-0.045 mm) and a mean particle size of approximately 0.025 mm (Sandvik Osprey Ltd, Red Jacket Works, Neath, www.smt.sandvik.com/ossprey).

Figure 2 RPD oriented and supported to avoid the fitting surfaces
The laser had a maximum scan speed of 300 mm/s and a beam diameter of 0.150-0.200 mm. The first two parts attempted were partially successful due to insufficient support and erroneous slice data. These errors resulted in complete RPDs. The third attempt was prepared with more support and the data was sliced using different software (VisCAM RP, Marcam Engineering GmbH, Wahrenheistrasse, www.marcam.de). This proved successful and produced a complete stainless steel RPD framework, shown in Plate 1.

Second experiment

The same RPD framework design was manufactured using cobalt-chrome alloy using a layer thickness of 0.075 mm (Sandvik Osprey Ltd). The principal reason for attempting the design in Cobalt-Chrome was for direct comparison with additionally made RPD frameworks, which are typically cast from the same material. Like the previous material, the SLM machine manufacturers have shown Cobalt-Chrome to be suitable for processing by SLM. As before the laser had a maximum scan speed of 300 mm/s with a beam diameter of 150-0.200 mm. The material used was Cobalt-Chrome spherical powder with a maximum particle size of 0.045 mm (particle size range 0.005-0.045 mm) and a mean particle size of approximately 0.030 mm. The part proved successful and produced a complete Cobalt-Chrome RPD framework, shown in Plate 2.

Step 4: finishing

Supporting structures were removed using a Dremel handheld power tool using a reinforced cutting wheel (Dremel, Reinforced Cutting Disc, Ref. Number 426). The frameworks in their initial form were well formed but showed fine surface roughness. This roughness was easily removed by bead blasting. This resulted in a framework that showed similar physical appearance and surface qualities as the investment cast items typically used in dental technology. Therefore, the treatment and finishing of the framework from that point onwards was conducted in the same manner as any other RPD framework, using normal dental laboratory techniques and equipment.

Results

The successful 316L stainless steel RPD framework was assessed for the quality of fit by fitting it to the plaster cast of the patient’s oral anatomy. The quality of the fit was assessed according to normal dental practice by an experienced dental technician and found to show excellent fit. The frameworks showed a quality of fit that was comparable with investment cast frameworks. However, repeated insertion and removal from the patient cast resulted in small but permanent deformation of the clasp components. The clasp components are the functional parts of the framework and are designed to grip the teeth to provide a firm location of the denture (the clasps are the elements shown in the close up photographs in Plate 3). Therefore, the permanent deformation reduces the ability of the framework to grip the teeth and the denture becomes loose. This meant that after several operations the clasps no longer held the framework as securely to the existing teeth as deemed necessary by the dental technician.

The Cobalt-Chrome RPD framework was complete, polished and finished well with the normal dental technology procedures. The framework proved to be an excellent fit, possessing good clamping when test fitted to the patient’s cast (Plate 4). This framework was test fitted
Rapid manufacture of RPD frameworks
Richard Bibb, Dominic Eggbeer and Robert Williams

Plate 4 Close up views of Cobalt-Chrome RPD framework fitted to patient cast.

In the patient in the clinic and found to be a precise and comfortable fit with good retention, shown in Plate 5. Therefore, the framework was fitted with the artificial teeth and the finished article given to the patient to use in exactly the same manner as a traditionally manufactured item. Unlike the previous stainless steel framework, the clasping forces did not result in permanent deformation of the clasps and the framework withstood repeated insertion and removal cycles.

Discussion
Sources of error
Various studies such as those by Stern et al. (1985), Murray and Dyson (1988) and Barsby and Schwarz (1989) have aimed to assess error in Cobalt-Chrome partial denture frameworks made using traditional investment casting techniques. However, in the absence of an appropriate intra-oral scanning technology the application of CAD/CAM in dental technology depends on the dental model, which is a laser cast taken from an impression of the patient’s dental anatomy taken by a dentist. Clearly, this paper cannot address issues relating to the quality of the original dental impression or the casting of the dental model from this impression. In addition, human error in the interpretation of the dentist’s instructions or in the dental technician’s chosen design for the framework is not addressed in this paper. However, the adoption of CAD/CAM/RP technologies may incur several process steps that may contribute to error between the theoretical design produced using CAD and the final manufactured item. The effect of these processes will be an accumulation of tolerances at each technology stage.

Table 1 shows the steps in the process investigated here and indicates nominal tolerances associated with the technologies used. The accumulation of tolerances leads to the maximum error that could be expected to result from the technologies alone, assuming no human error is encountered. As human skill level and error cannot be attributed a numerical value and might range from zero to complete failure, discussion is not included here. However, as this study aims to investigate the implications of adopting CAD/CAM/RP technologies in dental technology it is appropriate to attempt to illustrate their potential contribution to error in the final RPD framework. The tolerances used in this table indicate typical or nominal figures, which are quoted by manufacturers or set as parameters in software.

From the processes stated in Table 1 it is reasonable to expect a maximum tolerance of approximately 0.2 mm for these parts. It should be noted that cumulative negative and positive tolerances from the various steps may also partially cancel each other resulting in a lower overall tolerance. The contribution of each individual step would be difficult to demonstrate without a statistically significant number of cases. The closeness of the fit and effective clasping observed when fitting the frameworks to the patient cast, as shown in Plates 3 and 4, suggest that SLM RPD frameworks are in fact within this tolerance.

Error analysis
RPD frameworks are by definition one-off custom-made appliances specifically designed and made to fit a single individual patient. In addition, the anatomically fitting nature of RPD frameworks means that they are complex in form and do not provide convenient datum or reference surfaces. This makes it difficult to achieve an investigation that provides a detailed quantitative analysis of error in this application. Therefore, it is not practical to perform the type of repeated statistical analysis that would be commonly encountered in series production or mass manufacture. Instead, it is normal dental practice to assess the accuracy of an RPD by test fitting the device to the patient cast and subsequently, in clinic, to the patient. In this study, the RPD frameworks created were deemed by a qualified and experienced dental technician to be a satisfactory fit and comparable to those produced by expert technicians. This suggests that the approach and technologies used are fit for purpose in this application although further experiments with a range of patients with differing RPD designs will be required to ensure that this is in fact the general case.

Conclusions
SL has been shown to be a viable RM method for the direct manufacture of RPD metal alloy frameworks. Parts produced using the SLM process in conjunction with cobalt-chrome alloy result in RPD frameworks that are comparable in terms of accuracy, quality of fit and function to the existing methods typically used in the dental technology laboratory. The CAD and CAM approach offers potential advantages in terms of reduced inter-operator variability, repeatability, speed and economy over traditional handcrafting and investment casting techniques.
### Table 1: Process steps and associated tolerances

<table>
<thead>
<tr>
<th>Process step</th>
<th>Source of error</th>
<th>Tolerance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impression taking</td>
<td>Human/skill level</td>
<td>No value</td>
</tr>
<tr>
<td>Casting study model</td>
<td>Human/skill level</td>
<td>No value</td>
</tr>
<tr>
<td>Optical scanning of study model</td>
<td>Scanner</td>
<td>±0.050</td>
</tr>
<tr>
<td>Creating Polygon computer model from point cloud data</td>
<td>Software setting</td>
<td>±0.050</td>
</tr>
<tr>
<td>Import into CAD software</td>
<td>Software</td>
<td>0.000</td>
</tr>
<tr>
<td>Design in CAD software</td>
<td>Software setting</td>
<td>±0.001</td>
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<tr>
<td>Export of CAD data in STL file format</td>
<td>Software setting</td>
<td>±0.010</td>
</tr>
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<td>Physical manufacture using SLM</td>
<td>RP machine</td>
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<tr>
<td>Removal of RP pattern from machine, cleaning and support removal</td>
<td>Human/skill level</td>
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<tr>
<td>Surface preparation and polishing</td>
<td>Human/skill level</td>
<td>No value</td>
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<tr>
<td>Total</td>
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<td>±0.211</td>
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### References


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Rapid Prototyping Journal

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A Patient-Fitted Removable Partial Denture Framework Fabricated from a CAD/CAM-Produced Sacrificial Pattern

Robert J Williams, Richard Bibb, Dominic Eggbeer, Anne Woodward

Introduction

The difficulties of using Computer Aided Design (CAD)/Computer Aided Manufacture (CAM) milling technologies to fabricate removable partial denture (RPD) alloy frameworks have been discussed. RPD frameworks are extremely complex shapes and must be within small tolerances. To produce such shapes from a solid block is beyond current technology. A milling machine with many complicated axes would be necessary to thin-walled plates and bars. In addition, clamping the work piece to enable such milling to take place so that the framework would not flex under the pressure of the stone is also an obstacle. It is therefore not surprising that CAD/CAM technology has so far been applied to the production of the simpler shapes of crowns and bridges (fixed partial dentures (FPDs)).

However, the development of rapid prototyping (RP) machines has allowed the above difficulties to be circumvented. In broad outline, RP machines operate as follows. A computer uses RP software to take a three-dimensional model of an object, for example...
a model of an RPD framework, and then slice the model into a large number of very thin layers. These layers are then physically created under computer control by the RP machine. In the RP process used in this case, called stereolithography, the physical layers are formed by an ultra-violet laser beam that scans the layer onto the surface of a light-sensitive resin. The laser light polymerises the resin to form the solid layer. Once one layer is solidified, the system moves the layer downwards into the vat of resin by one layer thickness below the resin surface and the next layer is developed. The process is repeated until the complete physical object is built. Supporting structures need to be concurrently built for some shapes, but in principle, any shape can be produced.

The application of CAD/CAM/RP technologies to the fabrication of RPD frameworks has been discussed previously but so far there have been no reports in the dentistry literature of a framework so produced being fitted to a patient. This paper describes such a case.

**Materials and Methods**

The secondary cast of a patient requiring an RPD framework was three-dimensionally scanned using a structured white-light system that projected light onto the cast (Fig 1). A digital camera is also incorporated into the technology to capture approximately 140000 points in three dimensions on the surface of the object, termed a 'point cloud'. The particular scanner used was a structured white-light digitizer (Comet 250, Steinbichler Optotechnik GmbH, Am Bauhof 4, 83115 Neubeuern, Germany).

Multiple scans of objects, such as the one illustrated in Fig 1, are needed to overcome the difficulty of shadows. These are combined automatically using software (Polyworks, InnovMetric Software Inc., 2014 Jean-Talon Blvd. North, Suite 310, Sainte-Foy, Quebec, G1N 4N6, Canada).

The surface of the computer model created from the point cloud was produced using polygons in the form of a Standard Triangulation Language (STL) file, which is a suitable format for importing into the virtual sculpting environment, FreeForm. The FreeForm
FreeForm has a facility, termed the 'parting line' function, which identifies undercut areas from various angles. Fig 2 shows a virtual cast being analysed in the horizontal projection. Once a path of insertion has been selected, FreeForm's function 'extrude to plane' will eliminate undercut, as shown in Fig 3. Undercut depth can be measured by determining the distance between the extruded plane surface and the original model. Relief can also be added (Fig 4) and the whole virtually surveyed cast can then be saved as a 'buck' file in a manner that will prevent any inadvertent modifications occurring. Such a file is termed a 'buck' file. The 'buck' file format ensures that there can be no inadvertent or accidental modification of the file. The previously saved buck file is then re-imported and the RPD pattern is developed using various functions in FreeForm (Figs 5a and 5b).
Once the virtual pattern is complete, the RP stereolithography machine builds the physical pattern. The patterns are robust and allow some adjustment prior to casting (Fig 6). The pattern is sprued and cast without a duplicate refractory cast. The casting is finished and fitted to the master cast using conventional procedures. Fig 7 shows the casting fitted to the patient.

**Conclusion**

The techniques undertaken and described above outline a stage in the development of machine-produced RPD frameworks. Current advantages include the electronic surveying technique described above, which allows the almost instant identification of undercuts, survey lines and instant undercut elimination. Future developments may enable the computer to determine a suggested path of insertion automatically.

The research described here also points to many possible advances that can in principle be achieved. With software development, it would be possible to have an array of
ions of RPD components on screen that could be ‘dragged and dropped’ into position in the cast. Furthermore, scaling factors can be built into the production of the pattern and compensation for casting shrinkage may be improved. Finally, sacrificial pattern manufacture and casting may be eliminated altogether. RP machines which build directly in alloy are already available and the application of this technology will be explored in future studies.


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The computer-aided design and rapid prototyping fabrication of removable partial denture frameworks

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Abstract: This study explores the application of computer-aided design and manufacture (CAD/CAM) to the process of electronically surveying a scanned dental cast as a prior stage to producing a sacrificial pattern for a removable partial denture (RPD) metal alloy framework. These are designed to retain artificial replacement teeth in the oral cavity. A cast produced from an impression of a patient's mouth was digitally scanned and the data converted to a three-dimensional computer file that could be read by the computer-aided design (CAD) software. Analysis and preparation were carried out in the digital environment according to established dental principles. The CAD software was then used to design the framework and generate a standard triangulation language (STL) file in preparation for its manufacture using rapid prototyping (RP) methods. Several RP methods were subsequently used to produce sacrificial patterns, which were then cast in a chromium–cobalt alloy using conventional methods and assessed for accuracy of fit.

This work demonstrates that CAD/CAM techniques can be used for electronic dental cast analysis, preparation, and design of RPD frameworks. It also demonstrates that RP-produced patterns may be successfully cast using conventional methods and that the resulting frameworks can provide a satisfactory fit.

Keywords: computer-aided design, rapid prototyping, removable partial denture

1 INTRODUCTION

Computer-aided design and manufacture (CAD/CAM) and rapid prototyping (RP) techniques have been extensively employed in the product development sector for many years and have also been extensively used in maxillofacial technology and surgery [1–3]. In addition, CAD/CAM technologies have been introduced into dentistry, particularly for the manufacture of crowns and bridges [4–6], but there has been little research into the use of such methods in the field of removable partial denture (RPD) framework fabrication. This may in part be attributed to the lack of suitable dedicated software. Recent pilot studies have shown that computer-aided design (CAD) and RP methods of designing and producing a sacrificial pattern for the production of metal alloy components of RPD metal frameworks could have promising applications [7, 8]. These studies explored the application of computer-aided technologies to the surveying of digital casts and pattern design and the subsequent production of sacrificial patterns using RP technologies.

The potential advantages offered by the introduction of advanced CAD/CAM and RP into the field of RPD framework fabrication include automatic determination of a suggested path of insertion, the almost instant elimination of unwanted undercuts (re-entry points), and the equally rapid identification of useful undercuts. At another stage, components of an RPD could be stored in a library and ‘dragged and dropped’ in place on a scanned and digitally surveyed cast from icons appearing on screen, allowing virtual pattern making to be carried out in a much faster time than is achieved by current techniques. The quality assurance of component design can also be built into the software. Since RP machines build the object directly, scaling factors may also be precisely imposed in order to compensate for shrinkage.
casting. In addition to the potential time savings, the CAD/RP process also delivers inherent repeatability, which may help to eliminate operator variation and to improve quality control in the dental laboratory.

The current paper reports an investigation into the application of CAD and RP methods to achieve the advantages of surveying and design using an appropriate 3D software package. It also discusses the application of RP technologies to produce sacrificial patterns for casting the definitive chromium–cobalt framework component. The advantages, limitations, and future possibilities of these techniques are included.

MATERIALS AND METHODS

Three-dimensional scanning

A three-dimensional scan of a partially dentate patient's dental cast was obtained using a structured light digitizer (Comet 250, Steinbichler Optotechnik GmbH, Neubeuern, Germany). This particular type of scanner is used in high-precision engineering applications and has been used in the dental industry [9]. Multiple overlapping scans were used to collect point cloud data that was aligned using Polyworks software (InnovMetric Software Inc., Quebec, Canada). Spider software (Wavefront Inc., Toronto, Ontario, Canada) was used to produce a polygon-surface standard triangulation language (STL) (C. R. Manners, 1993, 'STL file format' available on request from 3D Systems Inc., Santa Clara, California, USA) model file that could be imported into any number of CAD software packages, including that used in this study.

CAD of the RPD framework

The CAD package used in this study was chosen because it is well adapted to the design of complex three-dimensional shapes that are required when designing dental appliances and devices that must fit human anatomy. The software has tools analogous to those used in physical sculpting and enables a manner of ‘buck’ setting pre-operative planning. The software utilizes a haptic interface (Phantom® Desktop haptic interface, SensAble Technologies, Inc., Woburn, Massachusetts). The software utilizes a haptic interface (Phantom® Desktop haptic interface, SensAble Technologies, Inc.) that incorporates positioning in six-dimensional space and allows rotational and translational movement in all axes, transferring hand movements to the virtual environment (Fig. 1). It also allows the operator to feel the object being worked on in the software. The combination of tools and force feedback sensations mimics working on a physical object and allows shapes to be designed and modified in an arbitrary manner.

Objects being designed or worked on are referred to as virtual ‘clay’, which can be rotated and viewed from any angle on the screen. A ‘buck’ setting prevents a model from being unintentionally modified but allows ‘clay’ to be added or copied.

2.3 Surveying

Surveying is undertaken in dental technology laboratories to identify useful dental features in order for the RPD design to be retained in the oral cavity effectively. Dental surveying identifies areas of undercut present on the patient's teeth and soft tissue. The effect is similar to analysing a product design to find the split line for a two-part mould.

Like many CAD packages, the CAD software used in this study has an automatic ‘parting line’ (also known as a ‘split line’) function, which was used to delineate up and down facing surfaces, thus identifying areas of undercut in a different colour from the ‘buck’ model. The effect is identical with the physical technique of using dental survey lines to identify and mark the most bulbous areas of teeth with a pencil line (highlighted in Fig. 2a). The undercuts were assessed in order to establish the best path...
CAD and rapid prototyping fabrication of removable partial denture frameworks

2.4 Removing unwanted undercuts

When creating an RPD most undercuts are removed so that the resulting framework can be inserted and removed in a comfortable manner. The STL file of the rotated cast was imported into FreeForm®, but this time using the ‘extrude to plane’ option. When the cast was viewed from above, this option took the maximum extents of the profile and extruded them down by a user-defined distance. This effectively removed undercuts and replaced them with vertical surfaces (Figs 3a and b).

2.5 Identifying useful undercuts

FreeForm’s ‘ruler’ tool was used to measure the distance between the original cast model and the version with undercuts removed. The useful undercuts were marked with a line for use in the design stages. RPDs provide firm location on the existing dentition by using flexible clasps. The clasp components of the RPD open on initial contact during insertion and removal and return to their original position within the undercut on final seating, thus providing secure retention.

2.6 Creation of relief

The areas without teeth require a spacer, known as relief to prevent the framework from resting on the surfaces of the soft tissues. Relief was created by selecting and copying an area from the cast with undercuts removed, and then pasting this as a new piece.
clay. This was then offset to the outside by 1 mm. The results of this process are highlighted in Fig. 4. The entire modified model was saved as an STL and then re-imported using the ‘buck’ setting to avoid unintentional modification during the next stages of RPD design.

**Framework design**

The RPD design employed in this study was based on recognized dental technology methods emphasizing simplicity, aesthetics, and patient comfort [10]. One of the key design features outlined in the design stages are labelled in Fig. 5.

The entire framework was designed on the relieved ‘buck’ cast with undercuts removed, with the exception of the clasp components. The clasp use the undercuts to function and were therefore designed on the original ‘buck’ cast. The following techniques were used in the framework design.

2.7.1 **Occlusal rests (a in Fig. 5)**

A combination of two-dimensional drawing and three-dimensional creation and manipulation tools was used to create pieces of clay that were copied and located where required on the teeth.

2.7.2 **Polymeric retention framework (b in Fig. 5), lingual bar (c in Fig. 5), acrylic line (d in Fig. 5), and non-active clasps (e in Fig. 5)**

The ‘draw’ tool was used to locate curves directly on to the cast surface. These formed the centre of the framework's profile (Fig. 6). The ‘groove’ tool was used to define and create the exact oval and square sectional dimensions as clay.

2.7.3 **Guide plates (f in Fig. 5)**

Guide plates were created using the same method as relief creation. The ‘attract’ and ‘smudge’ tools were also used to build up plate areas and to blend them onto the framework sections.

2.7.4 **Finishing**

‘Smooth’, ‘attract’ and ‘smudge’ tools were used to blend the components together. The ‘buck’ cast was removed, acting as a Boolean cutting tool to leave just the clay framework.
2.7.5 Active clasps

The clasps were designed in the same manner as the non-flexible parts of the framework, but using the 'buck' cast with undercuts. The construction lines were joined to the termination point previously marked in the undercut measurement stage. The 'buck' cast was removed leaving the clasps. These were joined to the main framework and blended in. Figure 7 shows the final virtual design. The entire framework was exported as an STL file.

2.8 Pattern manufacture

Four RP methods were compared: stereolithography (SL) (3D Systems Inc., Valencia, California, USA), ThermoJet® (3D Systems Inc.), Solidscape® T66 (Solidscape Inc., Merrimack, New Hampshire, USA), and Perfactory® (Envisiontec GmbH, Marl, Germany). Two SL resins were compared: DSM Somos® 10110 (Waterclear™, New Castle, Delaware, USA) and Accura™ Amethyst® (3D Systems Inc.). Both of the SL patterns were an epoxy-based polymer, the ThermoJet® was TJ88-grade wax polymer, the Solidscape® was a soft thermoplastic, and Perfactory® was an acrylate-based polymer. The Waterclear™ and ThermoJet® patterns were manufactured at The National Centre for Product Design and Development Research, Cardiff, and the others were prepared and built by external suppliers. The Amethyst, Solidscape®, and Perfactory® materials are used by the jewellery industry to produce sacrificial patterns.

2.8.1 SLA-250 in the Waterclear™ example

The STL framework design was prepared using Lightyear™ (3D Systems Inc.) with a 'fine point' support structure (Fig. 8). The framework was oriented with the fitting surfaces facing upwards to avoid the rough finish created by the support structures affecting fit.

Two build styles were compared: standard layers 0.1000 mm thick and high-resolution layers 0.0625 mm thick. Once completed, the patterns were carefully removed from the machine platform and cleaned in isopropanol. They were then post-cured in ultraviolet light to ensure full polymerization. The other patterns were produced according to the supplier specifications.

2.9 Pattern comparison

Of the four RP processes compared in this study, the SL processes provided the most suitable patterns. The SL patterns were accurate and robust and had an acceptable surface finish but did require relatively lengthy cleaning and finishing to remove support structures. The ThermoJet® build preparation was simpler and faster than SL and both the ThermoJet® and the Solidscape® processes produced accurate patterns with a good surface finish that required minimal finishing. These wax patterns were, however, extremely fragile and could not be cast. The Perfactory® produced pattern showed a very smooth surface finish but was also extremely flexible and was easily distorted when handled.

3 CASTING

The SL and Perfactory® patterns were cast in chromium–cobalt alloy without using a refractory cast. A slow mould heating cycle was used to avoid cracking. Figure 9 shows the unfinished cast from the SL Amethyst® pattern. This shows that air inclusions from the casting process did not adhere to the pattern surface.
Although casts were obtained from the SL and factory\textsuperscript{TM} patterns, it proved difficult to add sprues due to the thin framework sections. In order to prove casting, the design was thickened in eForm\textsuperscript{TM} and revised SL patterns were produced and cast. This improved the pattern's strength and casting reliability.

**Finishing**

The casts produced from the original thin Amethyst\textsuperscript{TM} and thicker Waterclear\textsuperscript{TM} patterns were polished and fitted to the original physical cast. These were visually assessed and judged to be satisfactory. Figure 10 shows the finished RPD framework that was cast from the high-resolution Waterclear\textsuperscript{TM} SLA-250 pattern.

## 4 RESULTS

### 4.1 Assessment of the RPD frameworks

Surprisingly few studies have discussed the accuracy of fit of RPD frameworks [11-13] and even fewer have attempted to quantify it. One study which did attempt to measure gaps between frameworks and tooth surfaces in crucial areas using feeler gauges found that, owing to the three-dimensional nature of the curved surfaces examined, the method may be flawed [13]. Thus researchers routinely rely on the same somewhat subjective assessments which practitioners use on fitting RPD frameworks to patients. For example, occlusal rests are pressurized to detect whether there is movement, the closeness of the adaptation of clasps to teeth is studied, and the alloy surface is checked for visible defects [14].

### 4.2 Sources of error

Error may be produced in all aspects of dental technology if the original impression of the patient's teeth and surrounding tissues is poorly taken or the cast produced from it badly made. Various studies have aimed to assess this error [12-14]. However, in the absence of an appropriate intra-oral scanning technology the application of CAD/CAM in dental technology depends on the dental model. Other than human error in the interpretation of the instructions of the dentist or in the design of the framework, the adoption of CAD/CAM and RP technologies may incur several processes that may contribute to error between the theoretical design and the final manufactured item. For the most part the effect of these processes will be an accumulation of tolerances at each technology stage. However, certain levels of care and skill may still affect the accuracy of these computer-controlled techniques.

The flow chart in Table 1 indicates the steps in the process investigated here and indicates nominal tolerances associated with the various technologies. The accumulation of the tolerances leads to the maximum error that could be expected to result from the technologies alone assuming no human error is encountered. As human skill level and error cannot be assigned a numerical value and may range from zero to complete failure, discussion of this is not included here. However, as this study aims to investigate the implications of adopting CAD/CAM and RP technologies, it is appropriate to attempt to illustrate...
their potential contribution to error in the final RPD. The tolerances used in this table indicate typical or nominal figures, which are quoted by manufacturers or set as parameters in software.

4.3 Error analysis

For this application, it is difficult to achieve an investigation that provides detailed quantitative analysis of error. The natures of the devices mean that they are complex in form and do not provide convenient datum or reference surfaces. In addition, the devices are by definition one-off custom-made appliances constructed to fit individual patients. Therefore, it is not practical to perform the type of repeated statistical analysis that would be commonly encountered in series production or mass manufacture. It is normal dental practice to assess the accuracy of an RPD by test fitting the device to the study model and subsequently to the patient. In this study the RPD frameworks created were deemed by a qualified and experienced dental technician to be a satisfactory fit and comparable with those produced by expert technicians.

The parameters set in software are often user selected, are usually set to extremely small fractions of a millimetre, and in all practical terms may be ignored. The significant errors are likely to be encountered at the optical scanning stage and the RP manufacturing stage. Through extensive experience over many years, these figures are frequently encountered in industrial applications of these technologies and as such may be considered typical. The cumulative effect of these tolerances remains submillimetre and as such is likely to be equivalent to or smaller than the typical human error encountered in the raditional dental technology laboratory. The remaining sources of error are encountered in traditional practice and the use of computer-aided technologies will not affect them greatly.

5 CONCLUSIONS

The design stages of this technique rely on having an accurate three-dimensional scan of a patient cast and an understanding of both RPD framework design and CAD techniques. This means that the time taken to produce castable patterns using the technology described is considerable but would be significantly reduced with familiarity and practice.

The most suitable choice of RP process was determined primarily by accuracy and part strength. The ThermoJet® and Solidscape® patterns, although accurate, were too fragile and were therefore not suitable for the tasks associated with spruing and casting. Although the Perfactory® pattern cast well, the accuracy was poor because of distortion inflicted on the flexible pattern during handling. The stiffer patterns produced by SL were easy to handle, were accurate, and produced satisfactory results. The layer effect exhibited by all RP processes was not evident after finishing and the difference between the high-resolution and standard SLA-250 patterns was negligible.

The techniques undertaken and described above outline a stage in the development of machine-produced RPD frameworks and point to many possible advances that can be achieved in the future. The application of CAD would allow access to new RP technologies that build parts directly in metal alloys, including chromium–cobalt and stainless steel. Sacrificial pattern manufacture and casting may be eliminated all together. This will be explored in future studies.
the introduction of digital design and RP production into current practices would present a significant change in the field of dentistry and is unlikely to happen quickly. Studies so far have shown how 3D and RP may be applied and some principles have been developed and established. Possible future benefits and the potential shortfalls have also been discussed.

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A Digital Method of Design and Manufacture of Sacrificial Patterns for Removable Partial Denture Frameworks

Dominic Eggbeer, R J Williams, Richard Bibb

Summary

Following two previous preliminary studies, a three-dimensionally scanned cast of a patient was electronically surveyed and a digital removable partial denture framework was designed using the software package FreeForm®. Sacrificial patterns were subsequently manufactured using four rapid prototyping methods. A comparison of these patterns was undertaken. They were then cast in a chromium cobalt alloy using traditional methods and visually assessed for accuracy. Although not specifically designed for this application, the tools available within the virtual sculpting environment FreeForm® were well adapted to the framework design and production. This study demonstrates that FreeForm® is a commercially available software package that may be used for the successful and accurate design of patterns that can be built by rapid prototype technologies and that these patterns are suitable for casting. Future benefits from using these methods include speed of pattern fabrication, high levels of accuracy, repeatability and rapid prototype-built alloy frameworks.

Key words

computer-aided design; rapid prototyping; removable partial denture framework

Introduction

Past studies have highlighted, computer-aided design/computer-aided manufacture (CAD/CAM) has been employed in the fabrication of fixed partial dentures. CAD/CAM and rapid prototyping (RP) have also been extensively employed in areas of maxillofacial technology. These techniques have recently been applied to the fabrication of components of removable partial denture (RPD) frameworks. Here, a pattern of several RPD components produced by RP methods was successfully cast. In a later study, the stages of electronically surveying and digitally identifying guide planes, producing survey lines, assuring undercuts, and creating relief and parallel surfaces were successfully undertaken on a three-dimensional scan of a cast using the software package FreeForm® (InsAble Technologies Inc, 15 Constitution Way, Woburn, MA 01801, USA) (Fig 1). However, to date these developments have not been applied to the design and fabrication of an entire RPD framework. Thus, the full potential of previous work has yet to be
realised. This study reports on the continued application of FreeForm® CAD and RP to survey, design and manufacture sacrificial patterns for an entire RPD framework. The RPD design used in this study was based on methods emphasising simplicity, aesthetics and patient comfort. The paper also compares the patterns and discusses their use in casting and fitting procedures.

Materials Four RP processes were used physically to manufacture five patterns of the same computer-modelled RPD framework in different materials. The first process used was stereolithography (SL) (3D Systems Inc, 26081 Avenue Hall, Valencia, CA 91355, USA), which produces parts in an epoxy-based polymer. Two resins were compared - DSM Somos® 10110 (2 Penn’s Way, Suite 401, New Castle, DE 19720, USA) for the SLA-250/40 and Accura® Amethyst™ (3D Systems Inc) for the SLA Viper. The Somos® 10110 material has been tested as a suitable burn-out material, and the Accura® Amethyst™ was designed specifically for jewellery casting. The second RP process used was ThermoJet® printing (3D Systems Inc), which builds wax parts that may be easily “burnt out”. The third process was Perfactory® (Envisiontec GmbH, Elbestrasse 10, 45768 Marl, Germany). This process produces parts in an acrylate-based resin and is also commonly used to produce casting patterns in the jewellery industry. The fourth RP machine used was a T66 from Solidscape® (Solidscape Inc, 316 Daniel Webster Highway, Merrimack, NH 03054-4115, USA). This process builds extremely finely detailed parts in a soft, thermoplastic material that is suitable for casting. It is also commonly used by the jewellery industry.

Although each of these RP processes use different materials and processing methods, they all build parts in a layer-by-layer fashion and are commercially available. The patterns were cast in a chromium cobalt alloy using conventional methods of spruing and casting. The resulting RPD frameworks were finished, fitted and visually assessed on the physical cast.
The technique relied on an accurate three-dimensional, digital model of the original patient cast. This was obtained using a structured white light digitizer (Comet 250; Bühler Optotechnik GmbH, Am Bauhof 4, 83115 Neubeuern, Germany). This scanner is accurate to within +/-0.06mm according to the manufacturer’s specification. The scan data was converted to a three-dimensional STereoLithography (STL) file (Manners, 1993, “STL File Format” available on request from 3D Systems Inc, Valencia, Ca, USA) using Spider software (Alias-Wavefront Inc, 210 King Street East, Toronto, Ontario, Canada, M5A 1J7). The STL file was suitable for importing into FreeForm\textsuperscript{®}.

The secondary cast of a patient was three-dimensionally scanned using the white light scanner cited above. The software package FreeForm\textsuperscript{®} was used electronically to analyse the digitised cast according to the principles outlined in a previous study and to determine the design. A horizontal cast position was chosen. Unwanted undercuts were eliminated using FreeForm\textsuperscript{®} “extrude-to-plane” function. Relief was added by selecting the required area, setting by 1mm as a new piece of clay, then joining this to the original cast. This digitally viewed cast was then exported as an STL file and then imported as a protected “buck” file, which avoided inadvertent modification during the following digital design stages.

The pattern was built on screen by first creating an occlusal rest using the FreeForm\textsuperscript{®} three-dimensional drawing tools to produce a semicircular section that was extruded to a three-dimensional solid piece and the “tug” modification tool (Fig 2) to create a depression. This was copied and positioned into occlusal rest seats on the cast according to the number of occlusal rests required. Fig 3 shows the piece, which can be copied and located over the prepared rest seat of the “buck” cast. The areas of the occlusal rest positioned “side” the cast are routinely deleted by the system later in the process when the “buck” is removed. Rests were then sculpted and refined further using the “attract” and “carve” tools. When these tools were employed, tactile feedback was provided by the Phantom\textsuperscript{®} haptic device (as shown in Fig 1).

Fig 2 The basic occlusal rest design.
Next, construction curves are positioned onto the “buck” cast that form the centre of the framework’s major and minor connectors (Fig 4). The “groove” tool can be used to define and create the exact oval sectional profile required for reciprocal clasps, polymeric retention framework and the lingual bar. This tool creates the framework as a modifiable “clay” structure joined to the protected “buck” cast. The dimensions of 1.5mm by 1mm were used for all clasps, prior to tapering the terminal ends with a sculpting tool. The retention for the polymeric sections of the RPD was then built using dimensions of 2.5mm by 1mm and the lingual bar using dimensions of 2mm by 4mm. These dimensions allowed for loss of material during finishing. Label a in Fig 5 shows the lingual bar and c shows the polymeric retention framework.

To create plate sections, the area of clay where plates are required was selected using the “paint on selection” tool. These areas were then copied on the selected areas and created as a new piece of “clay”. The new piece could be offset by the required thickness to form the plate sections (label b in Fig 5).

Fig 3 An occlusal rest located over a rest seat on the “buck” cast.

4 (left) A close-up view of construction lines on the left side.

5 (right) Labelled section of framework design.
These were blended to join the plate and framework sections together in a freehand manner using the FreeForm® sculpting, “smudge” and “smooth” tools and the Phantom® plus. Fig 5 shows a section of plate (b) blended into the polymeric retention framework and lingual bar (a).

The acrylic lines were created by drawing a construction line on the appropriate area of the lingual bar and using the “groove” tool to create a square cross sectional profile of 1mm by 1mm above the cast surface. These areas were then blended to the anterior sides of the lingual bar using the stylus, again in a freehand manner with the “attract clay”, “smudge” and “smooth” tools. Label d in Fig 5 shows the result.

At this stage, the buck model must be removed and the original model imported in order to expose the undercuts required to build active clasps. Once the buck model was removed, the framework could be viewed (Fig 6).
The active clasps were built on the original digital cast with undercuts that were imported into the sculpting environment as a “buck” file. The “parting line” function was switched on to make undercut areas (which are blue on the purple “buck” cast) visible and the centre line of the active claps drawn directly onto the cast using the “draw” tool. The stages of identifying clasp termination points have been discussed in a previous study.

Fig 7a and b shows the construction curves for the clasp on the mandibular left first premolar and the resulting clasp design when joined to the main framework. The active ends were tapered using the “smudge” tool and then combined with the previously created framework into the “buck” cast. The terminal ends maintained their position in the undercut areas and the new clasps were blended into the framework in a free-hand manner as described above.

To finalise the digital design the buck model was removed to leave only the framework visible. At this stage, the “smooth” setting within the clay coarseness option was used automatically to remove any unwanted jagged edges. The framework was then exported as an STL file. Fig 8 shows a rendered image of the complete, virtual design on the original digital cast.

**Stereolithography: SLA-250/40 in Somos 10110 resin**

The physical pattern of the design was prepared using Lightyear™ (3D Systems, 26081 Avenue Hall, Valencia, CA 91355, USA) to orientate the pattern with the fitting surfaces facing upwards. (This avoided the rough surfaces caused by the support structure affecting the fitting surfaces.) A “fine point” support structure was generated that attached the down-facing surfaces to the machine bed (Fig 9).

The prepared build files were transferred to the SLA-250 machine and the build process started.

On completion, the support structures were carefully removed with small wire cutters and a scalpel in order to avoid breaking the thin wall sections or distorting the overall shape of the RPD framework pattern. The pattern was then cleaned in isopropanol and
t-cured in ultraviolet light to ensure full polymerisation and dimensional stability.

The SLA-250 pattern was produced at PDR and the other patterns were prepared by the suppliers according to their standards using proprietary machine software. Four RP pattern types are shown in Fig 10.

All patterns were sprued and cast using standard direct casting techniques. A slow cooling cycle is essential for burning out or eliminating the plastic patterns, beginning at temperature of 150 degrees C for an hour and moving to casting temperature of 1050 degrees C over a period of three hours to avoid finning reported in a previous study. Fig 11 shows the cast of the SLA-Viper produced Amethyst pattern before finishing.

Though not designed specifically for this application, FreeForm® was found to be well suited to the design of RPD frameworks. The tools available and Phantom® stylus inter-made the build up of both plate and thin frame sections simple and accurate. Though the time taken to produce castable patterns using the technology described is considerable, it could be significantly reduced with familiarity and practice. Thus the techniques undertaken and described above outline a stage in the development of machine-castable RPD frameworks and point to many possible advances that can be achieved in the future. These include operators "dragging and dropping" RPD components onto a desktop computer, drag and drop system, from desktop icons. Once developed, this would allow fast "virtual pattern" building and the software that positions components will be able to ensure that the princi-

Discussion

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ples of component design are followed, thus providing inherent quality assurance. In addition, the authors are currently utilising RP machines that have been developed to build parts directly in metal alloys, including chromium cobalt and stainless steel, thus potentially eliminating sacrificial patterns and the casting processes.

Of the four RP processes compared in this study, the SL processes provided the most suitable patterns. The SLA patterns were accurate, robust and had an acceptable surface finish but did require lengthy cleaning and finishing to remove support structures. The Thermojet® build preparation was simpler and faster than SL, and both the Thermojet® and Solidscape® processes produced accurate patterns with a good surface finish that required minimal finishing. These wax patterns were, however, extremely fragile. The Perfactory® process produced a pattern comparable to the SLA, but with a smoother surface that required less finishing.

Although casting without a refractory cast is unusual for RPD patterns, the SLA and Perfactory® patterns were robust enough to withstand the stresses induced during spruing and investing and the definitive fit of the castings was judged to be satisfactory. Furthermore, air inclusions from the investment process did not adhere to the SLA patterns as much as to wax, which is evident in Fig 11 where the fitting surface of the plastic pattern is markedly smoother than the wax sprues. The appearance of fins was reported in an earlier study, but the heating cycle used in this study eliminated the problem.

Satisfactory casts were obtainable from both SLs and the Perfactory® patterns, but the Solidscape® pattern was too fragile to survive handling. The Thermojet® pattern was also extremely fragile, and only a partial cast was achieved, since the clasps were damaged.

The first three patterns were made slightly thinner than the final two. Although successful castings could be achieved with this design, some of the patterns showed a degree of distortion when test fitted to the cast. The design was altered using FreeForm® to thicken the framework sections to the dimensions outlined above. The modifications improved both the strength of the pattern and the fit. However, some slight distortion remained. Nevertheless, the active clasps remained in position, and minor bending of other areas of the framework after casting produced satisfactory results. The thicker sections also facilitated casting, and two frameworks were successfully cast, the last in the sequence.

Given the robust nature of the patterns and acceptable castings, the thicker, modified design was cast from the SLA-250 in Somos® 10110 resin. In order to evaluate the effect

Fig 11 The unfinished cast from the Amethyst™ pattern.
layering to the resultant casting, two build styles were used. The first was 0.1mm layer thickness and the second was 0.062mm layers and a “small spot” style. The “small spot”-produced pattern was slightly smoother in appearance and the stepping was less obvious. After standard casting and finishing procedures, there was no difference in the appearance and fit between the standard and “small spot” patterns. Fig 12 shows the final framework cast from the SLA-250 pattern, the definitive and best casting in the series.

Harnessing CAD as a tool for the design of RPD patterns will open up new possibilities for the manufacture of sacrificial patterns using RP technologies. These technologies are more versatile than machining from a solid block and can build extremely complex, thin shapes with high levels of accuracy. The inherent repeatability may also help to minimize operator variation and improve quality control in the dental laboratory.

The introduction of digital design and RP production into current practices would present a significant change in the field of dentistry and is unlikely to happen quickly. Studies have shown how CAD and RP may be applied, possible future benefits and the potential shortfalls. It may be considered that some of the shortfalls highlighted are due to the fact that FreeForm® is not specifically designed for this application and that with further software development more effective tools may become available.

The study showed that CAD/CAM and RP processes can be used in the manufacture of sacrificial patterns of whole RPD alloy frameworks. The software package, FreeForm®, could be used to undertake electronic surveying and the digital development of RPD framework patterns. The project studied a variety of RP materials and found that difficulties with burnout did not occur, provided a slow heating cycle was used. However, the materials for some RP materials were fragile and not well suited to the tasks associated with spruing and casting. The patterns were subject to distortion but the robust patterns produced by SL were easy to produce and patterns of the dimensions given produced satisfactory results.

**Conclusion**

The authors would like to thank Frank Cooper at the Jewellery Industry Innovation Centre in Birmingham, England, who kindly supplied the Perfactory® and Solidscape® RP systems, and Kevin Liles at 3D Systems Inc, who supplied the Amethyst™ RP pattern.
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CAD/CAM in the Fabrication of Removable Partial Denture Frameworks

Virtual Method of Surveying 3D Scanned Dental Casts

William J. Williams, Richard Bibb, and Dominic Eggbeer

Computer Aided Design and Manufacture (CAD/CAM) techniques have long been adopted a method of fabrication for fixed partial denture restorations and CAD/CAM and rapid prototyping have been extensively used in maxillofacial technology and surgery. However, there has been little research into the use of such methods in the field of removable partial denture (RPD) fabrication. A recent pilot study showed that rapid prototyping methods of producing a sacrificial pattern for the production of metal components of RPD metal frameworks could have promising applications and the advantages were discussed.

The use of a rapid prototyping-produced sacrificial pattern is the key to the introduction of CAD/CAM to RPD manufacture. Milling an RPD framework from a solid blank is possible with current technology. The difficulties of machining complex-shaped, thinned metal plates, bars or clasps include the problems of securing the work piece to the tool of the milling machine and deflection of the thin walled work piece under machining load. In the pilot study a virtual pattern was built on a 3-dimensional (3D) scan of a digital scanned dental cast as a prior stage to digitally producing a pattern for a removable partial denture framework. A partially dentate cast of a patient was digitally scanned and the data converted to a 3D computer file, read by the software package FreeForm®. This provided the basis for successful application of this software to the identification of survey lines, creation of parallel surfaces, measurement of undercut and creation of relief areas over residual ridges. Visual comparison of the results produced by conventional surveying and those achieved with FreeForm® software were encouraging.

In conclusion, the commercially available software package FreeForm® is ideal for electronic surveying.

Key words
AD/CAM; digital scanning; electronic surveying; FreeForm® software package; removable partial denture frameworks
Fig 1 A sacrificial plastic pattern produced by digital rapid prototype techniques and a casting of such a pattern.

Partial cast of a patient and displayed on screen, after which a plastic sacrificial pattern was constructed using rapid prototyping technology which copied the on-screen display, resulting in a successful cast (Figs 1 and 2). A careful study of Fig 2 shows that there appears to be a slight lack of fit. Although the initial stages of the process of electronic surveying were included in this study, the lack of a fully developed method of electronically surveying the cast prior to the digital build of a sacrificial pattern probably accounts for the deficit in fit.

The method for electronic surveying relied on the use of a software package, MATLAB® (The MathWorks Inc., 3 Apple Hill Drive, Natick, MA 01760-2098, USA). The surface of the scanned cast was defined using triangles and a program was devised to identify all downward facing triangles, which marked infrabulge and suprabulge areas.

Although digital methods are currently time consuming, the potential advantages in the future offered by the introduction of CAD/CAM into the field of RPD fabrication include automatic determination of a suggested path of insertion, almost instant elimination of unwanted undercuts and the equally rapid identification of useful undercuts. At another stage, components of a removable partial denture could be stored in a library and “dragged and dropped” in place on a scanned and digitally surveyed cast from icons appearing on screen, allowing virtual patterning to be carried out in a much faster time than is achieved by current techniques. The quality assurance of component design can also be built into the software. In addition, as rapid prototyping machines build the object directly, scaling factors may be precisely imposed that may compensate for shrinkage in casting. In addition to the potential time saved, the CAD/CAM process also delivers inherent reproducibility, which may help to eliminate operator variation and improve quality control in the dental laboratory.

Although the pilot study introducing the process represents an important first step, the principles of electronic surveying must be fully developed before the design and fabrication of patterns for metal RPDs using rapid prototyping can occur. Stages of cast analysis include the identification of survey lines and suitable guide planes, the selection of a suitable path of insertion and determination of appropriate undercut depths for direct retainers. Complete electronic cast analysis has not yet been achieved. The current
Article reports on the application of methods to achieve stages of surveying digitally, using a developed software package that provides a virtual sculpting environment: eForm® (SensAble Technologies Inc., 15 Constitution Way, Woburn, MA 01801, USA). Comparisons between the results of survey lines and undercut elimination produced by physical surveying and electronic surveying are also made.

A 3D scan of a partially dentate dental cast of a patient was obtained using a structured light digitizer (Comet 250®, Steinbichler Optotechnik GmbH, Am Bauhof 4, 83115 Luebeun, Germany). This particular type of scanner is accurate to within +/-0.06 mm according to the manufacturer’s specification, and is used in high-precision engineering applications and has been used in maxillofacial technology.\[^{15}\]

Typically, a scan from a static position captures a portion of the object’s surface that is in the device’s line of sight. Each scan captures the 3D location of approximately 1,000 points on the surface of the object. To capture the surface of the whole object, multiple overlapping scans are taken. This collection of data points is termed a “point cloud”.

The software Polyworks® (InnovMetric Software Inc., 2014 Jean-Talon Blvd. North, Sté 310, Sainte-Foy, Quebec, G1N 4N6, Canada) was used to combine automatically the multiple scans by aligning overlapping areas of scan data. The Spider® software package (Wavefront Inc., 210 King Street East, Toronto, Ontario, M5A 1J7, Canada) was used to produce a surface model from the point cloud. This was achieved by creating polygons that connect adjacent data points. The simplest form of polygon-surface is the triangularized surface model, which is commonly used in industry in the form of a stereolithography (STL) file (Manners CR, 1993, “STL File Format” available on request from 3Dems Inc., Valencia, California). The STL file format is frequently used to transfer objects between CAD applications and rapid prototyping technologies. The STL file is a suitable format for importing object data into FreeForm®.

Although the software does not rely as heavily on mathematically defined and connected geometry as engineering CAD, precision is built into the software and ensured accurately defined sculpting tools and precise measuring techniques. Shapes may also be designed and modified arbitrarily by the user in a manner analogous to handcrafting.
The computer model of the object being worked is referred to as virtual “clay”, which can be rotated and viewed from any angle on the screen. Clay shapes can be added to the model in precise ways and measurements in any direction can be established. The user interfaces with this software through a stylus (Phantom Desktop haptic interface, SensAble Technologies Inc.) (Fig 3) that incorporates positioning in 3D space and allows rotation and translation in all axes. In essence, the stylus acts as a 3D mouse and translates movement to the virtual sculpting environment. Force feedback sensations (e.g., when the virtual tool contacts the model) in relation to the tool position within the sculpting environment are fed through to the user with the result closely mimicking the sensation of a surveying tool contacting a cast during physical surveying.

The FreeForm® software was developed to work in conjunction with the phantom desktop stylus (Fig 3). They require a high-specification PC computer. The recommended computer specifications from SensAble Technologies are an Intel Pentium® Dual 1.7 GHz processor, 2 GB RAM, Windows 2000® (Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-6399, USA) SP3 operating system, An EPP or ECP compatible Parallel Port, NVIDIA Quadro4 900XGL graphics card. The system used met this specification.

An analysis was undertaken on the scanned cast using FreeForm®. The stages of electronic surveying performed are described in the following sections.
Stage 2 - Identification of Survey Lines

FreeForm® has an automatic method of displaying "parting lines". Parting lines (also known as "split lines") are primarily used in design engineering to identify where a component must split around a component for it to be ejected freely. The parting line identified by FreeForm® was used to delineate up and down facing surfaces. The effect is identical to the physical technique of using dental survey lines to identify infra and suprabulge areas. Once the parting line function was used in FreeForm®, all bulge areas of the cast were highlighted in a different colour to other areas of the cast. This tool was used on with the cast viewed from the vertical parting direction. This produced the survey lines as would be produced by a conventional surveyor with the cast in the horizontal position.

With the parting line function on, up facing, down facing and vertical surfaces were indicated by different colours on the virtual cast. Upward facing surfaces are displayed as purple (also the standard colour for a buck model), the vertical surfaces as red and downward facing as blue (Fig 5b-d). The survey line is located at the upper boundary of the surfaces around the teeth. Vertical surfaces, shown in red, facilitate the identification of guide planes when determining the path of insertion.

If an alternative parting direction is required, the cast must be rotated (e.g., given an anterior or posterior tilt) around the required pivot point first, then the parting tool turned on with the model viewed from the direction of placement. Again, the process of tilting the virtual cast in FreeForm® imitates tilting cast on a dental surveyor. A visual comparison (Fig 5a-d) was made between the physically surveyed cast and the virtual cast surveyed using the software. Positive 5° (degrees) posterior to positive 12° anterior tilt were also compared to test the accuracy of the results.

Stage 3 - Method of Removing Unwanted Undercuts

STL file of the original cast was imported into FreeForm®, but this time using the "rude to plane" option. When the model was viewed from above, this option took the maximum extents of the scanned cast profile and extruded them down by a user-defined distance. This effectively removed undercuts and replaced them with vertical surfaces. Key lines reappeared when the "extrude to plane" option was used because the vertical surfaces were a different colour from other surfaces, and, hence, the lines of maximum...
bulbosity were visible. Differences between the virtual casts before and after undercuts were removed (Fig 6a-b). Fig 6c-d shows a close-up of a molar with and without undercuts removed.

Stage 4 - Measurement of Undercut Depth

Undercut depth was measured by determining the distance between the vertical extrusions of the maximum extents of the cast and the scanned tooth surface. The software's ruler function gave a constant numerical and illustrative display of the distance between the vertical surface and the scanned tooth surfaces after the "extrude to plane tool" had been turned on. As the tool was moved over the surface of the model the distance between these surfaces was displayed. Fig 7a-b shows horizontal measurement and undercut depth of 0.25 mm in the buccal area of the mandibular left first premolar. The two spheres connected by a line are a visual illustration of the measurement.

Once the ideal position for clasp termination had been identified, a record of the position was copied on the cast.

Stage 5 - Method of Adapting a Relief Area in Edentulous Areas

The area to be relieved was selected from the scanned cast with undercut removed by drawing the perimeter of the area requiring relief using the Phantom stylus. Copying the selected area and offsetting it by 0.5 mm created a piece of clay that could be laid over the edentulous area requiring relief (Fig 8).
6a The blue areas represent undercuts.

6c The original molar.

6b The red areas represent vertical surfaces.

6d The same molar with undercuts removed by the "extrude to plane" option.

'a (above) The ruler tool measuring the distance between the extrude to plane and original casts. The red area lights the vertical surface of the cast with undercuts.

b (right) The outer ball touches the vertical undercut surface and the inner ball touches the undercut on original cast.
Once parallelism and relief areas were satisfactorily achieved, the entire modified model was saved as an STL file and then re-imported using the buck setting so that further unwanted modification would not occur at a later stage during the building of a virtual pattern.

**Designing a Virtual Pattern**

After the survey and design stages, a virtual pattern could be developed on screen. To regain desirable undercut areas, clasps could be digitally built on the original buck model. The buck model with undercuts removed can then be re-imported and the clasps can be joined to the remainder of the framework on this model. Such saving and importing is achieved in seconds.

**Results**

The work demonstrated that the tools provided with the virtual sculpting environment used in this study are well suited to accomplishing many of the requirements of dental surveying. The concepts associated with the relevant procedures of FreeForm® accord with those of physical cast analysis. The successful application of these concepts was verified by visual comparisons (Figs 3–4) between the results of physical surveying and electronic surveying of the same cast. The facility of importing an electronically surveyed scanned cast as a buck file ensures that when such a file is used at a later stage in building a virtual sacrificial pattern, the scanned cast of a patient will remain unaffected.

**Discussion**

Although the stages above are described linearly, it is possible to switch forward and backward between them as is usual during RPD design.

Disadvantages of electronic surveying in FreeForm® are that the operator must obtain skills in orienting the cast on screen using the stylus and the time taken to convert the scanned point cloud data into a solid model. However, both processes could improve in time with familiarization and software improvements.
In addition, the software was unable to produce a mark on the buck file to indicate the position of undercut depth in relation to clasp termination. The ruler is left in place on the model when the tool is removed from the model surface, but when another tool is selected the ruler disappears. The alternative practice described in Stage 4 of physically copying the position onto the model is not ideal. However, this shortcoming is being discussed with the software manufacturer.

Advantages include an automatic and instantaneous view of survey lines as the model tilted through varying degrees and planes on screen. Once a path of insertion has been chosen, the elimination of undercuts is also automatic and instant and is highlighted when the parting line function is employed. Another advantage may be that communication in relation to cast analysis between clinicians and laboratory technicians is facilitated through passing information electronically. Further, once a cast is scanned and saved, no damage can accrue.

Perhaps the greatest benefit offered by the development described, however, is as an early stage in the design and fabrication of sacrificial patterns for metal RPD frameworks through rapid prototyping processes.

eForm®, although not designed specifically for dental applications, has been shown to remarkably adaptable to the processes needed to complete electronic surveying. Many of the tools, which were provided for design engineering purposes, are ideally suited to a quick and accurate recording of survey lines, elimination of unwanted undercut and assessment of undercut. A sound basis for the development of RPD design and electronic modelling of a sacrificial pattern can be established with this software.

Conclusion

References

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A technique for fabricating patterns for removable partial denture frameworks using digitized casts and electronic surveying

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Although computer-aided design and manufacture techniques have shown some promising applications in the fabrication of crowns, inlays, and maxillofacial and oral surgery, the field of removable prosthetics has not embraced these technologies to the same extent. This article describes the development and investigation of computer-aided techniques that may eventually enable prosthodontic procedures such as surveying and the production of sacrificial patterns to be performed digitally. A 3-dimensional computer model of a conventional cast from a patient was obtained using an optical surface capture device (a scanner). The shape of a number of components of a removable partial denture framework was modeled on the 3-dimensional scan electronically, using computer-aided design software. A physical plastic shape of the components was produced using a Rapid Prototyping machine and used as a sacrificial pattern. Techniques to allow digital cast surveying before the production of sacrificial patterns were also developed. The results show that digital dental surveying and machine-produced sacrificial patterns can be accomplished. This article forms a basis for further developments leading to a fully integrated approach to the computer-aided design and fabrication of removable partial denture frameworks. (J Prosthet Dent 2004;91:85-8.)

Computer-aided design and manufacture (CAD/CAM) techniques have been successfully introduced in the field of fixed partial dentures and maxillofacial technology over a number of years. The development and evaluation of these advances continue. Advantages of such systems have been well documented and may well eventually become the "next generation" of methods of fabrication.

To date, however, CAD/CAM production of metal removable partial denture frameworks has remained only a theoretical possibility. Yet, the potential benefits possibly exceed those noted for the field of fixed partial dentures. For example, if electronic surveying programs can be developed, digitized surveying of a 3-dimensional (3-D) scanned dental cast may be almost instantaneous.

Various methods of scanning are used throughout dentistry, including laser and lined light. The scanner used in this article was an optical system that used projected light and digital camera technology to capture approximately 140,000 points in 3-D on the surface of the object, termed a "point cloud." The scanner can only collect data on surfaces within the line of sight. Areas on the surface that are obscured or at too great an angle to the line of sight will not appear in the scan data. Moving either the object or the scanner and repeating the process overcomes this problem. For a cast of a patient, several scans may be necessary.

Computer software was then used to create surfaces from these points. This method creates the surface of a 3-D object by approximating the point cloud with a series of connected triangular facets. These triangular faceted models, termed a stereolithography or STL file, are commonly used in transferring CAD models to rapid prototyping (RP) technologies (Manners, CR, "STL File Format" obtained on request from 3D Systems Inc, Valencia, Calif, 1993).

The quality of such a file is a function of how closely the triangular facets approximate the original surface. A large number of small facets provides a higher quality surface model but at the expense of increased file size. It is common to adjust the compromise between quality and file size to suit the given application. The triangle size for this article was comparatively large to minimize file size, thus enabling easy and rapid data manipulation during the research. Greater accuracy may be achieved with smaller triangles for a method that may be eventually used for patients.

It was necessary to develop an electronic method of surveying for this process. Electronic surveying of a scanned cast enables a pattern for a metal framework to be fabricated on the computer screen (Surface Studio; Alias-Wavefront, Toronto, Ontario, Canada) according to the principles of removable partial denture design. Programs were written for this technique using mathematic software (MatLab; The MathWorks, Inc, Natick, Mass) that reads the triangular faceted surface models (using the STL file format). Identification of
a survey line was achieved electronically by writing a
mathematic program that identified all downward facing
surface triangles on the computer scan described above.
In the interest of reducing memory requirements and
therefore increasing processing speed when creating
programs, the software was developed using a simple
cylinder shape. As work progressed, a "barrel" shape
(Fig. 1) was used for development. The program defined
the surface area of teeth apical to the survey line by
identifying the downward facing triangles. The upper
boundary of this area defined the survey line. As in phys-
ical dental cast surveying, the electronic survey line is
affected by the inclination of the cast. A series of rot-
tional transformations allowed survey lines at various
tilts of the cast to be identified. Figure 2 shows the barrel
with a tilt of 20 degrees. The effects when these pro-
grams are transferred to larger files of surface models of
a scanned tooth and a cast are shown in Figures 3 and 4.

Most of the current methods using CAD/CAM fab-
rication techniques in dentistry have concentrated on
milling from a solid block of material. However, ma-
chining complex-shaped, thin-walled metal plates, bars,
or clasps required for a removable partial denture is
difficult to achieve. The problems of securing the work-
piece to the bed of the milling machine and deflection of
the thin-walled workpiece under machining load are
well documented in the machining industry.

The authors developed and investigated digital tech-
niques that may eventually enable removable-prostho-
dontic procedures such as surveying and the produc-
tion of sacrificial patterns to be performed digitally using
CAD/CAM and RP techniques.

In this article, 2 simple clasps, guide planes, and a con-
ector were designed (Fig. 5 A) using CAD on the basis of
a scan of a cast of the posterior section of a patient’s man-
dibular left arch, with the first premolar and second molar
present and the second premolar and first molar absent.
Because of the experimental nature of the technique, oc-
cclusal rests were not added to simplify the casting.

TECHNIQUE

3-D surface capture
1. Obtain a 3-D computer model of a cast of a patient
using an optical surface capture device (Comet 250
scanner; Steinbichler Optotechnik GmbH, Neu-
beuren, Germany).
2. Align and combine the data points from each of these
scans using CAD software (Polyworks; InnovMetric
Software Inc, Sainte-Foy, Quebec, Canada) to pro-
vide a single coherent data set of the entire object.
Use the resultant data points (termed a "point
cloud") to create a 3-D surface model.
3. Produce a solid 3-D computer model on screen using
a triangular-faceted polygon mesh (EvalViewer;
Alias-Wavefront Inc, Toronto, Canada).

3-D computer-aided design
4. Electronically survey the scan using the MatLab soft-
ware package described previously. The depth of un-
dercut can be copied from the definitive cast to de-
terminate clasp termination.
Fig. 3. A, Program used to identify survey line on 3-D scan of model of large tooth—distobuccal view. File size: 517 KB. B, Lingual view of electronically surveyed tooth shown in A.

Fig. 4. Undercuts electronically identified on surveyed cast. File size: 2764 KB.

5. Model the shape of the components of a removable partial denture framework on the scanned surface model using 3-dimensional CAD software (Surface Studio; Alias-Wavefront, Inc).

6. Use an RP (stereolithography) machine (SLA 250/40; 3D Systems Inc, Valencia, Calif) to produce a plastic (WaterClear 10110 Epoxy Resin for Stereolithography; DSM Somos, New Castle, Del) physical model of the components described above. Use RP processes to create a sacrificial pattern of a removable partial denture framework, to be incorporated directly into existing casting procedures found in the typical dental laboratory.

Fabrication
7. Use the sacrificial pattern to invest, cast, and finish (Fig. 5).

DISCUSSION
This method of production was established as sound by visual inspection, as is the case with most removable partial denture frameworks used for patients. Much work must be achieved before the above methods can be fully applied to the fabrication of metal removable partial denture frameworks. The disadvantages of the methods at this time include the cost of the scanning equipment, CAD software, and RP techniques. Furthermore, a degree of time and experience is needed to create a valid surface from scanned “point cloud” data. However, as familiarity with this technology increases and more sophisticated software becomes available, these issues may be addressed so that the anticipated time to create a solid computer model from the scanned data may take a matter of minutes. The time required for the computer to calculate the survey line may similarly be achieved in a matter of minutes when software is developed using a more sophisticated programming environment. This may then compare favorably with the considerable amount of time required to manually survey a cast.

Another possible difficulty arising during this project was that some mold cracking appeared to develop at the investing stage, resulting in small fins appearing on the divested casting. This may be due to expansion of the plastic pattern resulting from exothermic heat of the investment material during setting. However, using
other RP technologies to allow a plastic pattern to be replaced by a wax pattern may overcome this problem. The authors are investigating these matters.

The adoption of CAD/CAM techniques may be highly advantageous in the field of removable partial dentures. The electronic surveying technique described previously allows the almost instant identification of survey lines but is only the first step in the development of dedicated dental design software. Future developments may enable the computer to automatically determine a suggested path of insertion and, with further research, unwanted undercuts could be eliminated and useful undercuts identified. At another stage, components of a removable partial denture could be stored in a library and “dragged and dropped” in place on a scanned and surveyed cast from icons appearing on the screen. This would allow virtual patterning to be carried out in a much faster time than is achieved by current techniques. In addition, as RP machines build the object directly, scaling factors may be precisely imposed that may compensate for shrinkage in casting. In addition to the potential time saving, the CAD/CAM process also delivers inherent repeatability, which may help to eliminate operator variation and improve quality control in the dental laboratory.

SUMMARY

This article shows that rapid prototyping (RP) processes may be a more appropriate CAD/CAM fabrication method than milling for the thin-walled, complex shapes typical of removable partial denture frameworks. The technique demonstrated that automation of the surveying process is possible.

The authors thank Mr Mohammad Ibn Mgren for his help in developing a routine central to this article.

REFERENCES

Recent use of video conferencing
VIDEO conferencing is the facility of being able to see and talk to an individual or a group at a distance by use of telephone lines or, more recently, by using the web.

At each location there are TV monitors and cameras to allow pictures of the participants in the conference to be sent. Sometimes there are specialised cameras that enable detailed close-up shots of items or text.

As respondents at one end speak, gesture or refer to text or items, they can be seen and heard at the other end, and vice versa. Of course, there is usually a short delay between responses, so it is not quite like having all participants in the same place, but it is very close to it. Additionally, there can be more than two sites involved in a conference.

For a week in February 2002, this facility was used by an Ivoclar Vivadent expert, Marc Northover, based in Leicester, and tutors and a small group of final-year degree students at UWIC to deliver parts of the Ivoclar Vivadent "Brand Prosthetics" course.

This short course lasted a week. The students and tutors at Cardiff had little or no prior knowledge of the BPS system, although the tutors were experienced in general complete denture construction.

Marc Northover made two day-trips to Cardiff: first, he spent a Monday morning explaining and demonstrating the techniques; the second visit was made at the end of the course to draw the programme together and provide final feedback and a final demonstration.

Two-hour-long video conferences were held on the Tuesday at 9.30 and 12:00, and another conference was held on the Wednesday at 9:00. During these times, students brought their exercises in progress to show Mr Northover, who was stationed in Leicester for the conferences, and receive feedback on their work before proceeding to the next stages.

Reasons

The reasons for delivering in this manner are as follows:

- **Convenience** – Marc made two day-trips to Cardiff, rather than spending a whole week, thus saving on time and reducing costs.
- **The method of delivery was experimental** – the need to develop and progress in dental technology education is, of course, of great importance.
- **There may be possibilities for tutors at UWIC to use such methods to deliver some courses to students or others at a distance** – before doing so, it was of great benefit to receiving a training simulating experience themselves through such technology.

### Evaluation

A summary of students' assessments of the use of video conferencing to introduce the topic of BPS Brand Prosthetic systems follows. This was carried out by an expert within UWIC who had no connection with the learning and teaching exercise.

Students were asked to rate video conferencing as a learning and teaching medium in terms of its effectiveness to:

1. **Convey a discussion on a practical demonstration**
2. **Deal with queries at a distance**

All students felt that video conferencing was effective for conveying this level of discussion arising from the demonstration: 67% of students felt that this was an extremely effective medium and 33% of students felt that this was an adequate medium for conveying discussion.

### R. J. WILLIAMS, MICHAEL LIGHTOWLERS, MARC NORTHOVER and IAN KERTON

**Report on the Technology used to Deliver Parts of Ivoclar Vivadent's 'Brand Prosthetics' Course at the University of Wales Institute, Cardiff**

Respondents listed the following topics:

- clear understanding given by an expert (statistics) would suit this format
- access to expertise
- to use resources at times
- web conferencing would allow for practical demonstrations of staining techniques

Students cited the following ways that this session had enhanced their learning:

- good for practical sessions
- use of examples for extended discussion
- liked the experience of this new technology for itself
- the room
- opportunity to converse with an expert
- quality of the video

Students cited the following aspects which had detracted from their learning:

- lack of time
- lack of handouts
- use of new terminology
- poor use of camera action may be misleading in practical demonstrations
- sound delay
- limited help from teacher

**Survey**

The survey asked students to comment upon:

1. **How comfortable did students feel with this new learning environment?**

All students were comfortable with this learning environment with a third of students rating comfort levels in each of the categories "just about comfortable", "quite comfortable" and "very comfortable" respectively.

Students qualified their ratings of comfort in the following ways:

- a nerve-wracking experience talking to potentially "unknown" people through this medium
- difficulty for some students to participate effectively
- it was fun and interesting and different
The BPS expert in Leicester receiving pictures from UWIC, Cardiff, prior to giving feedback.

2. The balance of live lectures with the expert and video conferencing
Sixty-seven per cent of respondents were happy with the balance of sessions whilst 33% would have preferred extra live sessions to cope with the demands of this new topic.

3. How the week should be structured
- video conferencing to be at the beginning of the week with the rest of the week being live;
- Monday, Wednesday and Thursday with the expert live, and the other days using video conferencing.

4. Preference for on-site (non-resource of this session)
All respondents were in agreement as to the usefulness of these stored resources with 37% agreeing strongly and 63% expressing agreement.

Conclusion
Some of the difficulties students cited could be improved with the benefit of experience. For instance, there could be greater familiarisation of the system prior to actual use, to include more time on developing manipulation of close-up cameras.

Video conferencing facilities within the familiar dental laboratory, at the point of learning, would also allay some of the fears expressed above. Such facilities could be practical with the introduction of web-based conferencing.

This may also offer the possibility of a “drop-in” contact with the expert without the prior need to book.

The potential advantages of using video conferencing to improve dental technology teaching and learning are clear. Expertise can be incorporated into programmes from a wide variety of sources otherwise unavailable. This can include various locations of the globe as well as the UK.

It was felt by all concerned that further use of this medium should continue to be explored.
Implications of a recent pilot study
Removable partial denture design
Introduction

Most clinicians and technologists are aware that on occasions appliances and restorations are not manufactured exactly as textbooks prescribe. No doubt there are reasons for some deviations, the most common of which is probably a desire to reduce time. However, there are some practices, particularly some aspects relating to the design of partial restorations, which are less easily explained.

This paper reports on a pilot study whereby two aspects of the design of removable partial dentures, which seem largely ignored, were studied.

Firstly, the concept associated with the reciprocation of the action of active clasps will be explained and then the design practices of 55 cases studied will be discussed.

Secondly, the necessity of positioning acrylic lines on gingivally approaching clasps where the flexible portions of clasps emerge from the acrylic will be outlined.

Finally, the results of a pilot survey of 55 cases will be given.

Reciprocation of clasps

The necessity to adequately counter the action of an active clasp arm on a tooth has been well documented. Basically, the textbooks argue that if a clasp arm is used, its terminal depth must almost exactly match that of the clasp arm. If this does not occur, the unwanted effect is acquired (see Figure 1).

If the reciprocal arm does not have a depth corresponding to the terminus of the retentive arm, the action of the clasp is not reciprocated. The reciprocal arm can be seen to be out of contact with the tooth as the denture is inserted. The active clasp arm exerts a pressure on the tooth, producing a very undesirable effect.

The same occurs when the denture is moved out of the in situ position. The natural tooth is pressurised and this occurs whenever there is any vertical displacing force exerted on the restoration.

Of course, tooth surfaces do not often allow the desirable positioning of reciprocal arms. In such a case, there are two courses of action:

1. to modify the enamel surface of a tooth so as to make it parallel with the path of insertion — this will ensure that the reciprocal arm is always in contact with the tooth as unseating pressures are brought to bear on the denture;
2. to incorporate a collet in the design to reciprocate the clasp’s action — a collet will always be in contact with the tooth at the point of greatest bulboosity, either as the denture experiences displacing forces or as it is inserted.

Survey of the design of 55 cases

A random survey of 55 removable partial dentures was conducted at two university dental schools over a period of three months. Fifty-nine clasps were studied. Fifty-three were designed with reciprocal arms and six were reciprocated by collets. Whether or not active clasp arms and reciprocal arms were in contact with teeth was inspected visually with the denture in a static in situ position as well as during displacing movement.

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It was found that all reciprocal arms in this sample were dysfunctional almost as soon as the denture was lifted out of its in situ position. The active clasp arms contacted teeth, thereby exerting a pressure, and possibly inducing movement. Collets, on the other hand, as expected, were functional in this respect.

The Incorporation of acrylic gutters on gingivally approaching clasps

The necessity of guttering is equally as well documented as the subject just discussed. A gutter is shown in such a case in Figure 2. The argument is that if acrylic is not correctly merged with gingivally approaching clasps, when they are activated over time, cracking of the acrylic around the junction will occur. Furthermore, a gutter will allow a smoother, more acceptable junction without excessive thinning of the acrylic.

In the same sample discussed above, there were 79 gingivally approaching clasps. None incorporated acrylic guttering.
Conclusion

The findings are presented as no more than a pilot study, with a fairly small number of actual partial dentures observed and only two institutions visited. Nevertheless, the findings are very suggestive and confirm long-standing informal beliefs held by many colleagues in dentistry.

In the case of reciprocal arms, a larger study, if it confirmed the above, could determine either that reciprocation is unnecessary (the effects on patients and restorations having been observed) or that greater care needs to be undertaken at the design and planning stages of partial denture construction.

In the case of acrylic guttering, it could be established what percentage of partial dentures over a certain period of wear display cracking and again, whether or not the textbooks are justified in their assertions.

In the final analysis, if it could be shown that textbook requirements are unnecessary for the majority of patients, it is still prudent to err on the side of caution. It may be only with hindsight that one would know with any particular case that the above-mentioned measures were really necessary. However, once tooth movement or cracking has occurred, it will, of course, be too late to take the measures advocated in the texts.

Further studies will be helpful in determining these issues and also how safe the prevailing current design and construction practices are.

References

Use of a cast flexible plate as a hinge substitute in a hinge-lock design removable partial denture framework

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Purpose. The use of a hinge for a removable partial denture with an opening labial bow was replaced by the design and construction of a flexible plate incorporated as part of a cobalt-chromium casting.

Methods. Three similar prostheses were constructed and tested in vitro on an endurance test machine. Each test piece completed 12,000 opening and closing operations without fracture, which a previous study showed is a probable life cycle of a typical removable partial denture with a hinged section.

Results. This plate provided sufficient flexibility to allow functional operation of the removable partial denture by a patient. (J Prosthet Dent 1998;80:220-3.)

The Swinglock removable partial denture (RPD) is a design that has been verified by several studies to offer clinically beneficial results. However, difficulties with the constructional technique have in part led to the fact that the design is not taught even on a theoretical basis by 44% of American dental schools. Other methods of constructing hinges have been developed, but they have also failed to gain wide acceptance. No method of replacing a hinge by a single cast component has yet been devised.

The purpose of this article is to describe the design and fabrication of a component cast in chromium-cobalt (Virocast, Bego, Bremen, Germany) to replace a hinge with a single stage casting technique. This component provides sufficient flexibility to allow other sections of a RPD, such as a labial bow, to open sufficiently. It also allows insertion of the denture and closure of the latch mechanism. This article also presents the findings of three in vitro tests that used an endurance test machine developed by Williams et al.

METHODS

Figure 1 illustrates a suitably designed flexible plate that could ultimately replace a hinge. The plate is part of the labial bow and is positioned outside and anterior to the denture base. Figure 2 illustrates the location of the plate and acrylic resin finishing line.

The design of the movable labial bar must be such as to allow operation by a patient to be effected with moderate and acceptable force. Achievement of this depends not only on how elastic the material is, its modulus of elasticity, but also on the cross-sectional shape of the flexible plate. The flexible plate should be quite thin, as explained theoretically in the following text. Nevertheless, this is a theoretical starting point and the demands of patient handling must also be considered. If a flexible plate is frail, it may produce desired flexibility under controlled in vitro conditions. However, such a structure would allow a patient to move the section into positions that produce large deflections and pure theory must be tempered by maintaining a clinical focus.

Figure 3 depicts a cross-sectional diagram of a plate being flexed. In the center of the plate, molecular forces of the upper surface are in tension, while those of the lower surface are in compression. Thus, there must be a point where forces are neutral as the change from tension to compression occurs. These points form a line along

Fig. 1. Labial view of flexible plate.

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the cross-section, which is defined as the neutral axis. The closer the surfaces of a structure are to this line, the greater will be the deflection for a given force. Hence, theoretically, a thin plate will provide the greatest flexibility. However, the proviso noted regarding patient handling must be kept in mind. The flexible plate must be approximated to a cantilever, so that stress is distributed along the plate section (Fig. 4), and so that maximum stress occurs close to the acrylic resin finishing line.

To examine the stress imposed on a variety of possible flexible plates, finite element analysis was conducted (IDEAS Master Series, Structural Dynamics Research Co-operation, Milford, Ohio). A simple computer model represents a movable labial bow (Fig. 5). This shape is the end result of the optimization process available through stress analysis. The structure could barely be termed a plate, but the exercise provides helpful dimensions before the design and production of test pieces that were operated in the endurance test machine.

Even with the finite element analysis, a considerable number of sizes and shapes of plates needed to be tested in the endurance test machine. To facilitate this, a fast and simple method of producing test pieces was devised. Contrary to the construction of hinged sections, one-piece castings with flexible plates and test standard latches were constructed comparatively quickly, having been quite easily cast in the open position. (This technique is not recommended at this stage for a prosthesis to be fitted in vivo because of a slight lack of fit of the extending fingers after casting. However, because the objective here is to flex the plate and determine its endurance, perfectly suitable test pieces were obtained with the method previously mentioned.)

To maximize the life of flexible plates, stress raisers were kept to a minimum by reducing the effect of surface scratches, and a highly polished surface on both sides of the flexible plate was developed. Sharp corners must be avoided, particularly in the flexing area. Flaws in the flexible plate caused by casting faults also must be kept to a minimum by sprueing to a thick area, close to the flexible member.

The fatigue endurance limit was best arrived at by testing the flexible plate under controlled conditions as near as possible to those encountered during operational use. An endurance test machine, described by Williams et al.,8 was used to open and close the labial bar to determine its fatigue endurance to a suitable limit.

RESULTS

Three identical prostheses were manufactured and tested in a locking endurance test machine. Each performed 12,000 opening and closing operations without showing any sign of fracture. A previous study showed that this is a typical expected endurance for a Swinglock RPD.8 The flexible plates at this stage exhibited no visible sign of fatigue and continued to function. Figure 6 illustrates one such casting duly tested.

DISCUSSION

There are advantages to a hinge replaced by a flexible plate and incorporated as part of a casting. A precast component for the hinge is not needed, technique sensitivities are reduced, and the method of construction is much quicker and offers economy of production generally.
DENTAL TECHNOLOGY EDUCATION: CURRENT INFLUENCES AND TRENDS

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ABSTRACT

In the November issue of THE DENTAL TECHNICIAN I tried to discuss the impetus for some of the changes in dental technology education and training. Unfortunately, due to an error at the printers, the article was inadvertently omitted. What follows, then, is a repeat of that article, with one or two additional points.

INTRODUCTION

Firstly I wish to consider the differences between training undertaken in current BTEC National at Diploma scheme. It is important to emphasise that I am referring to subjects such as City & Guilds system as it was then, and not as it is now, since it has undergone considerable changes in current educational thinking. To avoid confusion, I shall refer to it as an "Examination System".

I would also like to emphasise that it is not my intention to express a personal opinion here but to simply describe some of the developments that have taken place in dental technology education but the whole spectrum.

THE EXAMINATION SYSTEM

I see a need for a certain knowledge of this system since, I suppose, as the generation and before experienced "big" examinations. Our training and education were in some respects geared towards them. The system may have certain advantages but this type of educational format has been criticised. The subject produces certain competences which have been characterised as DEFICIENT (1). Skills and the knowledge of the highest order may not have been included in this system but are based around certain EXTERNAL factors. For instance, some of the examination papers are given information about a certain situation and its solutions to common place problems. Thus a student's capacity is dependent on how well he knows of other people's knowledge and other people's problems. Knowledge and skills are received from and tested by others.

Likewise the curriculum is received from outside without any assessment of external failure or quality (some educationalists would call it "labels") which are given externally. Priorities tend to be decided by others so the student has little experience of making judgements.

As far as dental technology is concerned, the Examination System did have the advantage of engendering within students an understanding of the importance of meeting standards and preparing for some of the laboratory procedures which tend to be routine nature.

THE BTEC SYSTEM

Assessment

It is widely known that a BTEC course is divided into small packages of work lasting typically for about 60-90 hours and that these are called UNITS. Each such unit may be either a Pass (20%), Merit (65%) or Distinction (85%). There is no equal of course examination. What is less widely known is that the grade for each unit may be determined by a variety of means. For example, a student may have undertaken practical, written tests, project work or written assignments and may have to do either of the latter within the context of a -team project or "collaborative learning" enterprise. Sometimes the item submitted for assessment may also have formed part, or even all of the learning process - a radical break with the Examination System. Furthermore, the tests or projects, or whatever in being assessed, only form an INDICATION to an Assessment Panel of the student's ability. The majority of the Panel will know students personally, so as opposed to an examination where only contact with the student may have been through a written test. Additionally, there should be no, as it were,archical testing up. Take the following instance. What overall grade for the unit would you give a student who had been given the following grades for six components of a complete unit?

(Answer to Assessment is overleaf)

COMMON SKILLS

As well as the main technical subjects such as Anatomy and Physiology, Dental Materials, Conservation, and so on, certain COMMON SKILLS should be developed within the student as well as the topics just mentioned. BTEC have defined for this academic year 18 Common Skills.

The main headings of groups of skills will give the reader an idea of the sort of thing covered:
Managing and Developing Self,
Working and Related to Others,
Communicating,
Managing Tasks and Solving Problems,
Applying Technology, and
Applying Design and Creativity.
A programme must be developed to teach such skills across the whole National and Higher National curriculums. Where it is felt that dental technology units alone are inadequate for developing specific skills, there are 2 units entitled COMMON SKILLS A & COMMON SKILLS B which must be used to develop the outstanding skills. Teaching Common Skills is at a very interesting point, I feel, a flexible work force able to adapt to new situations, to new tools, even different disciplines. The BTEC, for instance, can vary the person's aspirations and needs are different. (2) . We must remember that the students themselves might be younger, more flexible and responsible than the student of twenty years ago. We have to introduce the concept of action plans for all individuals aged 14 and up as the basis for achieving agreed objectives. BTEC have produced a "action plan", "individual" and "grouped objectives".

CONCLUSION

It might be well to discover that the BTEC system is unlikely to conform to the traditional teaching and learning passive forms of education. Students, they say, need to be involved in planning and negotiation, agreement, assessment and responsibility. Similarly, the Department of Employment in a recent paper (3) argues that the workplace of the future will need managers who are resourceful and flexible and who can adapt quickly to changes in the nature of their skills and knowledge. (4) Hence the need to be able to innovate, recognise and create opportunities, work in a team, take risks and respond to challenges, communicate effectively and be computer literate.

Finally, the RSA in November 1988, launched a Higher Education for Capability project which seeks to promote shared experiences of educationalists who seek to move towards learner accountability and responsibility.

The light of such policies, dental technology is a small fish in a big sea. Such tidal changes might be hard to swim against, even if one wanted to, so like it or not, dental education is developing in line with the current requirements of government, colleges of technology, the dental profession etc. How this fits in with the requirements of dental technology is not a question too be asked very loudly or very often.

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Sectional dentures: the manufacture of bolt and bolt-hole

R J Williams BA (hons). Ph D, LISIT, School of Dental Technology, Cardiff Institute of Higher Education, Western Avenue, Llandaff, CARDIFF CF5 2YB.

The Pullen-Warner sectional denture designs have much to commend them: aesthetically pleasing interstitial areas, positive retention, and, usually, little natural tooth preparation. It is sometimes argued that the number of suitable cases are few but it could be countered that it is perhaps more often the case that there is a lack of both clinical and technical experience. In fact War and MacGregor (1) state: (Sectional) dentures can be used in many different situations in the mouth because many different kinds of design can be employed.

Thomas (2) also argues for the wider use of sectional dentures in certain cases as an alternative to adhesives which are currently so often utilised.

Why, then, the reticence to adopt these designs "widely?" The concepts associated with the sectional denture are certainly difficult to grasp initially but even after the initial over, problems are often seen as the manufacture of the bolt and the formation of the mesh. Meanwhile, within the literature dealing with these topics there are several ideas which overcome the problems. It is well worth putting these ideas in the light of day because there is a potential market for any laboratory willing to offer the service of sectional denture construction and to persuade clients of their worth.

In particular, the retailed sectional denture is potentially a regular answer to many design problems. It is often under used, particularly in cases where an anterior post is employed. The use of a bolt in these cases would avoid employing a split post, thereby forming a more pleasing and natural impression and insertion and make a more positive method of denture union.

Bolt construction

Method 1

The original method of bolt manufacture by Pullen-Warner (3). It involves bonding the facial retainer at a right angle to the bolt of the shaft. The (bolt) is effectuated by inserting the bolt in a tube in order to achieve a sharp angle between the bolt and the tube facet. The groove is cut out along the tube, is a depth of about 0.3mm (into which is later slotted a transverse piece of wire which projects through the tube.) The bolt is locked by cutting another groove at right angles to the first one.

A tube of the same internal diameter as the bolt is cut to allow the transverse wire to pass through the tube, but run along the grooves in the bolt itself. The components are united by adopting a piece of stainless steel tape around the wire and after the soldering process. This means that the handle can be bent after bolt assembly. The two pieces of tube are held together in a further piece of tube cut longitudinally and spot welded to the other two pieces of smaller tubing.

This is an excellent idea but disadvantages with this method include: the fact that the result is a fairly thick bolt, which may be problematic to use on occasion, and the angle of the handle may not be as sharp as if it was bent within a tube, as recommended by Pullen-Warner (the process of the tube used to aid in forming the bend is worked but, of course, a couple of men may easily cut off the tube). Furthermore, the materials used by Craig & Anderson are stainless steel and silver solder (gold solder does not have a wide use of silver/alloy stainless steel). The solder may suffer tarnish and corrosion in the mouth. This is a most point because the bolt is contained in the mesh. However, only fluids will be attracted along the tube and the process of corrosion will ensue. Hence a further method has been developed:

Method 2

Williams & Sones (5) outline the above potential problem with the materials and suggest using "Wip-ten" wire for the bolt and locking pin in which case they can be soldered to the mesh. They also describe yet another method of bolt manufacture which has the advantages of greater simplicity over the two previously described methods and avoids some of the pitfalls. It is simpler and not over predicted the importance of corrosion.

3. The wire (which will form the locking pin) is soldered to the bolt about 4-5mm from the end. The locking pin is cut to a length of about 1mm. (Do not over predicted the importance of corrosion.)

A quicker is set in the bolt tube where the locking pin can

5. The bolt and tube are trimmed to the required length. This task is greatly simplified since the bolt can be withdrawn from the mesh and the external surface of the tube may be shaped to increase its retention on the acrylic. This is achieved by incorporating the components into the acrylic of the second part. Wax is to be built along the joint in the tube with the position. The wax must be of a sufficient height as how the locking pin is moved through it after processing a small amount of colour acrylic around the bolt and locking pin. The wax prevents the pin becoming entrapped by the autoclayning acrylic. Care must be exercised here so that sufficient wax is built along the tube preventing the acrylic from finding the movement of the pin. (If self cure acrylic is to be used for processing, the bolt can be incorporated into position without initially surrounding it with cold cure) Some technologies would be prepared to leave bolt construction of wax: there is no plate which the patient would not exert very pressure at this point in the procedure and then would probably be little wear of the retainer. The clinician can only, if the technician may like to incorporate a step before processing the putty and waxing around the mesh. This is accomplished by cutting a piece tubing in half longitudinally and then force fitting it to a right angle to the bolt of the tube and end to act as a handle. After processing, the internal opening of the bolt is stiff since the locking pin must be forced through the wax within the acrylic. However, after -5 excursions of the bolt, the wax is surprisingly quickly dislodged and normal friction is achieved. Alternatively, the locking pin can be placed in very hot water for a few seconds to dislodge the dislodged.

The final product is a bolt with a very pleasing action, opening easily and locking positively, avoiding the pitfalls ensuing from cutting grooves in the bolt.

Bolt-hole alignment

The original method described by Pullen-Warner.

1. A piece of Co-Cr tubing of the required internal diameter is filled with phosphated bound investment (simply insert the tube in a mix which is being vibrated. Capillary attraction will take the investment along the tube.)

2. The tubing will eventually eventually within the casting and to ensure that it will be retained in position, the area of tube (with bur is already cut in it) must be sanded over the bolt after the soldering process. This means that the handle can be bent after bolt assembly. The two pieces of tube are held together in a further piece of tube cut longitudinally and spot welded to the other two pieces of smaller tubing.

Fig. 1: The fact of groove of a P-W bolt

Fig. 2: Locking pin

Author's note: The locking pin is cut to a height no greater than 1mm.

Adendum

The bolt is placed inside the handle is bent, as described by Pullen-Warner and L'Economist.

A small amount of gold solder is applied to the end of a piece of stainless diameter "Wip-ten" wire which will form the locking pin, having flared it initially. (The wire may be a few inches long at this stage to allow hand-held soldering.)

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CA. TECHNOLOGISTS, Apr. 1990.

Acknowledgement

My thanks are due to Mr Ken Cherrington for the diagrams and photographs.

NEWS in brief... DTEAB

DTETAB hereby give notice that the election of one techni- cine of its membership in February 1991 has been carried out. The election was run on the Electoral Reform Soci- ety and Mr C G Lee was duly elected.

GAC move

O.A.Dental Laboratory has moved to Cheltingham House, Dims, Park, N.R. Pole- gate Eastbourne, East Sussex BN26 6HY, Tel: 0323 473737, Fax: 0323 478736.

THE DENTAL TECHNICIAN June 1991 7
INTRODUCTION

MICROS IN EDUCATION

Exploiting the microcomputer as a visual aid for teaching dental technology may at first sight seem rather a minor enterprise. However, the topic of dental technology education interests a wider audience than might at first be supposed. Not only educators but also students and employers should have an interest in the field. This thesis is as much for the latter sectors of the dental populus as anyone else.

Stananought (1983) pointed out that modern dental technology has come to require much more conceptual understanding than previously. To be more specific, many of the concepts at the heart of dentistry are concerned with MOVEMENT. Subjects such as functional occlusion, indirect retention, anchorage and the positioning of orthodontic springs are topics which come to mind almost at random. To teach such concepts, there are tremendous advantages in having moving coloured diagrams on a visual display unit with the instructor able to accurately control movements. The new technology of computer graphics offers dental educators this facility. Are there any further advantages and why should microcomputers be exploited in dental education?

ADVANTAGES

Educationally, the use of this resource is sound. The advantages of visual teaching aids have been well argued in many contexts (see, for example, Romiszowski, 1974). Additionally, computer graphics allow variation of the medium of presentation, which is an important point in educational practice, and computer graphics produce particularly striking screens, which maximise impact. There are also more particular advantages:

1. The presenter is able to move areas of a diagram around a screen very accurately with the minimum of effort and skill. This reduces the possibility of embarrassing "fumbling" in the middle of a lecture or class.
2. Extremely striking and professional effects can be achieved by the non-professional programmer.
3. Once a program is produced it can easily and conveniently be stored on a disc or tape.
4. Duplication is quick, simple, accurate and automatically carried out by the system as many times as required. This facilitates exchanges of programs and ideas between teaching institutions and other interested parties.
5. Microcomputers are self contained and always available for use.
6. They are reasonably transportable and not limited to areas with special terminal installations.

Whilst using computers as educational tools is new to dental technology, micros are not new to education in general. It is not that dental educators have unnecessarily lagged behind but rather that computer technology has progressed, putting what was formerly a vast amount of computing power into the hands of the smaller, specialist disciplines. What follows is a brief review of the wider educational spectrum.

HISTORICALLY

In the early stages of computer technology, programs running on large, centralised mainframe computers were devised. There were no other options. In the USA, for example, initially a fortune was spent on computers in education.

"Despite the millions of dollars spent on PLATO and other similar ventures (over 900 million dollars by some estimates), by the early 1980's only a tiny fraction of schools had installed such systems." (See Kurland and Kurland, 1987) p. 320.

The way forward really took place with the advent of inexpensive, easy-to-operate microcomputers and it was at this stage that British investment began with the well known "Micros in Schools" project. It was proposed that at least one micro should be available for pupils' use in every school. (Perhaps, in view of the PLATO sheme mentioned above, this is one instance where British reluctance to invest in the first instance has paid off!) However, micros initially had an influence through the back door, as it were, and to some extent still do, because teachers were developing programs on home computers and using them in schools and colleges. However, PTA's and bodies such as BTEC were also concerned that the new technology was used by children and young adults:

"Initially, micros entered classrooms through the initiative of enthusiastic teachers or because concerned parents demanded that their children learn about these peculiar new devices." p. 320 ibid.

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The Use of Computers in Dental Education

DENNY AWARD 1989
(Abridged)

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Computers are probably going to play a much greater role in education in the future. However, many people feel a growing sense of bewildement at the increasing speed of appearance of new machinery and software. Yet many of the new developments are going to make use of a computer easier, not more difficult. On the other hand, the jargon of 'computer-speak' is enough to put many people off making a start. However, I hope, rather, that the above review will be in the encouragement category rather than the other.

This completes a general review of micros in education. I now turn to the exciting challenge of putting micros to use in dental education. The question which should be at the front of our minds is "What can a computer do that other technologies cannot?" I try to highlight this as each programming technique is discussed.

PROGRAMMING TECHNIQUES: ANIMATION

Although there are systems available which can help to create graphics, there is a big advantage in NOT using such program at times since there are then no problems with copyright laws if at a later date one wanted to put the use of the developed program into the hands of other educators. I shall therefore be developing programs without such aids. Probably readers will find that the most interesting portions are the figures and descriptions of what occurs on screen. Programming is, perhaps, a somewhat dry area, especially if it is read in a vacuum, as it were, whilst not attempting to produce any programs. However, it is necessary to show how the effects are created and to this end, I must briefly discuss the techniques of producing a program.

PROGRAMMING: GENERAL CONSIDERATIONS

DRAWING SHAPES

The outline of an almost infinite number of shapes may be built up in computer diagrams from a series of triangles. The computer is told where the corners of each triangle are positioned as follows. The screen is mapped in a similar manner to Ordnance Survey grid references. Horizontal units move from 0 (on the left of the screen) to 1279 (on the extreme right). Vertical units are mapped from 0 at the bottom of the screen to 1023 at the top. Thus the point 0,0 is located at the bottom corner of the screen. Any point can thus be located by giving the horizontal figure followed by the vertical figure. These are called 'cartesian coordinates' (after the philosopher, Rene Descartes) or simply 'coordinates'.

To take an example, if the command "MOVE 100,100" is given to the computer, nothing occurs on the screen but the computer moves to this point ready for the next command. Now if it is told to "DRAW 200,200" a diagonal line appears from the first set of coordinates (100,100) to the second set (200,200). Another command, "PLOT, 85" with a third set of coordinates would produce a filled triangle between the three points.

To produce a simple program, then, one would put the above commands in a series of numbered lines as follows:

10 MOVE 100,100  
20 DRAW 200,200  
30 PLOT 85,400,100

Almost all the shapes in the figures in this chapter have been built up in this way.

It is possible to make these into "variable coordinates" by putting, say, symbols such as X% and Y% into the coordinates as follows: X% + 100, Y% + 100, X% + 200, Y% + 200 and so on. The advantage of this is that one can keep redefining X% and Y% (i.e. give them different values) and thus move the position of the figure. This is a very important technique for some forms of animation but in fact I almost always do this so that the figure can be re-positioned if necessary as the program develops.

This completes a brief description of drawing shapes.

PROCEDURES

The BBC computer has a feature of more advanced machines in that it allows the programmer to split the program up into what are called "PROCEDURES". These are little sections of a program which do specific tasks. They can be written, given a name (for example 'tooth') and stored away neatly at the end of the program. They are defined in a series of lines beginning with, say, "DEFPROTOOTH" and then the rest of the procedure follows. When the procedure is required in the program, it can be called upon with a command such as "PROCtooth;" not just once, but as many times as required.

LOOPS

A loop in a program is one or more lines which repeat themselves. I suppose one could say that the program, at such a point, goes round and round in circles! This is a very powerful feature of programming since each time around a loop, for example, the value of variables can be changed -increased or decreased. There are several ways of telling a computer to begin a loop. Commands such as "REPEAT" on the first line followed by "UNTIL" on the last line of the loop is but one example. The command "UNTIL" must be followed by that which must be achieved by the loop so that the computer can then move on to the next line.

STORING PROGRAMS

Once a program has been created, it can be stored or "SAVED," as the saying goes, on an ordinary cassette recorder or better still, a floppy disc. The computer's memory can then be wiped and "re-filled" with the program at a later date. It can also be reproduced in this form as many times as is required.
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2 DEFINING A CHARACTER

Computers operate by having areas of the screen defined by numbers. For example letters appear on the screen when the keyboard is operated because each letter (or "character") has a series of values which define it for the computer. There exist in the BBC, 'empty' characters, as it were, which allow the user to create any shape, albeit fairly small, by entering a specific string of numbers.

What follows is an original application of this technique. Figure 3 shows a view of a tooth, an active clasp arm in cross-section and a passive reciprocating arm, also in cross-section. The two arms are stationed above the tooth, ready for insertion. Upon contacting the tooth, having moved down the screen (figures 4 and 5), the active clasp is seen springing over the bulbous areas of tooth (figure 6) and finally, engaging the undercut (figure 7). This diagram is based on a figure which first appeared in McCracken's REMOVABLE PARTIAL PROSTHODONTICS (Henderson & Steffel, 1973) and illustrates how a passive reciprocating arm cannot perform its reciprocating function unless it is positioned properly and possibly, the tooth is prepared. Note from figure 4 that the clasp is pressurising the tooth whilst the reciprocating arm is not contacting the tooth.

The items to be animated are the cross-sectional shapes of the clasp arm and reciprocal arm and it is these which have been defined as characters (so called "Ascii characters").

The following figures indicate what appears on the screen.

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8
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The Use of Computers in Dental Education

demonstration programs contained in this thesis come out pretty well on such a comparison.

For example, it would be possible to demonstrate, say, balanced articulation with cut-out shapes of overhead transparencies and move them on an overhead projector. It is, however, sometimes difficult to get thin transparencies to move smoothly and accurately. I have also seen a technique utilising magnetic teeth on a board and this was even more difficult to control. Referring to the second program, I am not at all sure how one would begin to animate the action of an active clasp arm without the use of computer graphics.

Moreover, once one has achieved one's first goal, extensions of the programs almost always suggest themselves. The problem is making a start with computer programming. Once the spell is broken, production of computer graphics is very rewarding.

Next, I briefly discuss the use of still computer graphics in dental education.

PRORGRAMMING TECHNIQUES:

STILL DIAGRAMS AND SIMULATIONS

It would be difficult for a dental education unit to justify the purchase of a microcomputer system merely to display still diagrams and use it as a glorified blackboard. However, having set up the system to use it as described above it is a pity to leave it there. It can also be used to display still diagrams, pie charts and histograms. Furthermore, the diagrams can be printed out and used as student handouts. It is also possible, in principle, to simulate the running of a dental laboratory, though this would take a considerable amount of programming. I shall describe each of these uses.

STILL DIAGRAMS

On the following page, three figures (14, 15 and 16) show the relationship of upper and lower alveolar ridges in a class 1, 2 and 3 skeletal jaw relationship. The program is exceptionally easy to produce. The diagrams could, of course, easily be shown using a blackboard or OHP. The only advantages in this case are that the medium of presentation is varied (a very important educational principle) and the program is easily and efficiently presented. Simply by pressing the space bar, the position of the ridges change - class 1, 2 and 3 respectively, - and then with another press of the space bar, the whole sequence is repeated.

PIE CHARTS AND HISTOGRAMS

These can best be produced using commercial software. The data to be displayed are simply entered into the graphics package. Usually, one firstly gives a name and then gives a value to that commodity. For example, the constituents of a chrome/cobalt alloy could be entered into the computer. One would name "FIELD NAME 1" as "Chrome" and its "VALUE" in this instance could be 22%, so one would enter "22." And so on for each constituent. The computer then asks if the data is to be displayed as a pie chart, histogram or line graph. A few more simple questions must then be answered and the chart or graph appears on the screen. This can then be referred to in a class or lecture directly on the screen, or sent to the printer (printed out) for use as a hand out. The same data can be displayed as a histogram simply by returning to the main menu and answering a few simple questions.

SIMULATION OF LABORATORY MANAGEMENT

There is nothing on the market which performs this simulation but in principle, there is no reason why it cannot be programmed. The reader may be aware of the types of situation a computer can reconstruct. There are economics programs, for instance, which will give a description to the student of a scenario such as the Wall Street Crash! The
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Extensive studies on the use of computers in education generally show that computers are no worse or better than most other technologies. If anything has been learned, to again quote Kurland and Kurland, from about two decades of using computers and evaluative research (i.e., two decades since the use of PLATO), it is that IT does not have an influence over and above good curriculum design and skilful teaching. Why, then, all the fuss about CAI?

It has been shown earlier that CAI developed along the lines suggested in this thesis, for some purposes, is more efficient than other available systems and easier to use in the lecture room. Furthermore, computers can do things which other technologies cannot. Computers can simulate situations which are either impossible or extremely difficult to show using, say, a video camera. Diagrams showing molten gold being cast, denture saddles inserted at an 'in situ' position and the movement of the TMJ are but a few examples falling into this category.

It would also be possible to simulate situations which are either too complex or too risky to put the student in. Simulations of laboratory administration, as discussed in chapter 3, illustrate this point.

Conversely, a computer can simplify complex phenomena with simple outlines and GRADUALLY build up to the complex. The complicated geometry of balanced articulation is an example of such a use.

These points somewhat anticipate the next section to which I shall now turn.

3 FURTHER RESEARCH

One obvious way of extending the types of computer diagrams shown in previous chapters is by developing three-dimensional graphics. There are various methods of producing 3-D. One is to show the contours of a figure by producing lines over its surface. These may be either parallel lines or resembling a net in character. Shapes then become evident. Another way of programming three dimensions is to utilise the so called "WIRE DIAGRAM" method. Here, for example, all the corners of a box are denoted with lines. Very complex programs then become possible. For example, three-dimensional balanced articulation showing all the relationships of the teeth and the associated geometry. Geometry becomes much less complicated and easier to visualise when one can see it in relation to movement, so such a program as the one discussed here may simplify what is at the moment a very complex area.

Extremely expensive systems which combine video and computer technologies are also available: INTERACTIVE VIDEO, as it is called. Here a video film can be made showing the stages of a technique. The computer can accurately re-wind or forward-wind to specific stages of that technique. The student is then invited to watch the film and possibly try the technique. On the second showing of the film, the viewing is interrupted and questions appear on the screen. This again is a computer controlled function. The student must answer the question correctly before the film continues. If the answer is incorrect, the computer accurately re-winds to the appropriate stage of the film.

Interactive video obviously has an application to dental technology, especially in areas where techniques are very small scale. However, currently, the price is prohibitive.

The above suggests that present research is at the "cat-sat-on-the-mat" stage of program development for computer aided instruction and learning and 'ipso facto,' so is this thesis. I make no apologies for this. Every enterprise must begin somewhere.

To date, few institutions have taken up the challenge of applying computer graphics to dental education. Programming looks so complicated and daunting. And yet it only needs a slight introductory knowledge to gain skills to make a beginning. Then the spell is broken and as experience is gained, program production becomes quicker and quicker. Actually, the sky is the limit and to my knowledge no other country is involved in exploiting the computer as a teaching aid in this way. Britain could easily become a world leader in this field as far as dental education is concerned. Programs such as the ones presented here are being developed for many areas of education. Why not for the teaching of dentistry and dental technology? There is no reason.

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Self-assessment picture tests

Dental Technology

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The editors are grateful for the enthusiasm of our excellent contributors and especially for their respective families for their continuing forbearance.
A locking endurance test for hinged sections of removable partial dentures

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Cardiff Institute of Higher Education, Cardiff, United Kingdom

In this study an apparatus is described that will open and close a hinged section of a removable partial denture. A metal framework based on a "swinglock" type of hinge and latch design was constructed. An electric motor provided the drive for the opening and closing mechanism, which when operated set the device in motion. The device and results of a test run of 12,000 opening and closing operations are discussed. (J PROSTHET DENT 1995;73:482-6.)

There is no documented research on testing hinged sections of removable partial dentures (RPDs) in vitro, although other experiments have demonstrated interesting results from the mechanical testing of conventional RPDs. Conventional RPDs may be of limited value to patients whose remaining teeth have advanced periodontal disease and generalized mobility with a questionable prognosis. In these situations, a swinglock RPD is a possible alternative that uses hinged sections of RPDs to provide positive retention and bracing. The swinglock partial denture was introduced by Simmons in 1963.

This design is also useful in cases of localized tooth mobility where key abutments are missing or where the basal seat of the denture is inadequate and leads to poor retention. Several clinical studies generally argue in favor of the swinglock design.

Schulte and Smith clinically evaluated the oral changes in patients who received a swinglock RPD as part of dental treatment. It was found that the swinglock RPD was satisfactory when the dentist and technician followed the basic principles of removable partial denture construction and when the patient maintained a good level of oral hygiene. Gomes et al. conducted a clinical investigation to evaluate the long-term effects of a swinglock RPD on remaining natural mandibular teeth and their supporting structures. His study presented preliminary findings on patients who had been wearing mandibular swinglock RPDs for up to 2 years, and the design was judged to be favorable.

Since 1963, several methods of hinge construction have been described. A clinical comparison of these is, of course, difficult because of many uncontrollable variables in any studies that could be carried out in vivo. This article describes the construction of a test machine that will allow a series of comparative studies of variously constructed hinges and latches to be undertaken under well-controlled conditions and gives a set of results for a typical test. The machine will open and close a hinged section of a partial denture by means of an electric motor. The design of the RPD used for the test is shown and the test results of a run are recorded.

MATERIAL AND METHODS

Apparatus

The machine is activated by an electric motor that drives the opening and closing mechanism (Fig. 1). The motor is a variable-speed type and is set at a suitable speed for the tests (approximately 1 cycle per 2 seconds).

The opening/closing mechanism uses suitable actuators to perform the required action. Fig. 2 illustrates the operation of the mechanism. The shape and relative motion of the actuators is such that when they rotate and contact the labial bow, opening and closing is achieved. The RPD clamp is capable of withstanding the forces created during use and does not interfere with the method of operation of the test apparatus. The cycle counter is a mechanical lever type and is operated by rotation of a shaft, which carries the closing actuator.

Test sample

A chromium-cobalt design for testing was constructed on a partially dentate mandibular model with six natural anterior teeth and a left second molar remaining. The design incorporated a lingual plate as a major connector and a labial bar with three struts on the bar that engages undercut labial surfaces of mandibular anterior teeth (Fig. 3). Direct clasp retention could have been provided by a ring clasp on the mandibular left second molar. A laboratory-made hinge was placed on the left side of the arch and a laboratory-made lock/latch was positioned on the right.
PROCEDURE

The test RPD framework was clamped in position and used so that the closing actuator pressed gently on the labial bow as it revolved and thus closed the section. As the closing actuator revolved, a projection flicked the lock/latch open. The closing actuator turned and pressed on the so that the device locked. This process was repeated if the test reached completion. Initially, the machine set in motion for a test run of 500 operations, but after initial changes, test intervals of 1000 operations appeared to be more appropriate because the rate of wear down (Fig. 4).

Opening endurance is defined in terms of force required to open and close the hinged section and then, from the latch, to open it, by use of the apparatus shown in Fig. 3.

Five measurements of the forces required to open the section and five to close it were recorded. These were then averaged and the result was plotted on a graph (Fig. 4). It was considered important to hang the weights on the hinged labial bar in the same position at each measurement. After the weight required to lock the hinged section was determined, the RPD was inverted and weights were hung on the latch to determine the force required to unlock the appliance. An average of five readings at each test in

Fig. 1. Machine designed to test hinged sections of RPDs. A, Opening cam in process of opening labial bow. B, Closing cam in process of locking labial bow. 1, Supporting frame; 2, clamp to hold framework; 3, closing cam; 4, mechanical counter; 5, hinge of swinglock; 6, bracing part of labial bow; 7, lock; 8, opening cam; and 9, motor in housing.
Table I. Opening/closing force that corresponds to number of operations conducted

<table>
<thead>
<tr>
<th>Number of opening and closing actions</th>
<th>To lock (average of 5 readings)</th>
<th>To unlock (average of 5 readings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grams (mass)</td>
<td>Newtons (approximate)</td>
<td>Grams (mass)</td>
</tr>
<tr>
<td>0</td>
<td>250</td>
<td>140</td>
</tr>
<tr>
<td>500</td>
<td>208</td>
<td>87</td>
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<td>2,000</td>
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<td>43</td>
</tr>
<tr>
<td>14,000</td>
<td>50</td>
<td>43</td>
</tr>
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The decline in the force required to lock and unlock the hinged section is clearly illustrated in Fig. 4 and presented in Table I. There was a notable decrease in the force needed to open and close the section after the first 500 operations. After this initial reduction, the forces required to lock and unlock the section stabilized to some extent and went through various plateaus.

RESULTS

The in vitro system at this stage of course does not take account of the lubricating effects of saliva, the tendency of...
Fig. 3. Force measurement apparatus (computer scan). I, sights may be added or subtracted; 2, holding frame; 3, mp to hold RPD; 4, weight hook in position to lock mework; 5, partial denture framework.

patients to place pressure on the labial bar when locking latch, or the ability of the components to withstand stiaticatory pressures. However, the test apparatus will rate well to enable comparative studies to be under­
testing and comparing hinges and locking devices constructed in different ways.

CONCLUSION
Experience suggests that a slight modification to the de­
1 of the test piece would improve positioning in the ma­ne, aid standardization, and therefore aid consistency, he test machine and force-measuring apparatus are cotypes; thus, both can be developed further. he equipment presents the opportunity to develop a uard test for locking endurance of hinged sections of ovable partial dentures.

7ERENCES


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THE JOURNAL OF PROSTHETIC DENTISTRY

Fig. 4. Graph of force required to open and close a hinged device at varying numbers of operations.
Last month we published the first part of a report discussing developments in the field of automatically produced dental restorations. There are three research groups developing systems at the moment; two of them have already been described and the third, with which we shall begin this issue, is the French group. The conclusion of this paper attempts to draw out some of the implications for dental technology.

(3) The Hennson International Apparatus
An optical scanner containing photo-receptors is used to collect the data by hand. The receptors react to the intensity of reflections of laser beams as they pass over the teeth. Surfaces thus recorded would have been previously painted with a substance facilitating this process. The reflections indicate the shape and size of that being scanned and these signals are converted into a computer recognisable form and entered into a computer.

The apparatus is also capable of recording the movements of the mandible and the restoration can thus be produced to accommodate these.

After the information has been received by the computer, three-dimensional images of the scanned areas can be displayed on a video-monitor. The details from the scan of the prepared tooth, the adjacent teeth and the opposing dentition can be obtained by the clinician, it is claimed, in about three minutes.

The operator next moves to the keyboard and by using software, the missing area of tooth can be shaped and restored on screen to the specific, unique requirements of the individual patient. The design of the restorations can be chosen from a library of teeth held in the computer, or alternatively, the patient's own teeth can be scanned prior to tooth preparation and the size and shape recorded. Then the original natural tooth morphology can be recalled and copied at the design stage.

When the design has been completed, the CAM ('computer-assisted manufacture') component of the software determines the necessary movements of the instruments of the machine. The latter is a three-axis micro-milling machine which can cut the restoration from a solid block of material automatically under the control of the computer.

It is claimed that this system, which appears to be the most versatile of the three, will be capable of creating inlays, onlays, three-quarter crowns, full crowns, three unit bridges and even complete dentures. As far as accuracy is concerned, the tolerance is greater than 80 micro-millimetres.

Conclusion
Is the common use of the equipment described in this series futurology or science fiction? Does it seem unlikely that these systems will ever be in general use? Dr Francois Duret demonstrated the French automatic system...
take place and it could become common in the foreseeable future. With the Swiss system, inlays could be produced for the patient in one sitting. Likewise with the French system but, in addition to inlays, all-metal crowns could also be produced.

What about the automation of other areas of dental technology? The American and French groups state that their methods could eventually produce restorations in addition to crowns and inlays and the automation of other fields of dental technology, at the moment, seems dependent on the further development of these two methods. There are three factors which may inhibit wider use.

The first and most obvious factor is the cost. The French system may initially cost anything up to $90,000. The clinical equipment for the American system, on the other hand, is much cheaper (in the region of $5,000) but the transparencies must be sent to a milling centre for the restoration to be produced and whether that will be cheaper than current laboratory production remains to be seen.

However, it must be borne in mind that machines can work for 24 hours per day. Furthermore, the advantage of the restoration being produced in one sitting is lost with the American system.

A second limiting factor is that there is nothing in the literature which suggests how the delicate shading of teeth, be they prostheses or crowns, could be successfully incorporated into these methods. Processes seem to be limited to milling restorations out of solid blanks. Thus anterior crowns and bonded constructions are not immediately threatened.

Thirdly, the complexities of milling out a partial denture framework with clasps and other components, for instance, makes one boggle. It strikes me that this will remain an academic possibility rather than a commercial viability for quite some time.

In summary, the methods offer the possibility of using new types of materials and some of these may overcome the problem of shading mentioned above.

However, my personal conclusions are that while the use of automatic apparatus for the production of crowns and inlays constructed in a uniform material could occur in the foreseeable future, automation of other areas of dental technology will, it seems to me, take quite a bit longer. It must be said, however, that my humble opinion could prove to be wrong!

A NEW METHOD OF BOLT CONSTRUCTION FOR SECTIONAL DENTURES

Most people are impressed with the ingenuity of the Pullen-Warner sectional denture designs and it is perhaps unfortunate that they are not in wider use.

It is sometimes argued that suitable cases are not often encountered but it is perhaps more usually the case that there is a lack of technical and clinical experience concerning these appliances. In fact, Watt and MacGregor¹ state that sectional dentures can be used in many different situations in the mouth because many different kinds of design can be employed" (p.163).

In particular, the bolt retained sectional denture is potentially a regular answer to design problems. It is worth quoting Watt and MacGregor at length:

1. When a patient is unwilling to have teeth prepared for a bridge, a small sectional denture can often satisfy the patient by occupying little space in the mouth and restoring the patient's appearance.
2. Where there has been much soft tissue loss and the construction of a fixed bridge would fail to restore that loss, sectional dentures can often provide the best type of appliance.
3. Where a clasp on an anterior tooth would be necessary for retention, it can sometimes be replaced by a hinge-flange or sectional part of the denture.

Among the disadvantages of sectional dentures the above authors state that they are expensive to produce and that skilled technicians are required to construct and maintain them. Actually, most technicians skilled in Cr/Co work could very quickly construct a two-part, bolt-retained denture having once gained the experience of making three or four. In other words, greater use would undoubtedly have reduced the technical cost of these appliances.

One of the difficulties in the construction of bolt-retained sectionals is the manufacture of a positive bolt. The remainder of this paper discusses a simpler method of bolt construction.

To discuss the first point, it is only necessary to refer to a paper by Cragion and Anderson who state: "The main disadvantage of the P-W locking bolt" is that both a slot and a groove must be cut in the bolt itself. This is difficult to do with normal dental equipment; usually more material than necessary is

By R. J. WILLIAMS, BA, PhD, and N. T. SOMES, MIFMT
removed, leaving the bolt weak. Failures from this cause have been experienced clinically."

Cragion and Anderson go on to outline a design for a bolt (Fig. 1) which overcomes this disadvantage by having the locking device in the surrounding tube. The method is as follows:
1. Solder a piece of 0.8mm wire to the bolt wire. This will later form a locking pin.
2. Cut a groove in a piece of tube, which will form a collar (Fig. 1-B) along which the locking pin may slide. A locking device is created by the provision of a gap between the collar and another piece of tube (Fig. 1-A).
3. Reduce a wider tube in half longitudinally, assemble the bolt and smaller tubes and spot weld the smaller tubes to the half sectioned larger tube.

This is an excellent idea but it is possible to simplify construction and improve bolt materials.

Materials
Cragion and Anderson suggest the use of stainless steel for the bolt, tube and locking pin but of course, silver solder must be used with this material. Although the bolt construction is encased in acrylic, oral fluids will nevertheless be attracted along the tube and cause attendant problems when they contact the solder. The use of Wiptam wire for the locking pin and bolt would allow gold solder to be used and this material therefore commends itself. A suitable stainless steel tube, however, is a possible alternative to Wiptam.

Technique
1. Flux and apply the minimum amount of gold solder to the end of a piece of 0.8mm Wiptam wire. This will form the locking pin (Fig. 2).
2. Select the diameter rod which is to form the bolt (there are variations in the literature between 1.2mm and 1.3mm) bend the handle as described by Pullen-Warner and L'Esstrange and solder the 0.8mm wire locking pin to the bolt 3-6mm from the bend.
3. Cut a groove in the tube along which the locking pin can slide. Note which way the bolt should be turned to lock and cut the locking groove in the appropriate side.
4. Trim the locking pin to a height of 1mm and cut the bolt and tube to the required length. The latter task is simplified since the bolt can be withdrawn from the sleeve at this stage. Grooves may be incorporated in the tube to increase retention into the acrylic of the second part.
5. Prior to incorporating the bolt into the acrylic of the second part, wax must be built up along the grooves in the tube to a height of at least 1mm (with the bolt and tube assembled) to prevent auto-polymerising acrylic encasing the locking pin. Where the wax is discontinued, a half round piece of tube prevents complete withdrawal of the bolt.

This can be friction-fitted in place during auto-polymerisation.

After processing, initial opening and locking of the bolt is stiff but after 4-5 excursions of the locking pin along the grooves in the tube, the wax tends to quickly dislodge and normal function is achieved.

Conclusion
One of the major difficulties of bolt-retained sectional denture construction has been simplified with the technique of bolt construction described here.

The presentation of dynamic concepts in medical education

J. J. WILLIAMS

There are many areas of medicine and dentistry in which the use of animation is of immense value in demonstrating dynamic concepts. With the advent of microcomputers and the design of suitable software, it is now possible to produce simple animated computer graphics. The author describes the use of this technique for teaching moving concepts in dentistry.

Dentistry, like other areas of medicine, is a subject with many dynamic concepts at its heart. One common example which springs readily to mind is the articulation of complicated joints such as the temporo-mandibular joint. Computer graphics is a far more developed method of presenting these moving concepts to the neophyte. However, it should be noted at the outset that there is little point in using a computer to achieve what can easily and cheaply be accomplished with a paper stem or other method. That being said, there are several advantages of computerization which we shall discuss a moment.

Computer graphics is probably going to play a much greater role in medical education in the future. However, many people feel a growing sense of bewilderment at the increasing speed of appearance of new hardware and software, and the number of new terms. Yet many of the new developments are coming to make the production of software by non-experts much simpler, not more difficult.

Interested parties should note that there are many so-called 'authoring systems' currently on the market which can facilitate the production of some of the diagrammatic movements under discussion here. However, the advantage of attempting to create a program in the beginning is that there are no problems with copyright. Computer graphics is one area of programming in which it is relatively simple to acquire a skill, and using devices such as a mouse makes programming much easier. One can also build up a stock of programming routines which can be incorporated into new programs. (A routine, for example, is a few lines of program which will, say move a part of a diagram). Hence, programming becomes easier as one creates more programs.

Advantages of computer graphics over other presentation media

1. The presenter is able to move areas of a diagram around a screen very accurately.
2. Extremely striking and professional effects can be created.
3. Once the program is written, it can be easily and conveniently stored on a floppy disc or tape.
4. Duplication is quick, simple, accurate and automatically carried out by the system, as many times as required. This would facilitate exchanges of programs and ideas.

Microcomputers have the further advantages of being:
1. Self contained and always available for use.
2. Transportable to any lecture theatre, not limited to use in areas with special terminal installations.

The following discussion of types of movement is based around the commonly available BBC Acorn microcomputer but should be easily transferable to other types of micros.

Types of animation

The main advantage of computer diagrams is the animation it is possible to achieve. Dentistry is a discipline necessitating many dynamic conceptualizations to which computer graphics can easily be applied. There are various types of animation, and the corresponding lengths to which it is necessary to go will depend on what is being taught. Some examples of ranges of movement follow below. First, we shall concern ourselves with how animation is achieved.

In its simplest form, an image can be moved by being drawn on the screen, deleted, and being reproduced in a slightly different position. Although microcomputers draw very fast, it is not possible to achieve an acceptable animation by using these simple steps. Several programming devices must be utilized to create a suitably smooth effect. Some examples follow:

Example 1

The first type of animation is illustrated in Figure 1. There is a diagrammatic representation of a crucible in cross-section on the right, a molten ball of gold in the centre, and a cross-section of a mould which the gold will fill. The gold displays what is, perhaps the simplest form of animation and the computer achieves it by:

A. Drawing the shape of the gold.
B. Drawing the shape of the gold again, a fraction to the right of the first image.
C. Blotting out the tail of the first image by printing a shape in the background colour. The edge of this background shape in contact with the rear of the...
The gold moves from right to left. (1) Molten ball of gold. Crucible. (3) Mould.

Figure 1.

and is drawn so as to maintain the original shape.

Return to A.

On the BBC microcomputer, the shape of the gold can be defined in a procedure using variable horizontal coordinates. It can then be printed on screen time and time again simply by feeding in new coordinates using a loop in the program. If this were all the computer were programmed to do, a yellow streak would appear on the screen. Therefore, a shape is drawn in background colour, again in a procedure with variable coordinates, and is moved along with the new images of objects using the same loop in the program. Thus it is unnecessary to delete the whole of the image.

The disadvantage is that there is a slight elongation and shortening of the shape being moved. This is not too obvious and may be perfectly acceptable for some purposes. The bigger the image being moved, the more satisfactory the type of animation becomes.

Example 2

Figures 2–3 illustrate a prosthesis being inserted between two standing teeth. Here, elimination of the old image is automatically taken care of by the 'window' facility of hardware scrolling. Animation is therefore very simple and much smoother than in Example 1. The logical steps are as follows:

Two standing teeth are drawn.

A 'window' is defined so that animation will only occur in the defined area.

The image to be moved is drawn in window area.

The window is 'scrolled', that is, it moves downwards in this case, thus toning the representation of the prosthesis being moved in situ.

The disadvantage of this method is scrolling can only occur in the vertical or horizontal directions.

Example 3

The most versatile and smoothest animation is shown in Figures 4–5. Here two incisors are represented (side view) in their relative relationships when the mandible is moved into protrusion. Although the program routine for animation is fairly complicated, once the section of a program which carries out the task of movement is written, it can be saved on a disc to be incorporated in other programs to move other shapes (see, Williams, 1986, for such a routine). The tooth moves smoothly from the first position in Figure 4 to the final position in Figure 5 and is achieved as follows:

A. The first image is drawn.
B. The second image is drawn but in the background colour so that it is invisible whilst the first image continues to be displayed. Where the background image overwrites the first, the computer can be programmed to prevent the background colour disturbing the image.
C. The colour of the background image is flipped, virtually instantaneously, to the foreground colour whilst the original image is flipped to the background colour.

The BBC, like all micros, takes a while to draw a diagram but it can change colours in an instant and the switching from foreground to background colours vastly speeds up the process. The current image remains intact while the next image is invisibly drawn.

Educational feedback

It is acknowledged everywhere that there are a great number of variables in most forms of educational research. This makes sound quantitative analysis of, for example, a teaching aid very
difficult. In this case a questionnaire (Appendix) was used, asking students for their impressions regarding the use of computer graphics in class. The results (Table 1) are taken from a sample class of 18 students who had studied dental-related topics for about 6 weeks, at Burnham level 4 grading.

Question 4 asked subjects how well they could answer verbal questions at the end of the lesson. Responses were as follows: 11.3% said they could answer few of the questions.

33.3% could answer about half of the questions.
38.8% could answer most.
16.6% could answer all.

Responding to question 6, 70% of subjects thought the computer graphics were more accurate than other forms of teaching aids, 50% thought they were clearer and 65.5% thought they were more professional.

Analysis

Most results collected from the type of questionnaire used here usually show subjects responding by rating answers around the average. In the present study, reactions tended to polarize on questions 1, 2, 3 and 5, indicating that some were very much in favour of computer-aided teaching while others were not. That being said, the scores show that the majority were very much in favour.

Where respondents were asked to list any disadvantages, the perceived faults could be avoided by using different colours, a larger screen or improving the program. Advantages listed were:
a. That it was easier to relate the dynamic reality to accurately moving diagrams than merely studying a series of illustrations.
b. The images were retained in the mind for a long period.
c. There is no need for the presenter to spend time on focusing, etc.

Conclusion

Use of computer graphics in teaching conforms to many currently held educational principles. It has impact, provides variation of the medium of presentation, lends itself to recapitulation and can be an excellent representation of reality. Couple these points to its use in a discipline which has many dynamic concepts at its core and a very powerful teaching aid is at the disposal of the educationalist.

Reference


Appendix. Computer-aided teaching

Please tick the appropriate response

1 = POOR RESPONSE  5 = EXCELLENT RESPONSE

<table>
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<tr>
<th>SCORES</th>
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<th>3</th>
<th>4</th>
<th>5</th>
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</tbody>
</table>

Williams
Microcomputers in the Presentation of Dynamic Conceptualisations

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Llandaff, Cardiff

Dentistry is a subject with many dynamic concepts at its heart. Some examples which spring readily to mind are indirect retention, anchorage, and the articulation of the temporomandibular joint. Computer graphics is a so far underdeveloped method of presenting these moving concepts to the neophyte. However, it should be noted at the outset that there is little point in using a computer to achieve what can easily and quickly be accomplished with a paper system or other method. That being said, there are several advantages of computerisation which we shall discuss in a moment.

Computer graphics is probably going to play a much greater role in dental education in the future. However, many people feel a growing sense of bewilderment at the increasing speed of appearance of new hardware and software, and the number of new terms. Yet many of the new developments are going to make the production of software by non-experts much simpler, not more difficult.

Interested parties should be aware that there are many so called ‘authoring systems’ currently on the market which greatly facilitate the production of some of the diagrams under discussion here. However, the advantage of attempting to create a program without these aids is that there are no potential problems with the copyright laws. Computer graphics is one area of programming in which it is relatively simple to acquire a skill and by using devices such as a MOUSE, programming is simplified considerably. One can also build up a stock of programming routines which can be incorporated into new programs. (A routine is a few lines of a program which will, for example, move a part of a diagram). Hence, programming becomes easier as one creates more programs. There are, therefore, many encouragements to look in this paper at some varieties of movement which the non-specialist programmer can achieve.

Advantages of Computer Graphics over other Mediums of Presentation
1. The presenter is able to move areas of a diagram around a screen very accurately.
2. Extremely striking and professional effects can be created by the amateur.
3. Once the program is written, it can be easily and conveniently stored on a floppy disc or tape.
4. Duplication is quick, simple, accurate and automatically carried out by the system, as many times as required. This facilitates exchanges of programs and ideas.

Microcomputers have the further advantages of being:
1. Self contained and always available for use.
2. Transportable to any lecture theatre, not limited to use in areas with special terminal installations.
3. The following discussion is based around the commonly available BBC Acorn microcomputer but should be easily transferable to other types of micros.

Types of Animation
The main advantage of computer graphical diagrams is the ANIMATION it is possible to achieve. Dentistry is a discipline necessitating many dynamic conceptualisations to which computer graphics can be quickly applied. There are various types of animation, some being easier to create than others. The type or style of animation, and the corresponding lengths to which it is necessary to go when programming, depend upon what is being taught. Some examples of ranges of movement follow below. Firstly we shall concern ourselves with how animation is achieved.

In its simplest form, an image can be moved by being drawn on the screen, deleted, and being produced in a slightly different position. Although microcomputers draw very fast, it is not possible to achieve an acceptable animation by using these simple steps. Several programming devices must be utilised to create a suitably smooth effect. Some examples follow:

![Fig. 1](image)

The gold moves from right to left. (1) Molten ball of gold. (2) Crucible. (3) Mould.
EDUCATIONAL FEEDBACK

It is everywhere acknowledged that there are a great number of variables in most forms of educational research. This makes sound quantitative analysis of, for example, a teaching aid very difficult. In this case a questionnaire (see the appendix) was used, asking students for their impressions regarding the use of computer graphics in class. The results are taken from a sample class of 18 students who had studied dental related topics for about 6 weeks, at Burnham level 4 grading.

Table 1. Scores

<table>
<thead>
<tr>
<th>Question no.</th>
<th>Percentage</th>
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<tr>
<td>1</td>
<td>72.5</td>
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<tr>
<td>2</td>
<td>67.5</td>
</tr>
<tr>
<td>3</td>
<td>72.5</td>
</tr>
<tr>
<td>4</td>
<td>67.5</td>
</tr>
</tbody>
</table>

The figures in the table are percentage scores of the maximum possible score for each question.

Question 4 asked subjects how well they could answer verbal questions at the end of the lesson. Responses were as follows:
-11.3% said they could answer few of the questions.
-33.3% could answer about half of the questions.
-38.8% could answer most.
-16.6% could answer all.

Responding to question 6, 70% of subjects thought the computer graphics were more accurate than other forms of teaching aids, 50% thought they were clearer and 65.5% thought they were more professional.

ANALYSIS

Most results collected from the type of questionnaire used here usually show subjects responding by rating answers around the average. Conversely, in the present study, reactions tended to polarise on questions 1, 2, 3 and 5, indicating that some were very much in favour of computer aided teaching while others were not. That being said, the scores show that the majority were very much in favour.

Where respondents were asked to list any disadvantages, the perceived faults could be avoided by using different colours, a larger screen or improving the program. Advantages listed were:
a) that it was easier to relate the dynamic reality to accurately moving diagrams than merely studying a series of illustrations.
b) the images were retained in the mind for a long period.
c) there was no need for the presenter to spend time on focussing, etc.

Appendix. Computer-aided teaching

Please tick the appropriate response
1 = POOR RESPONSE 5 = EXCELLENT RESPONSE

<table>
<thead>
<tr>
<th>Question</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Did you feel you were able to grasp the concepts being explained by CAT?</td>
<td></td>
</tr>
<tr>
<td>2. Did you find it easy to relate the computer diagrams to reality?</td>
<td></td>
</tr>
<tr>
<td>3. Were you later able to recall the screen diagrams fairly quickly?</td>
<td></td>
</tr>
<tr>
<td>4. Could you correctly answer the questions asked in class after the lesson?</td>
<td></td>
</tr>
<tr>
<td>a. Few of them</td>
<td></td>
</tr>
<tr>
<td>b. About 50% of them</td>
<td></td>
</tr>
<tr>
<td>c. Most of them</td>
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<tr>
<td>d. All of them</td>
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<tr>
<td>5. Did you feel the computer diagrams retained your concentration for longer?</td>
<td></td>
</tr>
<tr>
<td>6. Were the movements on screen</td>
<td></td>
</tr>
<tr>
<td>a. more accurate</td>
<td></td>
</tr>
<tr>
<td>b. clearer</td>
<td></td>
</tr>
<tr>
<td>c. more professional</td>
<td></td>
</tr>
<tr>
<td>d. than other teaching aids you have experienced (e.g. overhead projectors)?</td>
<td></td>
</tr>
<tr>
<td>7. State any disadvantages of CAT which occur to you.</td>
<td></td>
</tr>
<tr>
<td>8. State any advantages of this method of presenting moving concepts which occur to you.</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSION

Use of computer graphics in teaching conforms to many currently held educational principles. It has impact, provides variation of the medium of presentation, lends itself to recapitulation and can be an excellent representation of reality. Couple these points to its use in a discipline which has many dynamic concepts at its core and a very powerful teaching aid is at the disposal of the educationalist.

Acknowledgement

This paper was based upon one which was first published by the author in THE JOURNAL OF AUDIOVISUAL MEDIA IN MEDICINE, July, 1987, 10, 3, pp 111 - 112. I am grateful to the publishers, John Wright, for permission to reproduce the figures, table and appendix here.
This article marks the start of a series which offers advice about computerising the dental laboratory. To that end, various items of hardware and software will be critically reviewed. To begin, then, what are the points to look out for when choosing a micro?

Pundits are predicting that one day the “paperless office” will become commonplace and that all business communications will not be via the printed page but rather via the visual display unit, or “screen” to those of us less articulate people. For instance, electronic mail is a method of sending information (say, a letter or invoice) from one computer to another along the telephone network.

Electronic mail has become fairly firmly established in the USA as the cheapest and fastest way of communicating through the written word. The sender’s message is keyed into the computer and when all is edited and acceptable, it is sent and it immediately appears on the recipient’s “mailbox” where it will be instantly acknowledged and stored for later attention.

Perhaps we are a few years away from electronic mail being the rule rather than the exception, but there are immediate benefits from computerising the running of a dental laboratory. Just how far one will want to go is, of course, a personal decision. Some have begun to employ the so-called “home computers” and many excellent software packages for accounts, payrolls and the like, can be used.

For those who wish to take a deeper plunge, it cannot be over-emphasised that software should be one of the major points of attention. Any micro is only as good as the program running it and what software is available for any machine under consideration is of prime importance.

Software specially written for running dental laboratories is available but can cost about half, or even be equal to, the price of the hardware. However, it is well worth looking at specialist software to see what can be achieved and thereby obtaining a yardstick, even if purchasing it is ultimately decided against.

Here, we shall try to find our way through the mists regarding the complexities of computers.

A MICRO FOR BUSINESS

It hardly needs to be said that there are huge numbers of computers on the market and that this is a source of great confusion. However, in the business world at least, a standard is emerging.

The large American computer manufacturer, IBM, has had software produced for it over very many years. It takes time and experience, even for professionals, to produce packages which are acceptable and popular with the public, and IBM software producers have acquired a great deal of experience.

They have programs for anyone from preachers to office clerks; you name it, they probably have it, and most computer manufacturers are now beginning to admit the advantages of IBM-compatible software. But that is not to say that IBM necessarily sells the best computers or offers the best value for money.

Many business computer manufacturers have in their range a model bearing the initials “PC”; Tandy, Epson and more recently Amstrad are some examples. The initials PC refer to the original IBM Personal Computer, first brought out in the far off days of 1981 — far off,
that is, in the fast changing computer world.

The companies listed above, non-IBM companies, imply that their PC models are compatible with software produced for the original IBM PC. Such compatibility gives access to a wealth of quality software, some of it written on the basis of long experience going back to the pre-microcomputer days.

Hence, purchasing the right business computer is perhaps easier today than at any time in the past. The demands of the business community have forced some standard into the rather haphazard computer world.

IBM compatibility seems now to be a must for any business computer manufacturer. For instance, Acorn has been trying to produce a package making its micros IBM-compatible but has been beaten by Watford Electronics which announced the breakthrough in February.

Atari unveiled its PC clone for the American market at the Consumer Electronics Show in Las Vegas in January. Further, the "Which? PC" journal stated last month that, "Almost all major micro manufacturers have now accepted, albeit reluctantly, the dominance of the IBM PC standard."

So there is much to encourage the first step into computerisation. Whilst finding one's way through the confusing number of wares on the market is clarifying, prices are falling. The Amstrad PC clone has forced other companies (Atari is one) to compete in a similar price bracket and this in turn has forced the price of software into a similar "budget" mould.

COMPATIBILITY

The issue of compatibility is deeper than one at first suspects. True compatibility is more than merely the ability to run some software written for the IBM PC. All applications of IBM PC software must run on a truly compatible machine and, if possible, so should software written for the later IBM models, the XT and AT.

If the PC is not completely compatible, whenever new applications are sought, they must first be tested on the machine to ensure that they will run. Even if they do run initially, problems could arise later. A good test for true compatibility is to get the dealer to demonstrate that software such as the business applications' package "Lotus 1-2-3" or Microsoft's "Flight Simulator" will run on the machine under consideration. Although the latter is a game, the program makes intelligent use of the operating system and the memory.

CONCLUSION

It has been suggested that IBM compatibility is a favourable factor when deciding on a micro for business. However, excellent programs exist for non-compatible machines and I am not decrying those in any way.

Next month, we shall look at another standard: software which is specifically designed for dental laboratory management. Until then, and until the advent of other items in the series, it may be beneficial to withhold purchases of computerware.
It cannot be emphasised too strongly that the commercial laboratory owner should see what software (i.e. commercially purchased programs which operate the computer system) is available for a microcomputer before buying anything.

There are few software packages specifically designed for running a dental laboratory but Specialist Dental Services (SDS) produces one such program. Consideration of this system would make a sensible first step for anyone thinking about computerising his business — even if one ultimately decides against its purchase.

It provides an excellent yardstick against which to measure the capability of other systems. So, if possible, see or arrange a demonstration. SDS's address is given at the end of this article.

SDS software is very flexible (having been written in the programming language called "RM COBAL") and will run on IBM compatible micros, plus a few others, any mainframe or any mini computer — not that many labs will have access to the latter two.

SDS will sell the software alone, or supply the software plus the best hardware system to meet a particular laboratory's needs. Laboratories which have already purchased micros may nevertheless be able to run the SDS package, since many machines are IBM compatible.

So what will the SDS software do? It will enable the laboratory to run at its maximum efficiency. It will greatly help the financial and general organisation and this includes employees in that it helps them to organise their work load. These advantages will become evident as the system is described.

**BOOKING WORK IN**

Suppose one is faced with a micro which has been set up with SDS software and the work arrives from the clinic. How would one proceed? The operator can quickly "book" a patient's work into the computer using a number-code to designate: (1) the dentist whose work it is; (2) the technician allocated to complete the work; and (3) the type of work required (F/F, jacket crown, etc.)

The client, technician and type of work are all assigned a number-code once and for all when the system is originally set up and SDS does this in consultation with the laboratory. A list of names and codes could be displayed where they can be easily consulted but operators of the system very soon retain many of the codes in their heads.

Any "special instructions" can also be entered against the patient's file at the booking-in stage using a numeric code. These are sentences of the laboratory's own choosing. Such sentences may be an instruction like, "Retain the special trays of this patient", "Construct a light brown crown on the neck of this crown", and so on.

Hence, not a great deal of typing skill is required. However, the patient's name must be typed in and the computer system, having given you several checks and opportunities to correct mistakes, will print out a work card for the job in hand and an identification label for the
work box. It also records information such as the cost of the appliance against the client's invoice for later use.

Also at the booking-in stage, the computer displays work required for any specified period, say the following few days, either section by section or it gives individual technicians' work loads. Hence the least busy areas of the laboratory can be seen at a glance, a great help in assigning the freshly received work. Additionally, the least busy days can be seen so that, if possible, completion can be scheduled for those times.

Sales ledgers are virtually automatically kept. At the end of the month, the system will produce completed invoices for each client. Daily work schedules can be produced for each of the technical staff, informing them of the work required for that day.

The system will tell who booked the work in so that if constant errors are made by someone, more training would be indicated. One can also detect the number of remakes each client has and may uncover the fact that perhaps a particular client is not worth having.

BOOKING WORK OUT

SDS software has booking-out facilities, which keep a detailed record of where the work is — whether it has been sent to the clinic or received back. Work which is overdue can also be analysed along with any expected completion schedules. The latter is very useful for discovering the next day's deliveries at a glance.

CONCLUSION

Probably if these figures were set against tax, computerising would soon pay for itself. For one thing, the work of the accountant in auditing at the end of the financial year would be greatly decreased and hence, so should his bill.

The SDS system is very flexible, can be tailored to the laboratory's needs (the "special instructions", for instance), has SDS back-up facilities of help and advice and the software is difficult to fault.

The price, however, is the rub but it should be remembered that any computer system is only as good as the software operating it. SDS's is arguably the most sophisticated on the market for dental technology.

Future articles in this series will deal with how to utilise software which is for general use but could be used for running a dental laboratory. These take more thought and effort to set up with considerably less help from the dealer than one would receive from SDS.

Perhaps such software "off the peg" would do less than SDS products but it may be perfectly adequate for, say three to four man laboratories where everybody has quite a good idea of the work load of their colleagues. It would also be considerably cheaper. Unfortunately, like everything else, in computing you get what you pay for.

SDS Computer Systems
is at West Side House, 123 Bath Row, Edgbaston, Birmingham B16 1LS.
As last month's article implied, businesses exist which specialise in helping dental laboratories computerise by supplying software and recommending or advising on the hardware.

In addition to SDS, Claudius Ash offers this facility and has chosen to deal with one of the Apple II series of microcomputers. Ash also supplies, as part of the package, a printer, two disc drives, a monitor (or 'visual display unit'), and software specifically designed for running a dental laboratory produced by Attar.

The system allows work details of a particular patient to be fed into the computer system as it arrives including, most importantly, the completion schedule. A list of the work required for any specific date can be obtained at any time, which the computer compiles in seconds from the patients' files. There is also an end of month invoicing facility which keeps a tally of work completed for clients month by month.

Entering information into the computer is a very similar process as that required for the SDS system (see "The Dental Technician", May 1987). One can use numeric codes to represent clients, technicians, and so on. It has an extra facility to check the amount of material (say, gold) being used in any month and also the output of employees. The micros which the software will run on are limited to any of the Apple II series. The software alone retails at £300 (plus VAT).

COMPUTERISING WITHOUT HELP

The advantages of purchasing from a company like SDS or Ash is that virtually no computer knowledge is necessary. Somebody takes you by the hand and leads you through purchases and operation procedures, and continues to give a certain amount of back-up help.

The disadvantage, of course, is that a great deal of extra payment must be made for such help and guidance than if a laboratory manager negotiated the complexities unaided. It is much cheaper to go it alone and, with a little time and knowledge, it is perfectly possible.

For individuals who choose to take the latter path, purchasing a micro is a topic discussed in a previous issue. For running a business, one will also need a dual disc drive, a monitor (probably monochrome will suffice) and a printer. Obviously, it is essential to make sure that all these items are compatible and will work with each other. There is rarely any problem in choosing a monitor or disc drive with the technology in its present state and it would be safe to rely on a good dealer.

However, as far as disc drives are concerned, we
should note in passing that they are the part of a computer system which stores information on a floppy disc. Discs may be 3.5 inches or 5.25 inches in diameter and disc drives operate one or other of these. The latter are cheaper and most popular and virtually all software is supplied on these.

The 3.5 inch discs are only just coming into their own and have a few advantages but, comparatively speaking, not a lot of software is distributed on these.

PRINTERS

Printers, however, are a little more confusing at this time. For dental laboratory use, computer technology really only reaches its ultimate usefulness when information appears on a piece of paper. To carry out this task, the computer system must have incorporated in it a printer. There is a variety of types, ranging from the low cost dot matrix which can retail at less than £200, to the laser printer which can cost over £4,000.

The former, as the name implies, builds up letters from a series of dots; the latter is the ultimate in terms of performance. It closely resembles a photo copier and works on a similar technology to transfer data from the computer to the screen. It is faster than all but the most expensive dot matrix printers and it is capable of printing text and graphics at such a quality that it is difficult to distinguish the laser printed page from a typeset page.

The laser printer also has a wide variety of “character fonts” (styles of printed characters). Unfortunately, at the moment, one would have to think about paying £2,500 to get one working with a micro. That is difficult to justify for most laboratories.

One of the difficulties of choosing a printer at the moment is that printer technology is changing so fast. Only a couple of years ago, if you wanted speed, you chose a dot matrix. If you wanted quality, you chose a “daisywheel” printer. This third type of printer is much more like a conventional typewriter than the other two and is likewise controlled by the computer.

Now, however, dot matrix printers can produce letter quality print at high speed and the dots making up the letters cannot be seen with the naked eye. The printhead on these so called “letter-quality” dot matrix machines uses much smaller pins to form the dots than other models which only come up to “near letter quality”, or “NLQ”. Thus, it is not as easy as it used to be to make a clear-cut decision between a dot matrix or a daisywheel machine.

Epson is a well-known, from page 7 tried and tested manufacturers which has recently brought out the LX 86 model. This is a low-cost dot matrix able to produce letter quality print but at a slower speed than others at a higher price. It can additionally produce a faster “draft” print where the dots are much more evident. A printer similar to this one or slightly more expensive would be well worth thinking about.

When choosing a printer, noise level should be considered unless there is a separate printer room. Generally, as well as being faster than daisywheel printers, dot matrix ones are quieter, but much depends on the speed, printhead and acoustic lid of a particular model. The message here is to try models under consideration with noise in mind.

There are many buyers’ guides available, magazine style, dealing with computers, disc drives and printers. It would be well worth looking through one or two of these. Relying completely on a dealer who does not know very much about running a dental laboratory might have its drawbacks.

CONCLUSION

There has been some help in this series for those who do not wish to employ a firm to help them computerise. So far we have dealt mainly with purchasing hardware. Decisions do not end at that point and later we shall look at some software requirements.

In fact, hardware and software should never be considered in isolation from each other so, before buying hardware, we shall have to break new ground and get to grips with what is required of software.

Acknowledgement

A very warm thank you to Martin Hamner of Adams’ Conservation Laboratory, Cardiff, for help with this article.
MICROCOMPUTERS IN LABORATORY MANAGEMENT

Part four: databases (1)

Continuing the series by R. J. WILLIAMS, BA, PhD, Lecturer, School of Dental Technology, South Glamorgan Institute of Higher Education

It has been said before that perhaps the best way of choosing a microcomputer system is by studying the software which has been produced for the hardware under consideration. A certain toing and froing between the possibilities in the software list and the hardware list is necessary and this series has reflected such a process to some extent.

It is probably time to study what a dental laboratory would require from what is the most important item of software, a database. Two commercial data management systems specifically designed for running a dental laboratory have been mentioned in previous months: the SDS and Attar systems. Both made extensive use of database systems.

It is possible to manage a laboratory without either of the aforementioned systems by purchasing an “off the peg” database which has been designed to be adapted for the specific purposes of the purchaser.

DEFINITION

What exactly is a database? Strictly speaking, the term “database” should be reserved for the very complicated programs operating on, say, a mainframe computer. Since, however, the term is in wide use with respect to micros, we will swallow our pride and follow suit!

An analogy often used when defining a database is to take a card indexing system. I might have, for example, hundreds of cards in a drawer each storing information about a person — names, addresses, ages, etc. If I wished to access information about one of those persons, I would have physically to hunt through the cards. Not very difficult and quite a simple operation if they were filed alphabetically.

But what if I needed to know how many individuals were under the age of 18? Quite a long and laborious search would have to be conducted. Not so, if the information were entered into a database.

Depending on the particular style of database, all I need do is something along the following lines. Simply type in the question, “How many were born after such and such a date?”, and within a very short space of time, up comes the answer. No sifting through hundreds of cards or taking them out and replacing them.

Very impressive, maybe, but how is this facility applicable in the dental laboratory? It will take this month and next to answer this question fully.

PROS AND CONS OF A SPECIALIST SYSTEM

There are many databases, which can be purchased for any micro, which are not designed for managing a laboratory but...
which can, with a little time and knowledge, be set up to do so. The advantage of purchasing such a database over opting for systems like the Attar or SDS is, predictably, one of lower cost. It is much cheaper to go it alone.

The disadvantage, of course, is that one gets less of a back-up service by way of advice and help with difficulties. Furthermore, perhaps one would not quite end up with what would be a “Rolls Royce” system. It must be remembered, however, that certain aspects of a Rolls Royce are not absolutely necessary.

Back-up facilities are not totally absent when “going it alone” because the dealer who initially sells the software could (or should) be available to help and this is a point to consider when choosing a dealer. Get one who is easily contacted and who has a reputation for after-sales service.

A monthly invoicing system could be set up by way of an “off the peg” database without too much difficulty and, when it comes down to it, that is after all the main component of the systems specifically designed for dental laboratory management.

These, then, are the pros and cons of specialist systems or “off the peg” databases. Naturally, the ultimate choice must be made by the laboratory owner.

SETTING UP A NON-SPECIALIST DATABASE:

To simplify the discussion, we should now define three technical terms. Again, referring to the card index analogy, the whole drawer of cards would be a file, each card would be a record and single entries on each card such as the name or address would be a field.

One of the main problems when setting up a database is in deciding exactly how to organise a file for the specific jobs which will be required of it. This is something the dealer will need to know when giving advice about purchasing a suitable database. For instance, are we going to keep a file of clients and enter the work completed for each one at the end of the day, or what?

Fortunately, in the case of dental laboratory management, a precedent exists regarding the organisation of files and a fairly sensible one at that.

It seems that files should contain records of patients’ work. This gives maximum flexibility, as one is able to fish out much more information than if the file was organised in another way. With this approach, for example, we are able to incorporate completion schedules and address questions to the database such as, “Which jobs must be completed by such and such a date?”

Further, we could ascertain the work completed for each client at the end of each week or month. Hence, one very important problem which our dealer/adviser needs to know has already been solved for us. The dealer will, however, need to know more than that and further problems will be dealt with next time.

CONCLUSION

Choosing a data management system that will best suit the needs of a laboratory will be dealt with next month and we will conclude the suggestions about how to set up an “off the peg” database.
Continuing the series by R. J. WILLIAMS, BA, PhD, Lecturer, School of Dental Technology, South Glamorgan Institute of Higher Education

Last month a discussion on how a database should be organised for managing a dental laboratory was initiated. It was suggested that the organisation should be based around a file of patients’ work. To continue the discussion on databases, it would be helpful if readers could define the terms “file” and “record” which were dealt with in the last issue.

A database for managing a laboratory will need to have, in addition to the file of patients’ work, at least two other files; a file of clients who are simply assigned a number code, and a file of “types of jobs” which should also be numerically coded and priced. The latter file is comprised of simple descriptions, such as “F/C”, etc.

We shall see later that these three files will have to be related to one another so the database must be of the type sometimes referred to as relational. What exactly is meant by this term?

DEFINITIONS

The simplest form of database sometimes has what is known as a flat file structure. Here, each record in a file must have the same structure and the records in a file cannot be related to a different file. Due to this latter aspect, this is exactly what is not required by dental laboratory owners. The alternative is where a file (say, of patients and work completed for them) can have a relationship to a different file (perhaps of clinicians).

So files should be able to have a “many-to-many” relationship. This can be gained from databases sometimes referred to as relational databases. These differences in the way a database handles sets of records is fundamental in choosing an appropriate database and readers of last month’s article will realise that it is the relational type which will be required by a dental laboratory.

THE OPERATION OF DATABASES FOR LABORATORY MANAGEMENT

Ideally, we should have a file of clinicians with records which designate each client a number, and another file which designates items of work a number. It would be excellent if we could then transfer these numerically coded items of work and numerically coded clients to the patient’s record when the work was being booked in simply by entering the appropriate number at the keyboard, and this is possible with the type of database discussed above. Apart from ease at the booking-in stage, the possibility of errors is kept to a minimum.

A further advantage of a relational database is
that the record of jobs carried out in the laboratory can be transferred from a file of patients' work to a file containing records of clinicians, ready for invoicing.

These requirements should be carefully discussed with a dealer who can advise on any possible purchases. The following points should also be borne in mind.

First, the number of records a file can contain is crucial. One way of arriving at how many a laboratory is likely to need is to estimate the maximum number of patients' passing through the laboratory in a month and to double it.

Check with the dealer that the database under consideration can handle that many records. If it cannot, it might be worth considering a weekly invoicing system, even if clients do not receive the invoices until the month is up. Deciding on a database requires a fine balancing between its cost and convenience.

Secondly, check the security system of the database. What would happen if the power was turned off without going through the normal close-up. That is the record of jobs carried out in the laboratory can be transferred from a file of patients' work to a file containing records of clinicians, ready for invoicing.

These requirements should be carefully discussed with a dealer who can advise on any possible purchases. The following points should also be borne in mind:

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Check with the dealer that the database under consideration can handle that many records. If it cannot, it might be worth considering a weekly invoicing system, even if clients do not receive the invoices until the month is up. Deciding on a database requires a fine balancing between its cost and convenience.

Secondly, check the security system of the database. What would happen if the power was turned off without going through the normal close-down procedure (which may occur, for instance, in a powercut)? What if the disc was taken out while the system was still in use?

It should be noted that such issues are not usually a big problem for a dental laboratory since probably the system would not be in use for longer than half-hour periods while each batch of work is booked in. Security on unauthorised tampering, on the other hand, is worth checking out.

These, then, are the main requirements. We should now turn to what we do not need a database to accomplish, since there is little point in paying for powerful applications which are not really necessary.

First, the record structures should not need to be changed once the format has been decided upon, so flexibility on this score is crucial. Further, if one did get a good idea and wanted to change the format of the records during operation, the flow of patients through the laboratory is quite rapid and this means that one could re-define the structure and very soon all the records would be operating under the re-defined format.

Secondly, speed in producing the invoices is not a problem. It can take five seconds or five minutes, since we only need it once a month, or some such occasional time span.

These are points to address to the dealer if his advice is being sought. To conclude this section, a summary of the requirements a database should have for keeping a record of patients' work follows:

1. It should be relational.
2. It should be capable of containing a sufficient number of patients' records in a file.
3. The safety and security mechanisms should be satisfactory.

CONCLUSION

This and the previous article in the current series have been concerned with defining the sort of database necessary for logging patients' work and invoicing clients. Putting a database to work requires a little more knowledge and I hope to deal with this at another time.

However, most of the major problems about how to organise files have been solved in these issues and that is what must be appreciated in order to make a decision about the type of database to purchase.

So far, readers of this series will have quite a good idea about what will be required of hardware and software for microcomputer laboratory management systems. Probably sufficient ground has been covered to enable an intelligent stab at purchasing to be made, provided the help of a good dealer or other non-specialist adviser can be enlisted. All the time it will be necessary to consider which database will run on which machine.

A less important item of software which is useful for dental laboratories is a word-processor. We shall be dealing with this topic over the next couple of months but the good or bad availability of word-processors for micros under consideration is probably not a factor on which to base a purchase decision. On the other hand, the availability of databases certainly is.
Teaching dentistry in the range of the computer

R.J. WILLIAMS, B.A.(Hons), Lecturer, School of Dental Technology, South Glamorgan Institute of Higher Education, Cardiff.

A moment’s reflection will lead one to conclude that the use of using computers as visual aids concerns a much wider audience than one might at first suppose. It interests not only teachers of dentistry but also students and pupils. The arguments developed here are for these students of the dental populous as much as anyone else.

Stananought (1983) pointed out that a great deal of content understanding is needed by students currently involved in dental education. To be even more specific, any of our concepts are concerned with movement. Take, for example, articulation, indirect retention, or the filling noids with material. To teach such concepts, there are at advantages (Footnote) in having moving, coloured graphics on a visual display unit with the teacher able to control movements by simply pressing various buttons. The new technology of computer graphics offers the teacher this ability. This paper (a) urges the wide exploitation of this source, (b) advocates a way for dental educators to proceed in order to maximise the sharing of programs and resources, and (c) concludes by setting out a simple program which illustrates the immense possibilities.

One encouragement for the novice in computer programming is that a competence in graphics is relatively easily acquired, compared to other areas of computer science. Although programs often look long and complicated, once they have been typed (or "keyed") into a computer, they can be stored on ordinary cassettes or disks and loaded into the computer in seconds. Programs are also easily reproduced on cassettes or disks for wide distribution. Once developed, then, programs offer convenience and great advantages in terms of clarity of teaching.

Programs can be displayed on ordinary televisions and large screen is adequate for use with classes of up to 20. For the bigger lecture, it is possible to purchase purpose-built visual display units which have the advantage of possessing a high resolution.

One does not, of course, have to be a computer expert to rate programs. Knowing what certain buttons will provoke is the only necessity for those who simply want to use the teaching aid.

2 MICROPROCESSOR

Though micros are less powerful than the large institutional (or "mainframe") computer, they have a wide range of graphics capabilities, including varieties of animations - enough to keep the ingenuity of dental educators employed for a very long time. They have several advantages over mainframe computers which are as follows:

1. Programs can be recorded on ordinary cassettes and loaded into the microprocessor in seconds without repetitive typing. This provides for a vast cross-flow of ideas in the dental world allowing program swapping between institutions with simple loading and cheap software.

2. Micros can be transported to any classroom and are not limited to rooms with special terminal installations.

3. Micros are always available for use and unlike many of the mainframe computers, need not have time booked in advance. Neither can they become "jammed" with too many other users just as the lesson or lecture is about to begin.

4. The micro is cheap and easily within the budget of dental educational institutions, even in these times of contraction.

UNIFORMITY

The most important point above, point 1, can only materialise if the same microprocessor is in use in all dental institutions. There are grounds for believing that this would happen in dentistry automatically, since the vast majority of schools and colleges have equipped themselves with the BBC "Acorn". This machine has a graphics capability which is far superior to other similarly priced microprocessors and is ideal for the purposes under discussion here. In addition to the beginner’s language, BASIC, it also possesses a machine code offering the advanced programmer smoother and swifter animations.

SAMPLE PROGRAM

The program shown in Figure 5 has deliberately been kept simple and superior animations are possible. However, it is quite adequate for what it demonstrates and though it would probably only take about ten minutes to teach, it nevertheless shows the vast potential of the computer as a teaching aid. It is intended, then, as an exemplar. The program is in the language of BASIC and is written for the BBC "Acorn", model B. It is not the intention here to explain each command in the program (the "Acorn" User Guide, 1982, will do this) but brief details of what is accomplished at some of the lines are provided. Before turning to these, an explanation of what occurs on the screen when the program is run is given.

Footnote

The advantages of visual aids in teaching have been well-documented in many places. (See, for example, Romiszowski, 1982.)
"Lost Wax Process" Program

1. A diagramatic representation of the crucible is on the left of the screen. On the right is the wax pattern of a clasp, sprue surrounded by investment material in cross section.

2. The space bar of the keyboard is depressed, the red wax pattern disappears ("burns out") and the gold nugget appears in the crucible.

3. The space bar is depressed again and the gold moves through the crucible, travels across the screen, and fills up the mould (Fig. 4).

4. The space bar may again be depressed to re-run through the program and the explanation of the "lost wax process" repeated.

THE PROGRAM

SAMPLE PROGRAM

```
10 MODE 1
20 VDU 19,3,3,0;
30 VDU 19,2,7,0;
40 VDU 5
50 GCOL0,2
60 MOVE 400,400: DRAW 400,460: PLOT 85,370,460:
    DRAW 370,400: PLOT 85,400,400: MOVE 400,570:
    DRAW 400,650: PLOT 85,400,570: MOVE 400,400:
    DRAW 150,400:
70 FOR X%:300 TO 620 STEP 10
80 PROCG
90 FOR F:0 TO 200:
100 NEXT
110 MOVE 620,505
120 GCOL0,3
130 VDU 243,11,8,241,240,10,8,242
140 IF GET=32 THEN 110
150 C=0
160 PROCFILL
170 IF GET=32 GOTO 10
180 END
190 DEF PROC PLOT
200 FOR A=-PI/10 TO PI/10 STEP PI/30:
210 DRAW S%:40: MOVE 680 TO 850 STEP 10
220 NEXTA
230 VDU 29,890;51,0;: S%:40:
240 NEXTA
250 ENDPROC
```
TEACHING DENTISTRY IN THE AGE OF THE COMPUTER

EXPLANATION

Lines 20 and 30 change the colours to the ones required.
Line 60 draws the crucible.
Line 70 draws the investment block.
Line 90 calls up a procedure (PROCFLFILL) which is
fined at lines 500 to 640. It gives the shape of the wax pat-
and sprue which can be changed to any colour.
Lines 130–160 define four characters which, when
ented together, give the irregular gold nugget.
Line 200 allows us to press the space bar to set the gold in-
ion by calling up a procedure (PROC) defined at line
1–430.
Line 320 calls up PROCFLFILL again in the colour of
low (line 310) to give the appearance of the mould filling
with metal.
Line 330 allows the program to begin again when the
ice bar is pressed.

INCLUSION

It is hoped that this discussion will broaden, giving access
ty many excellent teaching aids, some of which might
otherwise be unobtainable. (It would, of course, be
extremely difficult to film the event shown in the program
presented here.)

It is widely known that young people have an imagina-
tion well suited to the development of computer software
and so, it is hoped, the consumers of the product (the
students) will have much to contribute.

BIBLIOGRAPHY


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My thanks are due to my wife, Christine, for her untiring
help with the development of the program; Mr N.T. Somes
for his photographic contributions, and Mr K.W. Phillips
for commenting on a draft of this paper.
This paper is an empirical analysis of the way in which a group of scientists sought to maximize the attractiveness of one of their papers. It records negotiations about the title, the introduction, and the second paragraph (in which a polymer was characterized). The analysis suggests that scientists array or ‘network’ particulars in a way which they hope will allocate appropriate relative value to elements of that array. In doing so, three factors — the citation of colleagues, the display of facts, and problems of syntax — have to be simultaneously juggled.

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**Putting Facts Together:**
**A Study of Scientific Persuasion**

John Law and
R.J. Williams

_Watt:_ What was interesting to you in our last discussion?
_Williams:_ What would be publishable, how that affects what you do.
_Watt:_ But I think it's the same question as what is valid and meaningful. I don't think it's a different question.
_Morse:_ I think they both occur when you reach a set of conclusions.
_Gladstone:_ They're a combination of results and... getting more money for the next research! (Interview, 25 May 1978)

_This paper describes_ and analyzes a discussion that took place between two groups of scientists about a joint publication. That publication was on the capacity of a particular family of polymers, DIVEMAs, to stimulate the uptake of substrate by cells; it reports that, contrary to widely held views, DIVEMAs have little or no effect on such endocytic activity.

The two groups in question were ideally placed to study the effect of DIVEMAs on endocytosis. DIVEMAs are difficult to synthesize, but one of these groups (which we call here 'Stiftung') had specialized in their preparation. Stiftung was a German group of polymer chemists, represented here by two scientists, 'Gladstone' and 'Disraeli'. Disraeli was the relatively junior research fellow who had done most of the synthesis. Gladstone was the Director of Stiftung, and was in overall command of the programme of synthesis. The other group, a British biochemical laboratory which we call 'Chinatown', had developed a technique for measuring the rate at which a particular form of endocytosis — that of pinocytosis — takes place. The technique had originally been developed by 'Watt', the head of the laboratory, and others. In the present work, however, the actual experiments were undertaken by research fellows — 'Dover' and 'Smith'. The progress of the research, then, was as follows: DIVEMAs were synthesized at Stiftung, and sent to Chinatown. Dover and Smith measured the extent to which such DIVEMAs affected pinocytosis. Though the results were not all publishable, overall the Chinatown workers concluded that the DIVEMAs in fact had no marked stimulatory effect on uptake. This was a result which they had expected, as earlier experiments by the group with similar polymers had revealed no stimulation. The expectations of the Stiftung workers had, however, been somewhat different. On the basis of claims made by 'B', a polymer chemist working in America but well known to the Stiftung personnel, the latter had anticipated that there would be some positive effect. After discussion, however, the Stiftung workers accepted the conclusions of the Chinatown group in the area of pinocytosis, and readily agreed to coauthor a paper reporting the negative result. In any case, the experiments by B had concentrated on blood clearance rates — not a direct measure of pinocytosis — so the difference between B's results and those of Chinatown were open to reconciliation.

In an earlier paper we described these events in greater detail. Here we report more fully on the discussions that took place between members of the Stiftung and Chinatown groups concerning the paper that arose from this research. The meeting from which most of the data is taken took place in Germany at Stiftungburg in December 1978. Dover and Smith had prepared a first draft, and it was this draft that served as the basis for discussion.

Our concern is to explore what is entailed when a scientist (or a group of scientists) attempts to produce a paper that will have max-
imum impact. Most analyses of the scientific reward system, whatever their other differences, assume that in general scientists attempt to maximize their standing in the community by offering a product that is attractive to, and usable by, other scientists.² The product must be perceived by other scientists as having use value. It must be seen as both reliable and relevant. But the perceived reliability and relevance of a product is not something that is independent of the way in which it is presented. Consequently, scientists take great care to present their products to maximum effect. Like those who attempt to sell products in other areas of social life, scientists undertake a version of market research. They assess the likely value of their product to this group or that. They design the product in such a way that its value will be as clear as possible to potential users. They package and place it with the same considerations in mind. They act, then, in many ways like entrepreneurs who combine resources to generate a product that will ensure an optimum return.

Though such a marketing metaphor is useful, we do not wish to be seen as driving a wedge between the product — scientific knowledge — and its literary packaging. Our position is that the structure of bits and pieces in a scientific paper — a structure naturally influenced by market conditions — itself helps to constitute the structure of knowledge, the status of the facts, and their relationship with other findings.

We may now pose the basic question addressed by this paper: what is it that scientists are doing when they attempt to construct a scientific paper in such a manner that it is usable? The following suggests itself as a provisional answer: they are trying to array people, events, findings and facts in such a way that this array is interpretable by readers as true, useful, good work, and the rest. We may say that they are organizing bits and pieces. That is, they are attempting to structure and juxtapose elements in such a way that any interested reader will find himself compelled to interpret them in the manner desired by the authors.

Let us hasten to add that we use the word 'compel' ironically. No text can compel a particular reading. The relationship of the speaker/hearer to a set of juxtaposed particulars is active, not passive. The particulars are, in all cases, used as a resource upon which a variety of interpretive networks of significance, value, or meaning may be imposed. Properly speaking, then, in the way in which we use this term, a network is a state of mind or interpretation, and not a property of a set of particulars.³ Networking is the
work done by actors in imposing an interpretation on an array of particulars. The production or organization of a text is thus not synonymous with networking in our use of the latter term, though it naturally depends upon it. Our argument, then, is that scientists, when they write a scientific paper, juxtapose particulars in order to develop an array that is particularly susceptible to networking as a case of good or 'compelling' work.

Our analysis rests, of course, upon *verstehen*, and it naturally follows from the above argument that our own interpretation of the data is but one of many. Since no final defence of our reading of the material is possible, our analysis has pragmatic force only. Practically we have tried to ensure that our interpretation is consistent with an active model of agency on the one hand, and the actors' own understanding of events on the other. We do not, of course, wish to suggest that our subjects are in complete agreement with what follows. They sometimes feel that our selection of material is partial or, while conceding that our descriptions are accurate, they prefer alternative explanations. However, on matters of fact — including interpretations of motives — we have been able to achieve a workable agreement with them. This seems to be as much as one could hope for.

We would like to make a final theoretical point before turning to the analysis. Networking, which involves the allocation of significance to particulars, is a holistic or relational activity. That is to say, significance or meaning can only be allocated to an element by putting it next to, and seeing it in relation to, other elements. The intension and extension of the term ‘fish’, for instance, depends in part upon those of such adjacent terms as ‘mammal’ or ‘whale’. When links are forged, then, we may say that these are links of *relative value*. Thus, the writer of a scientific paper may attempt to assert that this scientist is worth this much, that fact worth that much, and so on. The claim that relative value is being asserted does not, of course, imply that there is one or more currency in terms of which the particulars may be measured. Rather, the notion of a currency *depends* precisely upon the imposition and stabilization of value across a number of particulars. Most of the time such stringent conditions are not collaboratively achieved. However, even with a simple comparative notion of value, where quantification or ordering are not possible, we nevertheless suggest that interaction, including scientific interaction, may be seen as a struggle to impose value. A scientific paper is a set of juxtaposed particulars susceptible to networking in a variety of ways by its readers. The
aim of the author is to propose a value for the paper, a value for himself, and a value for the bits and pieces so juxtaposed. It proposes a reality in which events, facts, and scientists have their place. Power in science, as elsewhere, comes from the successful capacity to create and impose value. And it is for this capacity that scientists struggle when they write a paper.

Title and Opening Paragraph

The title of a paper is obviously of great importance. In terms of the marketing metaphor, we may say that it constitutes a vital part of the packaging. It is designed to alert potential users, to persuade them that this is a valuable product, one with which they cannot do without. The scientists that we studied were naturally aware of this. Before the British scientists visited Germany to discuss the final draft Watt already had a title in mind:

_Watt:_ I wonder if this is [a] case for going for one of those snappy titles...that says 'DIVEMA derivatives do not stimulate pinocytosis.' You know — sort of summarizing the result. I don't know if _Cancer Quarterly_ go in for that sort of thing.

_Dover:_ Do you mean [the title] as a question?

_Watt:_ No. It's a statement. A summary of the result. It's one way of doing titles. Because they are quite right. It's the title people notice. We'll have to think about that. (Recorded: discussion, 23 November 1978).

Watt’s suggestion was adopted in essence, and the title suggested by the Chinatown group to their Stiftung collaborators in December was ‘Failure of DIVEMA (Pyran Copolymer) to Stimulate Pinocytosis’. This suggestion was adopted with acclaim. Thus, Gladstone commented:

_I like it. Its nice and aggressive! (He laughs.) It's perfectly okay with me. I like it (76-77)\(^7\)_

If the title is crucial, the introductory paragraph also forms a part of the packaging. The reader who has got as far as to pick up the publication must be persuaded that it is, indeed, usable. His interest must be engaged. The first few sentences must construct a context with which the reader can be allied. The authors of the DIVEMA paper are well aware that this is the case. As Gladstone put it:
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Everybody knows [that]... pinocytosis is supposed to [be stimulated]. This is described very nicely in the first part which is interesting. (35-37)

Consider the first paragraph of the British initial draft. The aim is to mobilize those with an interest in chemotherapy. An array of claims and hypotheses about DIVEMA and its compounds is so designed as to be attractive to those concerned with the chemical treatment of cancer. DIVEMA (or so this version of the literature suggests) has anti-tumour properties. But — and here is the crucial question — what is the mechanism of this activity? The work by ‘R’ suggests that DIVEMA stimulates phagocytosis. The work of ‘P’ (who is a collaborator of Gladstone’s) points in the same direction. However, the paragraph suggests that a gap remains to be plugged: ‘the effects of DIVEMA on endocytosis are therefore of further interest’. The paper is designed to pursue that interest and, indeed, to show that DIVEMAs have no effect on endocytosis.

Our point, then, is that by suitable juxtaposition of scientific particulars a case has been made for the paragraphs that follow. An array has been built that offers the reader a resource upon which to build a network; and it is this network which constitutes a context for the paper. What is more, a further array of actors — other scientists — has been simultaneously constructed. Findings and individuals are thus portrayed in a particular relationship to one another, and the reader is asked to allocate comparative value. The array that provides for this double imposition of structure is depicted in Figure 1. The overlapping claims made in the different papers are indicated in the figure by hatched lines.

In the course of discussion, adjustments to this array take three forms. Firstly, they involve citation: who should be tied into the potted history of the area, and how this should be done. Secondly, they affect substantive matters of scientific knowledge: the relationship and relative value of facts, events and findings in the area. And thirdly, they have to be done in grammatically and stylistically acceptable ways. In practice, of course, since each sentence involves all three dimensions, these cannot be disentangled. We start, however, by considering two adjustments to the array of citations, before considering the way in which they interact.

Gladstone, pointing to the reference to P et al. (1978) on line fifteen of the draft, comments:

I would use another publication here — because this publication is still not out. But we have...

Watt: Which one? The 1978 one?
Gladstone: Yes. . . . But I think that you should also cite the one publication [that is] out, which is the synthesis of all the compounds, and mention . . . the result [in one line].
Watt: Uh huh.
Gladstone: Because then [the audience] have something that they can look up. (111-20)

A few lines further on, Gladstone intervenes again:

The only point where I would hesitate [about] what’s been said is that I think we should try to get ‘C’ into the game. (129-30)

This further proposal to alter the array of scientists leads to the following exchange:

Watt: Fine. Isn’t [C] quoted anywhere? Don’t we quote him? What’s he done?
Gladstone: . . . C is reactivating what . . . happened five years ago. The whole DIVEMA . . . story [developed with] B [who] was against R who was overdoing it. [R] pushed into the clinical stages much too early.
Watt: Yeah.
Gladstone: A lot of very difficult problems arose so everybody said ‘Let’s get away from DIVEMA’. And C in his experiments [has] more and more brought it back. So I think it would be unfair to the C group not to cite them. (131-41)

And a little later in the discussion, still on C, we find Gladstone looking through a pile of possibly relevant offprints:

What he is really [examining] is the immune potentiating effect, and this is very successful. This is one of the papers I think we should cite, and there’s another one; ‘Macrophage Activation by Poly-amides’.
Watt: But is this all about DIVEMA?
Gladstone: [Yes].
Watt: Is it?
Gladstone: Yeah. [This] may be more of a review . . . This may be pyran. (He points to offprints.)
Watt: And that’s DIVEMA as well, is it?
Gladstone: That’s DIVEMA as well. Here, if you wish . . . Its not that I want to bring somebody in . . .
Watt: Oh, it’s most important to put these people in. Yes.
Gladstone: He’s the one that . . .
Watt: Yes. We must put B in, though. That’s the most important, isn’t it? (154-68)

These excerpts are of interest for the light that they shed on the way in which Gladstone and Watt discuss the links that are to be suggested between people and events in the paper. They show that each
FIGURE 1
The 'Initial Array'

**SUBSTANCE**
- DIVEMA
  - is a synthetic anionic polyelectrolyte
- DCM
  - is divinyl ether maleic anhydride

**METHOD OF UPTAKE**

**BIOLOGICAL ACTIVITY**

**METHOD OF STUDY**

- Inhibits phagocytosis two days after injection
  - Stimulates phagocytosis threefold six to eight days after injection
  - Effect on immune response/reticuloendothelial system
  - Blood clearance of colloidal carbon, lipid emulsion and $^{51}$Cr-red blood cells in mice

- Anti tumour
  - (B:1976)

- Anti bacterial
  - (B:1976)

- Anti viral
  - (B:1976)

- Ability to activate macrophages
  - (B:1976)

**3**
- DIVEMA-methotrexate complex (stronger effect than methotrexate)

**4**
- Methotrexate
  - Active, carrier-mediated transport (G:1971)

For explanation, see text.
NB: Methotrexate is an anti tumour agent used clinically.
of the discusants has a clear conception of the sort of links that have to be made, and values allocated, in order to produce a paper that is as acceptable as possible. The first excerpt shows that the standing of the paper is thought to rest in part upon the citation of papers that have already been published and can thus be presumed to be at hand for the readers. The second, third, and fourth excerpts involve the production of an account of the relationship between C's work and that of several other authors. C's work is ascribed high value because of its relationship to that of R, who was 'overdoing it'. A failure to cite C, who has 'brought DIVEMA back', would be unfair. It is altogether too valuable to be ignored. Not only would this be unfair, but since C's work emphasizes the anti-tumour activity of DIVEMA, the matter is of direct relevance to the present paper: it adds value to the finding that DIVEMAs do not stimulate pinocytosis. Finally, though Watt appears to know relatively little about the content of these papers, he can be seen as attempting his own assessment of their value in the present context: 'What's [C]... done', he wants to know. And later he asks, 'But is that all about DIVEMA?'; and again, 'And that's about DIVEMA as well, is it?' For Watt, valuable citations are those that have something to say about the relationship between endocytosis and DIVEMAs. B says that DIVEMAs stimulate phagocytosis. It is presumably for this reason that he says, 'We must put B in though. That's the most important, isn't it?' In the present context both Watt and Gladstone have a clear idea about how to allocate value to papers, past research, and authors. The aim — and here we are back with our metaphor of packaging a product for market — is to mobilize those with an interest in chemotherapy. An adjustment to the initial array (see Figure 1) is being negotiated which suggests a somewhat different allocation of value. It assigns worth to additional authors. It depicts past research both recognizably and usably.

So far in this section we have considered adjustments that affect authors alone. As we noted earlier, changes also involve both substantive matters and literary style. We now consider these, again by way of an analysis of the discussion of the first two sentences in the opening paragraph.

Disraeli: We should mention [B's]... paper and then we can go on with the primary effect on the immune response. Because here we have the link between the others and the immune response. After the first sentence we could add
another sentence where we say that the [investigation] of DIVEMAs as an immune stimulator is still in the clinical stages. And that there are new directions...

Gladstone: I would put it in here. Because here you have R. Then you could say, 'Investigations by the group of C and co-workers [examine] DIVEMA as an immune potentiator', and then we could cite two or three papers.

Watt: Okay. So we leave the first two sentences the same.

Gladstone: I would leave them as they are.

Watt: Let's just look at that first sentence. It's accurate, is it?

Gladstone: (reads) Yes. I would leave that.

Watt: This is a very general paper which includes all that.

Gladstone: Yeah. This was a talk B gave and [which] was published. (Reads) '...the immune response was investigated by R and co-workers...'. I would say...

Watt: Wait a minute. The next sentence is about R still.

Gladstone: Oh, 'They examined...'. Yeah.

Watt: Perhaps after that one, do you think?

Gladstone: After 'the six to eight days'?

Watt: That's right. What do we want to say?

Gladstone: Here you have to cite C.

(Pause)

Watt: Well, do you want to work out what to say now? Is that easy, or is it better...?

Gladstone: No. It's not so easy.

Watt: Leave that a moment, then. We could even leave that for you to write as an extra sentence.

Gladstone: We can do it today, no problem;

Watt: Right, fine. Okay.

Gladstone: The first thing we have to do at the moment is [include] the C papers.

Watt: Okay. So that's there.

Gladstone: One to two sentences.

Watt: It'd better not be too long, otherwise this'll be too long for a 'short paper'.

Gladstone: No, no. One to two sentences. (172-209).

And, indeed, the final draft includes an additional sentence prepared by the Germans in an unrecorded discussion. There is no ideal way of presenting the drafts through which the authors have moved in the course of this discussion. Instead, we content ourselves with a diagrammatic representation of the final draft (Figure 2) which may be compared with the initial draft (Figure 1).

In the course of this discussion, arrays of particulars are being proposed, considered and disposed of in short order. To pass, they must be structured adequately in terms of the three sets of considerations we have already mentioned. Facts and events have to be placed in a proper relationship with one another. People must be placed relative to one another — and, of course, to the facts and
events. And thirdly, literary conventions about what goes with what have to be considered. Much of the juggling that is going on here can be seen as an attempt to find a proper literary structure as a result of making decisions that alter the suggested links between people and events. Thus, as a result of the discussion we outlined in the previous section, the collaborators have decided to add further citations to the original text (S et al., 1977a, 1977b; S, Q and C, 1977). Though we cannot show that this is what concerned the authors (for there is no revised text at this point), it would appear that they think that there is a danger that this introduction will upset the balance between particulars already in the array. It implies, for instance, that the work of C and his collaborators has the same significance as that of B. We have already seen that Gladstone values the work of C more than such a joint citation would suggest.

As a way out of the impasse, Disraeli suggests the introduction of a new sentence (lines 172-79 in the transcript) which links these additional individuals to a proposition about immune response. At the same time he sees this as providing a convenient (literary) link between (original) sentences one and two. But both Gladstone (180-84) and Watt are concerned about literary imbalance. Events do not flow smoothly and ‘follow on’ from other events in the account. Statements about the work of R and his co-workers are separated from one another. This, then, is our first point: in the process of constructing an array — of juxtaposing and suggesting a value for particulars and persons — the value proposed for one such person or event is a function of its position in that array. The reader is being asked to network the particulars in a given manner — a manner suggested (though not, as we have seen, dictated) by the array. The aim is to upgrade C and his collaborators. It is proposed that their work has higher value. They are getting a sentence for themselves. The final draft suggests their value in a way in which the original version did not. There they were (if we might put it in this way), mere appendages to B, tacked on as an afterthought. In the final draft they were specified as showing that DIVEMAs activate macrophages to cytostatic behaviour against tumour cells in both in vivo, and in vitro systems.

But (and here is a second point which is nothing more than the obverse of the first) the rise in the value of C — suggested, as we have seen by inclusion of detail about his experiments — has a knock-on effect for other events and authors. As we suggested in the opening section of this paper, the lesson is general: disturb one
part of an array, and this is likely to disturb the interpretive network, and thus the value of adjacent parts. Drop a stone in a pool and ripples spread out from the point of impact. B originally led a list of citations. Now he is somewhat overshadowed by C and others. And a new context has been provided for the sentence that follows about the work of R and M. It is proposed that the latter should now be seen somewhat differently. We know, from our earlier analysis, that Gladstone sees C as ‘bringing back’ DIVEMA in the face of R’s earlier and premature clinical work. R is put in his place: his work is older, and now it has, perhaps, been overshadowed somewhat by that of C — at least in this presentation. The general point here, then, is that value is relative, relative to the position of the valued object in a network. Alter other parts of a network, and the value of the object that is of interest varies too. Since an array provides a resource for the construction of a network, changing that array affects the value of the particulars it displays.

Let us recall that the array of particulars that goes to make up a scientific paper is designed to persuade the reader of its accuracy, adequacy, truth, and utility. Our suggestion is that a reader comes to a paper with a large number of interpretive links lodged in long-term memory, and a set of motives or concerns. The array of particulars provides a resource for the construction of an interpretive network on the basis of memory and these motives and concerns. What is it, then, about an array that constitutes its persuasiveness? The general answer is that it must generate a network that is perceived as a recognizably accurate picture of the field. If the reader looks at the paper and thinks ‘this is unfair’, or ‘these authors do not know the literature’, then he has a reason for discounting their findings. It follows, then, that a persuasive presentation requires not only that the reader be interested in the findings reported. It also requires that a recognizably adequate context be constructed. Structuring a written array in such a way that a paper attracts credibility is thus a delicate balancing act: one needs (as we have already noted), to design a context that makes one’s own paper important and something that the reader does not wish to put down. On the other hand, one also needs to mention, structure, and propose a value for, the particulars which form a part of that context in a manner that is recognizably fair and reasonable from the standpoint of the reader. Where the writer succeeds — he is able to guess the relevant concerns and likely interpretive networks of the
reader — then the latter will be drawn into the argument. Where he fails, then, of course, the paper fails.

What is a DIVEMA?

For our second empirical example we turn to the discussion between the collaborators of part of their second paragraph — and, specifically, to their negotiations about what to say about the chemical structure and properties of DIVEMA. Here again, three problems require simultaneous solution: what should be said about DIVEMAs? Who should be cited? And how should this be presented in acceptable literary form? The structure and characteristics of DIVEMA lie within Disraeli’s area of competence. It was he who did the necessary chemical work on the basic DIVEMAs in order to make a number of the derivatives which were subjected to test by the Chinatown group for their effects on pinocytosis. Accordingly, Disraeli produced a draft at this point which filled out and substantially altered the British initial draft. For reasons of space we will not present Disraeli’s draft and the subsequent discussion in full. Rather, we will content ourselves by listing the main features of Disraeli’s proposed description of DIVEMA:

1. Presentation of molecular weights. (The British had included some of these, but an error had crept into the figures. They thus required correction.)
2. A chemical description of DIVEMA.
3. A chemical description of DIVEMA derivatives.
5. An indication of the source of origin of the DIVEMAs — which had, in fact, been sent by an American chemical company (which we will call Bio-Co) to Stiftung.
6. A clear indication of the Bio-Co designation for each of the unmodified DIVEMAs.
7. The citation of an author associated with Bio-Co (we will call him X) who had written widely about the synthesis of DIVEMAs.
8. An outline of the chemical and biological properties of the DIVEMAs: hydrophobicity, toxicity and solubility.

Perhaps unsurprisingly, Disraeli (and, to a lesser extent, Gladstone) felt that this section of the paper should be somewhat longer than suggested in the British initial draft:
Disraeli launched into the list outlined above. All the authors were, however, aware that space was at a premium, for in earlier discussion they had agreed to send the paper as a ‘Short Communication’ to Cancer Quarterly — and they were thus limited to a maximum of 1,500 words. Dover, for instance, voiced the view that space was short:

I think we're going to have to be careful about the number of tables and figures... It may be that we can't put it in a short paper.

Watt: Well, let's see what we would want ideally, first. (261-67).

The result was practical pressure (for reasons of space) on the size of the array that Disraeli might make — and, more particularly, on the way in which this might be presented. A ‘Short Communication’, they had earlier argued, would lead to quicker publication. Thus Disraeli’s description of the preparation of DIVEMA derivatives (number 4 in our list above) was eroded. He started by suggesting:

Here we have examined the effect of these different DIVEMA derivatives prepared by esterification of anhydride-containing DIVEMA in N-methyl pyridine as a solvent. (269-72)

This was whittled down to the final draft:

The DIVEMA derivatives 4-6 were prepared by reaction of a DIVEMA anhydride form... with different alcohols.12

The array was simplified, and the number of suggested links cut. Furthermore, this was not the only place where Disraeli’s suggestions were defeated. For instance, his discussion of the toxicity of the molecules was lost (part of 8 above), though the hydrophobicity and insolubility of one of the polymers is mentioned at several points in the text.

Why were those suggested links defeated? We have already given
one reason: space was at a premium. But this is not a full answer, because other particulars suggesting links, connections and values are retained. The answer is, of course, that overall the authors did not feel that such details enhanced the standing of the paper. Perhaps this was because the paper was being directed at an audience of chemotherapists. Polymer chemists care about the way in which polymers are synthesized, but chemotherapists are presumed to be more concerned with their biological effects. It is with this thought in mind that we turn to the presentation of the remaining facts about DIVEMAs.

Most of these were put into a Table located at the appropriate point in the Introduction. This is an economic presentation of what were taken to be salient features of the DIVEMAs tested in the collaboration between Chinatown and Stiftung. Attributes (1), (2), (3), (5), (6) and (7) from the above list end up in a single Table. Why is this array required? Why do molecular weights, chemical descriptions, sources, company designations and citations need to be piled up upon one another in such a manner? Is this not a case of overkill? The Stiftung reasoning behind this list is quite clear: they want to be sure that their readers know exactly which chemicals they are talking about:

Disraeli: I would suggest [that we] give the compound's current number, [to which] we can refer in the text, and [in the Table] the number of the DIVEMA which they give it in the Bio-Co, so everybody knows which DIVEMA it is.
Gladstone: We could have here...cite X, because then everybody can look up other papers.
Dover: These are the DIVEMAs X used?
Gladstone: Yes, they are. Yes.
Watt: Oh, that's good, isn't it?
Gladstone: Those are not just the compounds. They are some results so everybody can compare it. But we have to make this clear by a footnote saying these are the expressions used by X from the Bio-Co. (303-15)

The aim of this organization, then, is to persuade the reader that the results of this paper are directly comparable with those of X. It is also designed, so far as possible, to ensure that a reader who wishes to enter into the DIVEMA field knows exactly how his efforts relate to the work of the Stiftung-Chinatown collaboration, and that of X. This too, then, is the construction of an array designed to evoke a particular interpretive network in the mind of the reader: it is an attempt to propose as unambiguous as possible a
link between the present work and other past and future reports. It is designed to maximize comparability. Correspondingly, it is designed to maximize the adequacy of the paper with a particular audience — one that has followed the past work of B, X, C and others on the endocytic effects of DIVEMA. It is designed to stop audiences shrugging off the negative findings presented in the present paper by saying ‘Well, they were different DIVEMAs, weren’t they?’ The danger of such a reaction is very real, of course, amongst those who have accepted the notion that DIVEMAs stimulate uptake. Their own status is clearly related to this claim. And, given the complexity of DIVEMAs and their derivatives, such an escape route is easy. This is because there are endless possibilities for explaining the apparent discrepancy by talking of ‘differences’ between DIVEMAs. A minor example of terminological confusion appears in the course of discussion between Watt and Gladstone:

Gladstone: Could you say that: ‘DIVEMA samples’?
Watt: This is what we wanted to ask you about because we felt we wanted to be consistent about this, because we’d noticed that in this paper we’d sometimes used the word ‘DIVEMA’ to mean just DIVEMA, and in other places we’d used it to mean the copolymers as well as the er...the modified [form]. It isn’t really a copolymer, is it?
Gladstone: No, no.
Watt: It’s the same backbone with extra bits stuck on.
Gladstone: It really means copolymer — chain polymer — because if you have different units you can look at them as units on a chain.
Watt: You can, yes.
Gladstone: Use ‘DIVEMA and DIVEMA derivatives’.
Watt: I’d thought of the word ‘copolymer’, but ‘derivatives’ is better. (287-301).

Here a minor matter of detail is rapidly clarified. However, such a lack of detailed chemical knowledge might well be endemic among chemotherapists who are not, after all, first and foremost polymer chemists. This is why such a dense array is constructed around the term DIVEMA in the present paper. The status of the paper rests in part upon a clear understanding of precisely what kind of polymer it is about.

Discussion

We have considered a small part of a long series of discussions bet-
ween five collaborators that led to the submission of a scientific paper on the biological effects of DIVEMAs. Our analysis has highlighted certain features of such negotiations: specifically we have outlined the manoeuvres undertaken by authors in their attempts to maximize the chance that their paper will be well received. These authors had decided that the paper should be sent to a cancer journal. Accordingly, they devised a title and an opening paragraph for the paper that was designed to display its relevance to chemotherapy. The substances tested were characterized in such a way that those who have worked on, or are committed to, DIVEMAs would find the results difficult to ignore by arguing a lack of comparability between the Stiftung-Chinatown work and their own.

In their attempt to elicit a satisfactory reception for their paper, we have described the way in which our subjects have constructed an array in which events, findings, people, facts and titles are optimally juxtaposed. These scientists, like all other actors, can be seen as creating resources structured in such a way as to induce readers or hearers to network them in an appropriate manner, ascribing high value to the array itself, low value to facts that are held to be false, high value to the assumed truth, and so on.

In the context of the scientific paper, we have detected three dimensions in which such arrays are constructed. They tie together objects and facts. They tie together people. And they tie them together in a manner that is stylistically and grammatically acceptable.

The construction of arrays and the interpretive networking to which it contributes has a number of implications. We will briefly underline some of these by indicating the relationship between our analysis and three other strands of thought in the sociological and philosophical literature. The connection with ethnomethodology is, of course, obvious. To say that the value of a term depends upon its position in an interpretive network — a network of which it, itself, forms a part — is to point to what the ethnomethodologists call indexicality and reflexivity. More generally, to argue that the construction of arrays and the consequent networking underlies the production of knowledge is to assert that active sensemaking practices are matters of routine for human beings; indeed, it is to offer an avenue through which to investigate such practices.

Secondly, and here we are pleased to make an important intellectual debt explicit, the notion of networking grows out of Mary
Hesse's powerful network theory of scientific knowledge. The connection is of great importance, because Hesse's theory offers a formidable range of rigorously developed resources for the analysis of scientific knowledge. We cannot do more than touch upon these here. First, let us remember that her theory proposes that both the extension and intensional reference of a term relates to its position in a network. Secondly, she argues that, though certain terms are more firmly entrenched than others, none are immune to change. Thirdly, she suggests that disturbance at one point in a network is liable to affect the meaning of terms elsewhere. Unsurprisingly, we have observed all of these phenomena in the course of our analysis of the Chinatown-Stiftung negotiations. But fourthly, and most important for our present purposes, she discusses the role of coherence conditions — those principles which structure networks. She takes the view that some of these are psychological. Others, however, are social. She has little to say about the operation of the latter, but this, of course, is the job for a sociologist and not a philosopher. Our attempt to understand networking by looking to the motives of the scientists, as well as to their cultural resources, is an example of the way in which the sociologist might go about understanding the operation of social coherence conditions. We have repeatedly noted the way in which discrete bits and pieces are juxtaposed and proposed to have a relative value. Such networking has always been directed by a concern with the optimum reception for the paper. But it is in this concern with juxtaposing and valuing that we come to our third intellectual resource — the sociological writing of Michel Callon. Drawing on the work of Michel Serres, Callon has made use of the notion of translation in an analysis of a French science policy initiative:

To say that problems $P_1$, $P_2$, $P_3$, ..., can be related together is to suggest (a) that there is a set of related meanings shared by problems that were previously posed in different terms, and (b) that the solution of an overall problem depends upon its movement through a series of different modes of presentation. The term 'translation' corresponds exactly in meaning to this. Understood generally, translation postulates the existence of a shared field of meanings, preoccupations, and interests... If it conceals the existence of divergences and irreconcilable differences, it nevertheless affirms the underlying unity of distinct elements. To translate is to create convergences and homologies out of particulars...
For Callon, science is a struggle to impose translation: to allocate value to groups, individuals and facts as part of a larger organization. So it is for us. The construction of arrays is an attempt to suggest appropriate networks. Persuasion is a tentative matter, a constant attempt to propose a set of interrelationships and values. We have seen that the production of an array does not ensure its acceptance. This depends upon a balancing act. He who attempts to impose a structure must make his array plausible, realistic, and usable. He must relate his array in a satisfactory manner to the cognitive preferences of his readers. And here, of course, is the payoff: our analysis allows us to think simultaneously about knowledge and interests. The spoken and written arrays are but the tip of a complex but largely concealed structure of interpretation. Most of this is hidden from view. All scientific papers, therefore, suggest a branching set of connotations. Scientific words mean this. They connect with other terms which also have extension and intension, terms which are not mentioned at all by either writer or reader. Again, citations, as our American colleagues have shown, lead to an endless network of scientific papers and authors. Further tacit meanings and connections are proposed here. For the most part, then, the structure of such networks — whether of speaker or of hearer — is not given in the speech or the writing. It is the mistake of much discourse analysis to ascribe power to the words themselves. It is rather people who operate with, and alter, these networks. It is through their networks that they structure and give expression to their interests. Hence, both persuasion and power depend, in the last instance, on the capacity of whoever seeks to control, to align his array with that of the hearer at valued points. And this, in their own small way, is exactly what our British and German subjects were trying to do as they drafted their paper.

**NOTES**

We would like to thank all those who commented on earlier drafts of this paper, including, especially, Michel Callon, Karin Knorr, and an anonymous *Social Studies of Science*. 
of Science referee. However, we owe a double debt of gratitude to our ‘Chinatown’ respondents, who allowed us to tape record their conversations over a long period of time, and then contributed constructively to the drafting of this paper.


3. That this is so can be seen for the present case in Michel Callon and John Law, ‘On Interests and their Transformation: Enrolment and Counter-Enrolment’, *Social Studies of Science*, Vol. 12 (1982), 615-25, where the rejection of the paper in question is briefly discussed; see also John Law, ‘Luttes autour de la publication d’un article dans un laboratoire de biochimie’, *Social Science Information*, forthcoming (1983). It is perhaps, worth making it clear that this use of the notion of network has nothing in common with the ‘network analysis’ of social relations used, for example, in the sociology of kinship.

4. Sociology at present lacks an adequate theory of the nature of the actor. Here we simply want to note that the capacity to network rests on the ability of the actor to select salient links stored in long-term memory and ultimately derived from prior experience. The stability of these links naturally rests upon their experienced workability. Our proposition, then, is that agents may be treated as learning machines where the nature of that learning is a function of the basic cognitive capacities of perception and memory, and such socially mediated factors as experience and salience. Despite its psychological twist, the sociological reader will immediately see that in its present state this represents little more than a restatement of Mannheim’s notion of the documentary method.

5. Consider, as a particularly obvious case of this proposition, the arguments that surround the value of environmental as opposed to economic considerations in the development of nuclear power.


7. All these quotations are taken from the tape of the December meeting at Stiftungburg, unless otherwise stated. The numbers are transcript line numbers.

8. This paragraph reads as follows:

Divinyl ether-maleic anhydride (DIVEMA) is a synthetic anionic polyelectrolyte which has been shown to display a wide variety of biological activities including antitumour, antibacterial, antiviral activities and also the ability to activate macrophages (B, 1976). The possibility that DIVEMA’s primary effect was on the immune response was investigated by R and co-workers (M et al., 1970), who investigated the effect of DIVEMA on the reticuloendothelial system. They ex-
amined the blood clearance of colloidal carbon, lipid emulsion and $^{51}$Cr-red blood cells by mice, and concluded from their results that administration of DIVEMA caused an inhibition of phagocytosis 2 days after injection but a threefold stimulation of phagocytosis by 6-8 days. Recently a DIVEMA-methotrexate complex was synthesized with the aim of combining antineoplastic and immune stimulating activity; the polymer complex was more potent than methotrexate alone against murine leukemia and solid tumour (P et al., 1978). The effects of DIVEMA on endocytosis are therefore of further interest as a DIVEMA-methotrexate complex is likely to be taken up by endocytosis, whereas methotrexate itself is interiorized by active carrier-mediated transport (G, 1971).

9. The final version of the opening paragraph reads as follows:

Divinyl ether-maleic anhydride (known either by the acronym DIVEMA or as ‘Pyran Copolymer’) is a synthetic anionic polyelectrolyte which has been shown to possess, in addition to a wide variety of other biological actions (including anti-tumour, antibacterial, antiviral activities), the ability to activate macrophages (B, 1976). Recent work (S, Q and C, 1977, S et al., 1977a, b) has shown that DIVEMA can activate macrophages to become cytostatic against tumour cells in both in vivo and in vitro systems. The possibility that DIVEMA’s primary effect was on the immune response was examined by R and co-workers (M et al., 1970), who investigated the effect of DIVEMA on the reticulo-endothelial system. They measured the blood clearance in mice of colloidal carbon, lipid emulsion and $^{51}$Cr-labelled red blood cells, and concluded that administration of DIVEMA caused an inhibition of phagocytosis two days after injection but a threefold stimulation of phagocytosis by 6-8 days. Recently a DIVEMA-methotrexate complex has been synthesized with the aim of combining antineoplastic and immune stimulating activities; the polymer complex was more potent than methotrexate alone against a murine leukemia and a solid tumour (P et al., 1978a, b). This further adds to interest in the effects of DIVEMA on endocytosis since a DIVEMA-methotrexate complex is likely to be taken up by endocytosis, whereas methotrexate itself is interiorized by active carrier-mediated transport (G, 1971).

10. See lines 154-58, of our transcript.

11. Readers will recognize that this is a version of Barry Barnes’s argument that knowledge which is visibly directed by a concern with social control alone lacks persuasive power: See Barnes, Interests and the Growth of Knowledge (London: Routledge and Kegan Paul, 1977), 32-33.

12. The numbers 4 and 6 in this excerpt refer to numbers in a Table added to the paper. See our discussion below.

13. It does not, of course, actually ensure comparability, because this rests on a tacit assumption that all relevant factors have been determined and controlled. It does not require much ingenuity — as Harry Collins has elegantly demonstrated, in ‘The Seven Sexes: a Study in the Sociology of a Phenomenon, or the Replication of Experiments in Physics’, Sociology, Vol. 9 (1975), 205-24 — to devise additional factors that might undermine comparability: what, for instance, is the shelf life of DIVEMAs? Does their esterification lead to unforeseen chemical changes?

14. For the actual reception of the paper see Callon and Law, op. cit. note 3.

16. Readers who wish to develop this line of thought might consider the proposition that ethnomethodologists are primarily concerned with the prospective-retrospective instability of intension and extension. They might also consider what happens in ethnomethodology to the notion of ‘reference’ in network theory.


18. Ibid., 52.


20. It should be noted that Hesse’s network theory has been used in a variety of other contexts in the sociology of science — see, for instance, D.C. Bloor, ‘Durkheim and Mauss Revisited: Classification and the Sociology of Knowledge’, *Studies in the History and Philosophy of Science*, Vol. 13 (1982), in press. In this paper Bloor uses the term to refer to shared knowledge. He uses it, among other things, to indicate that culture is holistic, and that terms are context dependent and revisable in science. In the present paper, networks are seen as being personal attributes generated by the operation of memory on an array of particulars. These two usages are compatible. Our understanding of the interpretive capacities of actors leads, indeed, directly to the network analysis of culture offered by Bloor.


22. Michel Callon, ‘Struggles and Negotiations to Define What is Problematic and What is Not: the Sociologic of Translation’, in Knorr et al. (eds), op. cit. note 6, 197-219.


24. This point was brought home to us recently when we began to discuss an earlier draft of this paper with Dover, Watt and Smith. Dover suggested that we often seemed in danger of getting things out of context by making it seem as if the collaborators were in complete disagreement. In fact they shared many basic assumptions, but these assumptions were not mobilized in the course of the reported
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discussions because in these the scientists were exchanging ideas in a rather grey area. In fact, of course, all the negotiations that we have detailed are at the margins. Like politicians who wish to change the policies of their predecessors, the disagreements which we have chronicled are all small in scope because of the prior existence of commitments to see and to do things in prescribed ways. This is not, however, to say that such negotiations are trivial, for today's negotiated outcomes may become tomorrow's institutionalized commitments.

25. For an exploration of certain aspects of such networks from the standpoint of charting scientific change, see the following important statement: Michel Callon, Jean-Pierre Courtial, William A. Turner and Serge Bauin, 'From Translation to Network: An Introduction to Co-Word Analysis', Social Science Information, forthcoming (1983).

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Beyond the Bounds of Credibility

ROB WILLIAMS and JOHN LAW*

Abstract — The construction of knowledge in a biological laboratory is described in terms of the credibility model advanced by Latour and Woolgar. Thus, the scientists are seen as having attracted a certain degree of credibility which allows them to acquire and combine resources in order to produce knowledge. Their strategies are partially explicable in terms of research for further scientific credibility. It is, however, argued that a full explanation of research strategy depends on other socially constraining factors — for instance the necessity for maintaining satisfactory social relationships of a non-scientific nature both inside and outside the research group. It appears that the credibility model needs to be generalized: all actors make investments, seek returns in a number of dimensions. The explanation of action depends on an understanding of the demand for making investments in which these different dimensions or “markets” are related.

Introduction

Do scientists work to produce knowledge? The standard explanation argues that scientists are motivated to offer contributions to the scientific community in exchange for recognition. This exchange is likened by Hagstrom[1] to the pre-capitalist exchange described by Mauss and illustrated by Malinowski. Bourdieu’s alternative theory of the ‘balance’ between science and capitalism: scientists (and others) are seen as attempting to maximise their symbolic capital and effect a monopoly of authority in a field by means of appropriate investment strategy[2].

Third, and potentially most fruitful theory advanced by Latour and Woolgar[3] analyses the above two models for their failure to account for the content of science, for scientists are deeply concerned with each others’ outpourings or, to put the same thing in a more general way, for the demand for scientific production. Latour and Woolgar develop what they call the “credibility model” by noting that there is a circulation of two commodities in the scientific community. In the one direction flows...
scientific information. In the other direction flow resources that make possible the production of scientific information. They argue that these resources are best seen as constituting an investment — that is, they are extended to a laboratory or individual in anticipation of a return in the form of credible information. In general such a return is important to the investor because he in turn wishes to make use of such information to produce further credible information that will satisfy those who have invested in him. Again, of course, if the latter investors are satisfied, they and others will be more willing to extend further resources to him in the future.

In this way, then, Latour and Woolgar picture science as a chain of investments placed in order to secure a return. The individual scientist aims to increase his ability to attract investment (and hence enhance his productive potential), and his success (or lack thereof) is reflected in the increase or decrease of his credibility. Naturally, if he produces information for which there is no market, then his credibility will dwindle. If, on the other hand, he produces information for which there turns out to be high demand, he will be seen as an excellent risk for future investment, and his credibility will rise. Credibility thus depends on market conditions.

In this model “credibility” takes a variety of forms. The general standing or prestige of a scientist is but one. Investment of money may be repaid with useful data which gives the scientist prestige and allows him to obtain a better position where he can direct the work of subordinates to produce further findings, and so on. Such a chain of events reveals that credibility (like capital in Marx’s analysis of the accumulation thereof) takes a variety of forms. Indeed, it is precisely the rapid circulation of credibility through a variety of different forms that is the aim of the scientific entrepreneur. At the same time this model stresses that it is not possible to separate epistemological, social, and economic variables. To talk about the reliability of findings is simultaneously to talk about the scientist who produced them, and the capacity of that scientist to produce further investment.

There is little doubt that the credibility model (whose ramifications are much more extensive than the above brief discussion suggests) marks a major step forward in the analysis of the dynamics of scientific production. To an extent it reduces the persistent “internal/external” distinction that has hindered work in this area; it accounts, at least partially, for the content of scientific production; it allows links to be made between macrosocial analyses of science (for instance “specialty growth” studies) and microsocial studies of laboratory practice and it replaces a “normative” with an “economic” model of scientific production where actors are seen as manipulating resources in terms of their interests rather than as doggedly obeying rigid norms of behaviour. In the remainder of this paper our own adherence to the basic approach of the credibility model may be taken for granted. Our aim is to explore certain aspects of the model, and particularly how it might relate to phenomena that are, perhaps, more amenable to alternative or additional sociological explanations. Specifically, we will consider the relationship between credibility and other forms of investment, and discuss the ways in which investment decisions are made.
In the first section of the paper we describe the development of a scientific project and the coincident deconstruction of a claimed fact in a biological laboratory in Northern Europe. The material has been gathered by one of the co-authors in the course of an extended period of observation. Most of the events referred to have been observed—though some of the “prehistory” was reported to us by participants. In the second section we show that much of the course of this project (and consequentially the dissolution of the fact) is explicable in terms of the credibility model. In the third section we explore some of the limitations of this model as they arise in relation to our data.

THE CHINATOWN—STIFTUNG COLLABORATION

Introduction

What we shall call the “Chinatown” laboratory is the well known research division of a British university department. Most of the people involved with experimental work in the laboratory are Ph.D. students or Research Fellows, though the work is directed by senior personnel with wider teaching and administrative responsibilities. The four Chinatown members who feature in our story are “Dover”, a Ph.D. student, “Smith”, a Research Fellow, “Watt” who heads the laboratory, and “Morse” who although also senior, still undertakes experimental work from time to time.

As we shall indicate in greater detail below, these four work on and are exploring the characteristics of a system for studying pinocytosis that was devised and first reported in 1975 by Watt and his collaborators. They use the technique to determine the effects on pinocytosis of different substances and hope, thereby, to elucidate the mechanisms of uptake utilized by living cells. They thus keep a weather eye open for likely substances which may be examined with their system.

The story that we wish to tell involves a collaboration between Chinatown and members of a German research laboratory which we shall call “Stiftung”. The German laboratory had been working, for several years, on substances called DIVEMAs—polymers which have a range of biological properties. It had been suggested, for instance, that some of these properties might be due to DIVEMA being able to stimulate the uptake of substrate into cells—a claim amenable to testing by the system developed by Chinatown. Furthermore, if true, this would have been of great interest to the Chinatown workers because, at that time, no substances with such a stimulating action were known—and such a discovery would undoubtedly have contributed to an understanding of the mechanisms of pinocytosis.

There are, however, several further considerations. The first is that the synthesis of DIVEMAs is itself a skilled and tricky process—and the necessary expertise had been

Pinocytosis is a term which describes the uptake of substrate by living cells. Pinocytosis refers to the uptake of small droplets of fluid, whereas phagocytosis describes relatively large scale uptake by engulfment. In the process of pinocytosis solutes are captured either in fluid phase or by being bound to the cell surface.
developed by two members of the Stiftung laboratory, "Gladstone" who heads the laboratory, and "Disraeli", a Research Associate. There was thus some reason for Chinatown interest in a collaboration with Stiftung, for the latter was in a position to supply scarce polymers. Secondly, however, the experience of the Chinatown scientists arising out of work on polymers closely related to the DIVEMAs led them to doubt the stimulating effects of the latter. In this, then, they differed from the young workers who believed that DIVEMAs stimulated uptake because such conclusions had been reached by "B", a biochemist with whom they had sustained a close relationship over several years. Thirdly, however, the general interest about DIVEMAs played in the literature suggested that any finding, even if negative, would be of interest to the scientific community. As Watt put it: "(The Stiftung) . . . were keen to these results because they would relate to existing data and the extrapolations that had been made from them. We said it was worthwhile doing these experiments although were fairly sure they wouldn't give positive results. The point is this, . . . we may the paper published in spite of our findings being wholly negative because there is a y of data already existing which needs explaining and even negative results are vant to this. On the other hand, if we took some other compound which nobody ever worked with and found that it had no effect in our system nobody wouldlish it! Anybody can do that! Unless there is some reason to suppose that it might e had an effect it's just not worth doing." [Watt, interview; 18/1/79]. The bulk of this er, then, records the collaboration between the Chinatown and Stiftung laboratories, the series of experiments undertaken by Dover and Smith to test the effects of DIVEMAs on uptake, and the final conclusion, notwithstanding the prior expectations Gladstone and Disraeli, that DIVEMAs indeed have no effect thereon. Having set the eg, we shall next follow through the collaboration chronologically.

prehistory

have already mentioned that the technique devised by Watt, Morse and others, waslished first in 1975. It was a technique which involved the culturing of rat yolk sacs a medium containing a radioactively labelled substrate. A related technique for uring macrophages was published by the group in 1977 — a technique with which ith had been most heavily involved. Both systems are currently in use.

Watt and Gladstone first met in 1972 or 1973 as a result of a visit by the latter to a irner chemist working at the Chinatown site. The two of them quickly realised that possibility for collaboration existed. At this time, however, the yolk sac system had been perfected. Chinatown were still working on it, and it was clear to both parties it the time was not yet ripe. In 1974 Watt was invited by Gladstone to visit the tung laboratory and again the possibility of collaboration was discussed. By 1975, eever, Watt had concluded that the system was sufficiently advanced, and he icated to Gladstone that collaboration was now possible. This was agreed, grants e obtained, and after some delay caused by contingent factors, work started in uary 1978.
Most of the work that we shall report was undertaken by Dover (who operated the yolk sac system) and Smith (who worked with the macrophages) though Watt, Morse, Gladstone and Disraeli were all involved, in various ways, in planning, discussion and the drafting of papers. In January 1978 Stiftung sent the DIVEMAs to Chinatown with precise instructions about how they were to be dissolved, and information on their properties such as molecular weights, chemical characteristics and so on. Dover and Smith, following their usual practice, placed the cells in a medium which included the dissolved DIVEMAs and a radioactively labelled but inert polymer, the fluid phase marker PVP. The pinocytic activity of the cells was measured in the habitual way by determining, radioactively, the extent to which PVP was taken up by the cells of the suture at a variety of different concentrations of several different DIVEMAs. In a second series of experiments, radioactive colloidal gold was substituted for PVP, though the principles were identical.

Early in May 1978, Disraeli, the member most involved in the Stiftung synthesis of DIVEMAs visited Chinatown to learn about the yolk sac system, and to help solve some practical problems of a chemical nature that had arisen. In late May Gladstone joined Disraeli at Chinatown, and all the collaborators reviewed progress to date. By this time the effect of four of the DIVEMAs at three concentrations had been studied in the yolk sac system, and three of the DIVEMAs had been similarly studied with the macrophage system. The discussions in large measure related to the apparent fact that the DIVEMAs failed to stimulate uptake, the outcome anticipated by the Chinatown workers. As we shall see in a later section, Gladstone was not immediately willing to accept this conclusion, and in any case stressed the importance of even negative results in a manner not unlike that of Watt quoted above: “The story about DIVEMA is interesting that even a result which is disappointing for an outsider is interesting to It would be worthwhile making a short publication ready.” [Tape 3/1/3; 24/5/78]

The collaborators agreed to prepare a paper, a decision which necessitated further work on DIVEMAs of different molecular weights and at various concentrations. In the following month Smith, Dover and Watt reviewed the work further in order to determine whether any of the experiments (some of which appeared to give erratic results) had to be repeated. Repetition was ruled out, and Dover and Smith continued work on which was virtually completed by September 1978. Late in November the three Chinatown collaborators discussed a preliminary draft prepared by Dover and Smith, a draft which included the last of the experimental results. Finally, in December, Watt flew to Germany to visit the Stiftung team, and a final draft was negotiated with Gladstone and Disraeli.

is a marker that is adsorbed by the cell membrane. In previous experiments uptake of gold has been shown to be stimulated by some positively charged polymers, but not by negatively charged polymers. MA is negatively charged.
CREDIBILITY AND THE PRODUCTION OF KNOWLEDGE

Many features of the above summary account may be understood in terms of the credibility model. That is, the two laboratories may be seen as operating on borrowed capital in order to produce a return that will be credible, useful to others, and hence encourage the extension of further credit. In other words, others have invested in the Chinatown laboratory, and this investment has been converted into a system for measuring uptake by Watt and his co-workers. Now they seek to use the technique to produce further marketable results with which creditors may be encouraged to invest further.

For the Stiftung laboratory the story is similar. Others have invested in them, and they have converted this investment into DIVEMAs. Now they seek to market their product and this can be done by using a system such as that developed by Chinatown which studies the effect of (for instance) DIVEMAs on the behaviour of living cells. The two laboratories clearly have much to offer one another.

In a short paper it is clearly impossible to discuss the experiments briefly outlined above in any detail. Instead we shall consider two episodes more fully, and discuss the degree to which they can be interpreted in terms of the credibility model.

Analysis of the results

As we have mentioned, the effect of DIVEMAs on uptake was determined for both the yolk sac and macrophage systems with two markers — PVP and colloidal gold. For convenience, then, we may think in terms of four sets of experiments. Both macrophage experiments appeared, in a straightforward manner, to support the hypothesis (anticipated by the Chinatown scientists) that DIVEMAs do not stimulate pinocytosis. The yolk sac experiments, however, were less clear cut. We will consider the yolk sac/PVP marked experiments first.

When Gladstone arrived at Chinatown in May 1978 he had certain expectations about the results. The Chinatown workers presented the results to him in the course of the following interaction:

Gladstone: This is the DIVEMA problem?
Watt: Yes. May we have the results written on the board, please?
Gladstone: Remembering our discussion in Stiftung we expect to find big differences.
Watt: That was what you expected!
Gladstone: Yes. I remember you were a little sceptical!
Watt: Well we had other experiences to make us sceptical!
The results were written on the board in the following table.\(^3\)

\(^3\)If DIVEMAs had a tendency to stimulate uptake, everything else being equal one would expect the figures in each column to increase with increasing concentration (and for them all to show a higher value than the control).
Table 1.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Code numbers for various types of DIVEMA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>59</td>
</tr>
<tr>
<td>10μg/ml</td>
<td>1.66±0.05</td>
</tr>
<tr>
<td>50μg/ml</td>
<td>2.56±0.08</td>
</tr>
<tr>
<td>100μg/ml</td>
<td>2.54±(2)</td>
</tr>
<tr>
<td>Control</td>
<td>2.34±0.2</td>
</tr>
</tbody>
</table>

The discussions continued:

Gladstone: The 1.66 sticks out.

Watt: Is that just an early series?

Dover: There is just one low experiment out of three.

Watt: But I thought your standard error was 0.05.

Dover: Yes.

Watt: What about S14 at 10μg/ml? 1.73 is it?

Dover: Yes.

[The toxicity of S14 is discussed]

Gladstone: Let me come back to the 1.66 figure. Is this something to be simply accepted or repeated?

Dover: I could repeat it. I've done it three times.

Watt: When you did it three times... was it at the beginning or have you done it along with other experiments?

Dover: The ten and fifty concentrations were done near the beginning using as little polymer [DIVEMA] as possible.

Watt: So the experiments which gave you 1.66 also gave you, say 2.56?

Dover: I can't say off hand. I would need to refer to my notes.

Gladstone: Is this acceptable to you, being experts in the area?

Watt: It is a bit...

Dover: I would say it was marginal. It is difficult to say whether it is a true inhibition. I wouldn't like to risk saying it was.

Watt: Except that you have a very small standard deviation.

Dover: It is still within experimental error.

[Tape 3/1/1; 24/5/78]
these indecisive results can be seen in the light of the expectations of either Chinatown or Stiftung. Looked at from the standpoint of the former, it appears that they (a) threatened the legitimacy of the yolk sac system; (b) may be seen to contrast with corresponding results from the macrophage system, which suggest that DIVEMAs have no effect; (c) may be seen to contradict expectations (based on past experience) that suggest DIVEMAs would not stimulate uptake; and finally (d) require to be explained away if the thesis that DIVEMAs do not stimulate uptake is to be suspect.

these suggestions are put in the economic metaphor preferred by Latour and Redg, we can say that the Chinatown team are reluctant to invest in the suggestion because they think that it is a bad risk and is, in any case, not significant enough to be interesting. This is best shown by looking at a further snatch of conversation, this time between Dover and Watt alone, after the departure of Glad- and Disraeli:

**Dover:** You remember the S9 experiment at 10µg/ml? That is the one which is slightly on the low side. We considered whether we should repeat the experiment to see whether it is a true inhibition.

**Watt:** That's right but we've decided that it is too close to the norm to be interesting anyway. [Tape 4/1/1]

**Dover:** The result that they [Stiftung] were most interested in was the S9 at 10µg/ml. They wondered if it really was low. I think that if they were here they would want to look at that again.

**Watt:** But I think we have decided that it doesn't count, does it?

**Dover:** I think so. [Tape 4/1/4; 27/6/78]

the experiment could, of course, have been repeated, but there is great reluctance to do so. Other, more attractive and finite resources to do so, for members of the Chinatown team believe that no positive or interesting results are likely to be forthcoming. A set of standard ploys have been marshalled here to handle the apparently anomalous results. Phrases such as being "within experimental error", "too close to the norm to be meaningful" and "it was marginal" are used to pigeonhole the results as being of little significance, and hence to avoid the necessity of replication. Perhaps this talk of a "final" result has been seen as a gloss growing out of a set of prior investments. Let us also note, however, that nothing is being done in bad faith. Nothing has been ignored or missed, for guesses about the success of further investments of effort and time are tenuously bets about the way in which the world is likely to behave. There is, of course, no end to the variations that could in principle be made to parameters such as concentration of DIVEMAs. Likewise, there is no obvious point at which to stop investigation. A cut-off point must be imposed somewhere — and that cut-off point is chosen by the Chinatown group's best bet about nature and how to use their...
resources of time and finance — and correspondingly about how to proceed to maximize credibility.

From the Stiftung standpoint, the same results suggest that DIVEMAs might have an effect on uptake. However, the Stiftung workers are not qualified to judge these results. The above conversational extracts suggest that Gladstone defers to the expertise of Watt and his co-workers. This can be further illustrated:

Gladstone: It looks to me at the moment as if those who know the area think that there is nothing happening, nothing worth following up. [Tape 5/1/6; 24/5/78]

The negotiation about the stimulating effects of DIVEMAs was, then, very lop-sided, despite published claims by polymer chemists about the biological effects of DIVEMAs. It seems to have been impossible, given tacit knowledge about who had invested in what kinds of resources and correspondingly had “rights to speak” on a given subject, for Gladstone to press his prior view on DIVEMAs.

It is, of course, the case that the attitudes and expectations of the parties were subject to change. Gladstone and Disraeli changed their views but, apparently, did Watt. In the conversational excerpt on page 301 we find him hedging his bets. It was Dover, who had undertaken the experimental work, who was adamant that the results were not significant. Further (unfortunately unrecorded) discussion between Dover and Watt persuaded the latter of the pointlessness of experimental replication. It is clear that given the present cast of actors and available resources Dover and Watt were together unbeatable.

Turning now to the yolk sac/gold experiments Chinatown found that the results were rather scattered and “not particularly reproducible”. Indeed, they were not included in the final draft of the paper. Instead it was simply stated that: “A limited number of experiments were performed using colloidal Au as a substrate, and again no evidence for stimulation of pinocytosis was obtained.”

Why were the details of this set of results omitted? The decision to do so was made in the course of the following discussion:

Watt: Now there’s something funny about the yolk sac/gold results. What is funny about them?

Dover: Well, they weren’t particularly reproducible but I was working with small numbers of yolk sacs. These are the graphs taken if you average out all the points at each time interval. Now S9 is all over the place really. There’s a couple of high ones and a couple of low ones.

Watt: And how many experiments are there?

Dover: Three. But you see, some of them have only got a small number of yolk sacs, so there might only be the average of two there. We had two which were exceptionally high, which were in the fifties for some reason. So it
can't bring them down very far. Usually they compensate for one another and we get straight lines. It's the same with these points. They're low on all three points here. This is the day when Professor R came. They were done at different times, which were unusual. So they're just from an individual culture and they're not being normalised. They're not being averaged out with the rest. The other points seem to fall in quite well. S13 is inhibitory. I think that's pretty linear.

[Pause]

Watt: Its a great mess, isn’t it?
Dover: Mmm.

Dover: ... I don't think anything is really having an effect.
Watt: No, but I think we’re going to have to admit they are very peculiar. There's nothing gone wrong with the controls?
Dover: The controls are variable to say the least! On the last day it was 1.5 and then 5.35! I mean they weren't exactly reproducible. It's a strange batch of gold altogether.
Watt: Well, would it be wiser to leave them out? Leave them out completely?
Dover: Possibly.
Watt: There is absolutely no point in publishing stuff that we don't trust. It would be better just [to] give the yolk sac results on PVP. I don’t think that anybody would criticise us for that. We've demonstrated that its a very reliable marker. But I'm a bit unhappy about putting in a set of data that we aren't sure about. What about the gold with the macrophages, Smith? Have we got similar worries about that?
Smith: Not really, no. It came out very well, really.
Watt: Yeah.
Smith: But then gold is more of a macrophage marker . . .
Watt: . . . more of a macrophage marker, that's right.
Dover: It was a strange batch of gold, and strange yolk sacs.
Watt: Well, if that is the case, we'd be barmy to publish it, surely? It isn't as if they tell us anything extra.

What should the protagonists make of these erratic results? They could, at least in principle, be taken to suggest that the system for measuring pinocytosis is inadequate. However, this suggestion was never entertained. As is indicated by the credibility model, this alternative is far too costly to contemplate, for extensive resources had been invested in the system, its reliability had been claimed, and the facts had been pro-
duced. All this credibility would be at risk if the system were now deemed to be unreliable — and indeed cumulative scientific change would be rendered impossible if every adverse result were taken as a cause for re-examination of first principles. The virtue of the credibility model here is that it emphasises the intimate relationship between the scientific and the social. On the one hand, the scientific (the standing of the method and past facts) is at stake. On the other hand it is also social, for the credibility and general standing of the group is also at stake. The commonsense distinction between scientific and social is clearly unhelpful.

In other words, the model suggests that such moves as the above are not to be seen as unscientific or wrong. On the contrary, they are constitutive of science[4]. Putting this series of experiments in context, we may say that a progressively accumulating investment has been made in the system for measuring pinocytosis. In the initial stages of this process it would not have been too costly to abandon development if results (for whatever reason) had turned out to be unreliable. Now, however, the system has become institutionalised and the cost of abandoning it is prohibitive. If it fails to produce acceptable results then this must be as a result of the operation of special factors. Some of these were mentioned in the previous section — for instance the notion of “being within experimental error”. In the above transcript we note that there is recourse to the notion that it was “a strange batch of gold”, there were “strange yolk sacs”, that “gold is more of a macrophage marker”, that there were low numbers of yolk sacs, and that control results were variable.

In general, then, these results fit well with the credibility model. An investment in the technique had been made, and the occasional results that did not maintain this were discounted. Furthermore, the Chinatown team had no strong incentive to replicate the yolk sac/colloidal gold experiments, which although erratic suggested negative findings, as this would have required the further investment of limited resources for a return they expected to be marginal. The usual range of glosses was available for accounting the decision to avoid replication of the series of experiments.

Let us briefly summarize. We have argued that past investment leads the Chinatown team to discount at least one interpretation of the results, namely the hypothesis that the system of its nature produces unreliable results. Interpretation of the results is, then, firstly a function of commitment to the system. Secondly, it appears that the language of science offers a legitimating armoury for glossing apparent inconsistencies in its institutions. Thirdly, the treatment of both of the sets of results discussed above is a function of the belief, held by members of the Chinatown team, that DIVEMAs will not stimulate uptake. This belief grows out of past experience with similar polymers —

There are all sorts of legitimations that may be used when apparent inconsistencies are to be dealt with. This contention has been well made by Flood[9] in his discussion of scientific reasoning. He imagines a confrontation between a group of actors and an outsider who detects what he takes to be an inconsistency in their views. Logic, argues the outsider, would lead them to act in a way other than they actually do. However, in order to avoid any inconsistency, all that they have to do is to feed in a further assumption. The “lead” given by logic then changes direction, making their actions perfectly reasonable. Logic, then, is a malleable tool which can be called upon after the event to legitimise an action or belief.
experience that is used as an indicator that DIVEMAs themselves will have no such properties and hence do not warrant an extended investment of resources.

Why, then, are Chinatown willing to spend any time at all on this series of experiments? Firstly, let us clarify the attitudes of members of the Chinatown laboratory:

Dover: We’ve got a good in vitro system which is well defined and that is why Gladstone wanted to test his substance in our system. We should have been able to pick up any effect on pinocytosis which DIVEMA might have had in one of our systems. We could not, and that is interesting to him.

Williams: But not to you?

Dover: No, not really. [17/1/79]

And again:

Watt: I think Gladstone is more interested in DIVEMA than the Chinatown group because they’ve invested more effort into DIVEMA. We would never have heard of it had it not been for them. But there is some interest in the idea of using DIVEMA as a carrier of a drug. [18/1/79]

The collaboration took place because the Stiftung team are able to produce other materials which interest Chinatown to a greater extent — which would, to put it in terms of the credibility model, offer a commodity more marketable in the Chinatown area. The DIVEMA work can be seen as a prelude to what, it is hoped, will be a more profitable collaboration from the standpoint of the Chinatown members. In addition, however, it was clear that the work on DIVEMA could be quickly and straightforwardly completed, and that it might, in any case, be marketable. Watt put it this way:

Watt: We could have chosen all sorts of polymers with which to experiment but we chose DIVEMA because other people had already done things with it. This will make it easier to get a paper published. If we simply went in cold and said: “Here are some compounds which have been made, they don’t do anything!” nobody would publish it.

Morse: These polymers have got star quality! [Tape 3/2/7; 25/5/78]

The marketability of work on DIVEMAs had a strategic advantage:

Williams: What was the reason for a quick publication?

Watt: Firstly, we wanted to get into the field and give people the opportunity to know about us. At the moment the joint group [Stiftung and Chinatown] have produced nothing. The collaboration between us is something that the world doesn’t know about. We’re quite keen that they should! [18/1/79]

The aim, then, is to establish the Stiftung–Chinatown collaboration as a credible enterprise, one that is capable of producing marketable results, and one that will attract
Further resources. In terms of the economic metaphor that lies behind the credibility model, we may picture the two teams as creating a jointly owned subsidiary through which, for the time being, they are going to market a joint product. The DIVEMA work offered a quick avenue for the creation of such a product, despite Chinatown's observations about their stimulating effects.

A similar analysis can be developed for the Stiftung end of the collaboration. The Stiftung workers believed, as we have seen, that an investment in DIVEMAs would bring in a good return, given the general interest in these substances combined with their belief that they stimulate endocytosis. However, collaboration with a group such as Chinatown was necessary if their investment was to be made marketable.

Nevertheless, the Stiftung workers were only lightly committed to their view that DIVEMAs stimulate uptake, for they had never gone into print on the subject. Thus, in the discussions that took place in May, though preferring to argue that DIVEMAs had an effect, they did not press this view very strongly. The positions adopted by both teams in the May negotiations are thus readily explicable in terms of the credibility model — though it may be, as we shall argue in a later section of this paper, that the model needs to be placed in a broader context.

Drafting the publication

Here we wish to consider one issue only. This is how the participants solved the problem of how to present the results which suggested that DIVEMA does not stimulate uptake in such a manner that a confrontation with B, the author who claimed to have noticed such an effect, was avoided.

An initial draft of the paper presenting these results was prepared by Chinatown. In referring to the "fact" that B had argued that DIVEMAs stimulated uptake, this first draft ran as follows:

[A] In contrast, B et al. were using blood clearance of phagocytic substrate as a measure of reticuloendothelial activity. The hazards of using in vivo systems to measure endocytosis have been outlined extensively.

Gladstone who, as we have already noted, maintained working contacts with B was unhappy about this rather bald form of words:

[B] I would not like to push this to a conflict. The differences may be just a difference in the systems used.

[10/2/2; 14/12/78]

This and several other views can be seen in the following discussion of the above passage:

[C] Dover: Are we really saying, "In contrast, B's method is imprecise and unreliable?"
Watt: Well, that is what we are saying really.

Dover: I think that is bad really.

[Q]

Watt: It is rather. Perhaps the “In contrast” could come out. That is rubbing it in a bit.

Gladstone: Yes. Let’s take it out.

Watt: Simply start off, “B et. al., using blood clearance . . .”

Gladstone: Yes. Then all we stress is the difference in the method and we do not stress how good either group is!

Watt: That’s right.

[The next sentence is read out]

Watt: Really the difficulty is in all the extrapolations and assumptions one has to make.

[F]

Gladstone: Saying “hazards” is a bit strong too. [10/1/3; 14/12/78]

[. . .]

Watt: The logic of this is that we say we can’t see any stimulation. That is fine. I am happy about that. Then we say, “Experimental data presented here does not really reinforce the experiments of B. It is possible that the differences seen relate to the different endocytic capacities of the cells involved. Rat yolk sacs are restricted to pinocytosis, macrophages were in this instance too. B was using blood clearance.” I wonder about the “hazards” sentence. The argument goes like this. We are saying that we can’t get data which reinforces B’s, but it is possible that this is because what we’ve been doing is looking at pinocytosis and they [B] have been looking at phagocytosis. Isn’t that right?

[G] Dover: That is point number one. Yes. The second point is that it might be their method of quantification. Everyone knows that an in vivo system is not ideal.

[H] Watt: Well let’s say, “The hazards of using in vivo systems have been outlined extensively,” and add, “Other explanations apart from enhanced phagocytosis are possible.”

Dover: Yes. Or “… have been outlined and it may be that a mechanism other than phagocytosis is in operation.” [11/12/11; 14/12/78]

[. . .]

Dover: I think that sentence needs changing.

Watt: Which one? The “hazards” one?
Beyond the Bounds of Credibility

Dover: Yes. I don’t think it is quite right. If we just said that we pointed out the hazards and they were realised by B’s team it would be better.

Watt: Yes. Could we add it to the sentence about blood clearance in some way? Say, “A method whose hazards were realised by . . . .”

Gladstone: Yes.

Dover: Or perhaps a better word.

Watt: “Appreciated”? “Understood by”? Yes. “Hazards” is perhaps the wrong word, is it? Mmm, . . . let’s say, “A method whose weaknesses . . .” “Understood” is the wrong word. Nobody understands them!

Gladstone: “Were mentioned by . . .”

Watt: Yes. “Whose weaknesses were mentioned by [Ref.] and discussed by [Ref. to forthcoming paper by Chinatown group].”

[12/1/3; 14/12/78]

The outcome of this set of negotiations is that the original draft [A] has become the following:

[1]

Bet al. were using blood clearance, a method whose weaknesses were mentioned by [Ref.] and discussed by [Ref. to forthcoming paper by Chinatown group], as a measure of reticuloendothelial activity.

Anyone who has ever attempted to draft a collaborative paper must have sympathy for the participants in the protracted discussion outlined above. Perhaps the reader’s first reaction is to view it as an example of verbal quibbling. This, however, would be an error, for much is at stake here. Participants are arguing about the “facts” and how they are to be related, and they are simultaneously trying to relate two possibly contradictory claims to credibility. One might say that they are negotiating about the commitments, both social and scientific (if we may separate these for a moment) with which they will enter the next round of creating or altering social structure. Insofar as their paper is credible to third parties, it will in addition influence their commitments to social and scientific structure in turn.

We have attempted to outline some of the different formulations (see Table 2). In one sense the strong claim [A] of the original draft of the Chinatown group has been watered down in the final statement [1]. How might this set of negotiations be understood? Firstly, in accordance with the credibility model, we may safely assume that attempts are being made by all concerned to maximize credibility. On the one hand this requires the group to make bold claims — the bolder the better. On the other hand, it is also necessary for the group to minimize its risks. Thus, little credibility will accrue to
Table 2. Different accounts of the relationship between the results of the Chinatown/Stiffing Team, and those of B

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<td><strong>A</strong></td>
<td>[Dover, Smith and Watt]</td>
<td>In vitro system (Chinatown)</td>
<td>contrasted with</td>
<td>In vivo system (B)</td>
<td>blood clearance “hazardous”</td>
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<td>No stimulation of endocytosis</td>
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<td>Stimulation of endocytosis</td>
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<td><strong>B</strong></td>
<td>[Gladstone]</td>
<td>In vitro system (Chinatown)</td>
<td>difference in two systems</td>
<td>In vivo system (B)</td>
<td>No stimulation of endocytosis</td>
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<td><strong>C</strong></td>
<td>[Dover (formulating [A])]</td>
<td>In vivo system (B)</td>
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<td><strong>D</strong></td>
<td>[Watt, Gladstone]</td>
<td>In vitro system (Chinatown)</td>
<td>difference in two systems</td>
<td>In vivo system (B)</td>
<td>No stimulation of endocytosis</td>
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<td><strong>E</strong></td>
<td>[Gladstone]</td>
<td>In vivo system (B)</td>
<td>hazard too strong</td>
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<td><strong>F</strong></td>
<td>[Watt]</td>
<td>In vitro system (Chinatown) (rat yolk sac cells and macrophages)</td>
<td>difference in two systems</td>
<td>In vivo system (B) (blood clearance)</td>
<td>No stimulation of pinocytosis</td>
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<td>Stimulation of phagocytosis</td>
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<td><strong>G</strong></td>
<td>[Dover]</td>
<td>In vivo system (B)</td>
<td>not ideal</td>
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<td>Stimulation of phagocytosis may be either</td>
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<td>(b) artefact</td>
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<td><strong>H</strong></td>
<td>[Watt and Dover]</td>
<td>In vivo system (B)</td>
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<td>Stimulation of phagocytosis may be either</td>
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<td><strong>I</strong></td>
<td>[Watt]</td>
<td>In vivo system</td>
<td>Hazards wrong, better weaknesses</td>
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<td><strong>J</strong></td>
<td>Final Draft</td>
<td>In vitro system (Chinatown)</td>
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<td>In vivo system (B) Weaknesses known</td>
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<td>No stimulation of pinocytosis</td>
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<td>Stimulation of phagocytosis seen, but might be either</td>
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the group if it makes bold claims about the virtues of its in vitro method in contrast to the in vivo method used by B, only to find that the community later concludes that DIVEMAs do indeed stimulate phagocytic uptake. The situation is similar to that outlined by Collins in his description of the gravity wave experiments[5]. Both nature (DIVEMAs stimulate uptake) and the comparability of methods are negotiable, though the community in this case probably finds the Chinatown in vitro system more credible.

It is clear from study of the transcript and table that different members of the group have a tendency to assess the risks in different ways. Thus it is clear that Gladstone wishes to avoid an open conflict with B and his group, while at the same time agreeing that DIVEMAs have not stimulated pinocytosis in the Chinatown system, and Dover, in stressing the difficulties of the in vivo system, appears initially concerned to contrast the two systems rather more directly. Watt can be seen as attempting to balance between these two tendencies, though he tends to the weaker position preferred by Gladstone. Such distinctions are relatively small, and their existence should not be seen as evidence of basic differences between the collaborators. Nevertheless, we shall suggest in the next section that they lead, at least in part, beyond a simple concern with scientific credibility.

BEYOND CREDIBILITY

We have argued that the various events described above are in general conformity with the predictions of the credibility model. Scientific actors have commitments to particular beliefs or methods as a result of their prior investments of time, money, and effort in those methods. Their ability to attract future such resources depends upon the continued production of a marketable product. We have seen how the production of a fact “DIVEMAs do not stimulate pinocytosis” was influenced by such prior investments and the continuing search for a marketable product. Various other possibilities that were equally plausible in the abstract (for instance, “the PVP/yolk sac system is an unreliable method for studying pinocytosis”) were disregarded on grounds of their extreme cost to the standing of the Chinatown group.

The credibility model comprises two main aspects. Firstly it is collective. It talks of marketability, the existence of markets, and hence assumes that actors operate in a set of social circumstances that are unlikely to be more than marginally under their control. It also makes individual assumptions, and in particular rests upon the supposition that the scientific actor tends to maximise his credibility. The economic metaphor calls out for development in several respects. For instance, we know little about the indicators utilized by actors in the course of their decision-making. How, in other words, do actors see present investment circumstances as being similar to those they have already encountered? In what sense did the Chinatown group see DIVEMAs as being “like” other polymers that had, in their experience, previously failed to stimulate uptake? Though this is an interesting question (and they most certainly have their reasons) we will discuss it no further here.
Another, and perhaps more general problem, concerns the relationship between different symbolic markets and the methods by which actors balance their investment strategies in order to achieve a maximum return on investment overall. There are several thorny questions here which we are at present only in a position to raise and not to answer. For instance, it is not clear how we should think of the different investment dimensions open to the actor. Our guess is that to think of such different systems as the "scientific", the "economic", the "personal" and so on is to be at one and the same time too simple and too definite. Valued goals, we suggest, merge into one another and are contingent in nature. Different definite systems do not stand separate and immutable in the way that such a description might suggest.

A related problem concerns the balance between the various commitments made by the actor. Here the difficulties are equally acute, though there are a few guidelines available in the literature. We refer, in particular, to Becker's admirable paper on commitment in which he systematized the notion of a "side bet". Using an economic metaphor that is quite compatible with the essentials of the credibility model, Becker wrote that: "The committed person has acted in such a way as to involve other interests of his, originally extraneous to the action he is engaged in, directly in that action . . . . The consequences of inconsistency will be so expensive that inconsistency in his bargaining stance is no longer a feasible alternative." [6] The credibility model assumes that links are made between the various aspects of credibility — for instance knowledge and scientific standing — but it leads us away from the networks of side bets that may, in one way or another, link scientific and non-scientific activity. This is why, though we have used the credibility model to organize and account for a large part of our data in earlier sections, we have at several points intimated that other commitments may be involved, and that credibility calculations may be influenced by the latter.

Why, for instance, does Watt tend to take a mediating role? He did this both in the discussion about the anomalous yolk sac/PVP experiment, and in the later negotiations on the form of words to be adopted about the experimental approach preferred by B. Our data on this question are inadequate, but the following suggests itself. The pursuit of credibility rests, not only upon the production of marketable papers, but in a prior and constitutive manner upon interactional order. That is, unless the co-participants are able to maintain some semblance of mutual self-esteem, then it will not prove possible to collaborate at all. This is not exactly a side-bet because there is nothing contingent about the relationship between the interactional order and collaboration. Nevertheless, a withdrawal of mutual deference will lead to the collapse of scientific co-operation. Naturally all members of a team must co-operate in such mutual face-saving. However, it is perhaps the case that the responsibility for preserving the esteem of individuals rests particularly upon the senior members of a group, if only because such participants have the greatest ability to sustain a particular definition of the situation and the individuals therein. Goffman, always sensitive to the nuances of interpersonal interaction, wrote of the chief surgeon in the operating theatre that he: "is something of a host to people at his party . . . . He is under pressure . . . . to make sure that those at his table feel good about what is happening." [7, p. 113] Watt, though not accomplishing role distance, is host to this party, and like the surgeon, may be seen as
pursuing strategies that sustain the face to face interaction, and improve the efficiency of the group. One such strategy is that of apparent open mindedness — he is willing to listen, to understand the sometimes divergent points of view of those round about him and seeks a line that will, so far as possible, accommodate the different members of the team. To say this is neither, of course, to say that he deliberately adopts such a strategy, nor to suggest that he has no views of his own. It is rather to suggest that one way in which a team leader may act in order to preserve the functioning of the team is as a diplomat.

The diplomacy of Watt can be seen in two of the three episodes we have discussed above. In the first case we find him mediating between the divergent expectations of Gladstone and Dover over the stimulating effects of DIVEMAS. The question was whether Dover should replicate the experiments or not. In the second case we find him searching for a middle path between the initial draft with its tendency to contrast the Chinatown system with that of B and his group and Gladstone's wish to avoid any appearance of invidious comparisons. In both cases it is important not to overplay the differences in the group. These are not rigid positions adopted by Gladstone or the others. They are conversational positions, quickly adopted, perhaps equally quickly abandoned. Nevertheless in each case Watt holds the ring.

Whether or not our speculative remarks about Watt's diplomatic role are warranted, we would nevertheless want to stress the necessity of interactional order and mutual regard for the sustaining of scientific (and other) work. However, given such mutual deference, it becomes clear how at least one kind of side-bet may be generated. Out of any such interaction, however initiated, may grow other kinds of commitments. Actors come to value their colleagues as friends, confidants or opponents. Time and effort are invested in these other involvements, public positions are adopted, and the network of side-bets grows and becomes constraining. Such side-bets are naturally capable of influencing calculations of scientific credibility. In the context of the present data it is apparently the case that Gladstone's concern to moderate apparent criticism of B rested in part on his personal esteem for the latter. Lest we be understood, in making this claim, to be saying that Gladstone's action was in some way improper, let us hasten to add that no attribution of bad faith is involved. Gladstone is quite right to press his view given the logical relationship between the two experimental systems and his high regard for B on scientific and other grounds. In the long run it may well turn out that the two systems do indeed produce different but equally valid results.

The general point that we wish to make is that calculations about credibility rarely take place uninfluenced by non-credibility issues. This is, of course, a way of saying that science is constitutively social in a manner even broader than that suggested by the credibility model. To view science as the disinterested search for credibility is, in its own way, as misleading as to view it as the disinterested search for the truth. The credibility model is a triumph in that it offers us a way of analyzing one dimension of scientific activity, but unfortunately the task of understanding science is not yet complete. The contingent entanglements of those who practise science require further analysis. The social does not stop with the search for credibility. Latour and Woolgar
are naturally aware that such other commitments exist, but they choose to treat these as noise. While recognising the heuristic value of this position, it is clear that in the long run such commitments must also be subject to systematic analysis.

In this section, then, we have briefly considered the interactional requirements for collaboration, and suggested that, on the one hand, they may bring about distinctive strategies by different team members, and on the other hand that they generate side-bets. Both strategies and side-bets influence and moderate the search for credibility as a matter of course. To say this is not to cast doubt on the value of the credibility model, but rather to ask that it be placed in a broader social context — a context that includes both strategies and interactionally generated side-bets, as well as commitments in non-scientific contexts beyond the scope of this paper.

POSTSCRIPT

A difficulty in reporting recent scientific episodes is that it requires considerable forbearance and tolerance on the part of the subjects. The six scientists whose work is discussed above submitted almost daily to our intrusion on their activities over a period of 12 months. They then found their casual utterances discussed (albeit in a somewhat disguised manner) in papers such as this. The first impression of the casual reader is possibly that they have been "unscientific" and cut corners, and our subjects must be forgiven if they feel that we have betrayed their trust and misrepresented them. This postscript is intended to serve a triple purpose. First, we wish to correct any lingering impression on the part of the casual reader that the work we have studied is in any way below standard or inferior. Secondly, we wish to apologize to our subjects if, indeed, they feel that we have betrayed their trust. Thirdly we wish to indicate that our own work, including our sense of relationship with our subjects, is open (like all social activity) to analysis in the same terms.

Firstly, we should indicate explicitly that the Chinatown group with whom we were primarily involved are an outstanding team with an international reputation. We are not, here, on the margins of science. The members of the group are first rate, and the science they produce is correspondingly rigorous. The pinocytosis system is extremely well thought of, and is held by the peers of the group to produce results that are both reliable and interesting. Secondly, we should also indicate, as we have above, that their decision to let us investigate the most intimate processes of scientific decision-making is both unusual, and reveals their commitment to the investigation of the natural and social worlds even when the spotlight is turned on them. Unsurprisingly, when casual conversation is recorded verbatim, it turns out that not all the utterances are grammatical or fluent — though of course our subjects do not differ from anyone else in this respect.

It may be that our analysis looks like debunking though this is far from our intention. Rather we have tried to press home a view which is rather distant from the "standard view of science"[8]. In practice, we would argue, science is carried out in the world and
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like all earthly activities can have pragmatic force alone. Thus, the work described in this paper is scientific in the proper meaning of the term. It was rigorously undertaken by highly qualified personnel who made a series of practical decisions on proper scientific grounds.

Our own position is, of course, equally open to such an analysis though we do not have the scientific standing of our subjects. We too have our commitments, in this case to a version of the credibility model, and we organise and interpret our data in terms of those commitments. We too seek credibility from our peers, and make side-bets that influence the form in which we write about our research. Among these side-bets we count our attachment to the subjects of this paper. We are constrained in what we write by the fact that we wish to retain their respect.

REFERENCES