ABSTRACT

INTRODUCTION: Healthy pregnancy causes significant changes in maternal hemodynamics that lead to structural and functional adaptation of a woman's heart. Reductions in ejection fraction have been reported in healthy pregnancy; however, this measure of cardiac contractile function is over simplistic and insensitive to the underpinning hemodynamic load. Indices of systolic myocardial deformation, such as left ventricular strain and twist ('LV mechanics') may therefore provide a more accurate assessment of cardiac function during gestation. As such, the aim of this study was to evaluate LV mechanics in the second trimester of healthy pregnancy and secondly, to determine the influence of underpinning hemodynamics (heart rate (HR), preload and afterload) on LV mechanics during gestation.

METHODS: We conducted a cross-sectional study of non-pregnant (*n*=18), primiparous pregnant (22-26 weeks gestation; *n*=14) and postpartum (12-16 weeks after delivery; *n*=13) women. All pregnant and postpartum women had uncomplicated, singleton gestations. Cardiac structure and function were assessed using echocardiography. LV mechanics, specifically longitudinal strain, circumferential strain and twist/untwist, were measured using speckle-tracking echocardiography. Differences between groups were identified using ANCOVA, with age, HR, end-diastolic volume (EDV) and systolic blood pressure (SBP) as covariates. Relationships between LV mechanics and hemodynamics were examined using Pearson's correlation.

RESULTS: Pregnant women had significantly greater resting longitudinal and basal circumferential strain compared to non-pregnant women (-22±2 *vs*. -

17±3%, *P*=0.002 and -23±4 *vs.* -16±2%, *P*=0.001, respectively) but not apical circumferential strain or LV twist. No statistically significant relationships between LV mechanics and HR, EDV or SBP were observed within groups.

CONCLUSION: Compared to the non-pregnant state, pregnant women in the second trimester of healthy pregnancy have significantly greater resting systolic function, as assessed by LV longitudinal and circumferential strain. Contrary to previous work, these data show that healthy pregnant women should not exhibit reductions in resting systolic function between 22-26 weeks. The enhanced myocardial contractile function does not appear to be related to hemodynamic load and could be the result of other physiological adaptations during gestation.

INTRODUCTION

In order to meet the demands of gestation, healthy pregnant women experience significant cardiac adaptation, with a greater cardiac output secondary to increased preload and heart rate (HR) and reduced afterload (1). Despite these favorable hemodynamic changes, it has previously been suggested that systolic function, assessed by ejection fraction (EF), may be reduced (2-4) or unchanged across pregnancy (5-7). However, EF is insensitive to underpinning hemodynamic load (8) and oversimplifies myocardial function. An emerging cardiac imaging technique known as speckle tracking echocardiography may allow more accurate evaluation gestational changes in cardiac function (9).

Indices of systolic myocardial deformation, such as left ventricular strain and twist ('LV mechanics') are sensitive to subtle subclinical changes in function, such as that experienced during healthy pregnancy. In the healthy non-pregnant heart, acute increases in HR, preload, or decrements in afterload are associated with increases in LV mechanics (10, 11). Therefore, it could be hypothesized that LV mechanics would be elevated during gestation, however the response to chronic exposure of altered hemodynamic load in pregnancy is not well known. There are marked inconsistencies in the literature showing LV strain to be unchanged (6, 12) or decreased (3-5, 7, 13), and twist to be increased in the third trimester (12-15) and importantly, in most cases, the influence of hemodynamic load was not considered. This currently limits our confidence in knowing whether systolic function is maintained, decreased or in fact, increased during pregnancy. Consequently, measuring LV mechanics may elucidate how cardiac function is altered during gestation; however, this is

currently hindered by a lack of standardized values that have been interpreted alongside the underpinning hemodynamic load. Increased understanding of healthy cardiac adaptation to pregnancy, specifically through use of the more sensitive assessments of LV mechanics, may in the future enable the earlier identification of maladaptation observed in hypertensive complications of gestation (16).

The aim of this study was firstly, to evaluate LV mechanics in the second trimester of healthy pregnancy and secondly, to determine the influence of underpinning hemodynamics on LV mechanics during gestation. It was hypothesized that, in comparison to non-pregnant and postpartum women, pregnant women would have significantly greater LV mechanics and that these would be related to the altered HR, preload and afterload associated with gestation.

METHODS

Study population and recruitment

The experimental procedures for this cross-sectional, observational study were reviewed and approved by the Cardiff Metropolitan University Research Ethics Committee. The study complied with the guidelines set out in the Declaration of Helsinki and written voluntary informed consent was gained from all volunteers. The study took place in the Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University between January 2015 and April 2017. The data presented in this manuscript was part of a larger cross-sectional study that investigated cardiovascular responses to physiological challenges during and after pregnancy (manuscript in preparation). Power analyses were completed for the larger cross-sectional study using preliminary

cardiac output data of 18 non-pregnant and 9 pregnant women (G*Power, Version 3.1.7.). Data for non-pregnant female controls and pregnant females at rest and during aerobic cycling were analysed with a repeated measures analysis of variance (RMANOVA) using GraphPad Prism 5 (GraphPad software, San Diego, CA). Results from the RMANOVA analyses were used to calculate partial eta squared (η_p^2). The η_p^2 was entered into the G*Power software to compute an effect size, which allowed the determination of the required sample size. A statistical power of 0.8 and alpha level of less than 0.05 were set. A sample size of 10 per group was required to detect differences between groups. This value was increased by 10% to account for the development of pregnancy complications, leading to a requirement of 11 individuals per group.

Women were recruited from the local community through advertisements and social media. Non-pregnant women were eligible to participate if they were of pre-menopausal and had not experienced a previous pregnancy. Pregnant and postpartum women were eligible for inclusion if they were primiparous and had a singleton, uncomplicated pregnancy. Exclusion criteria included current smokers, preexisting cardiovascular or metabolic disease, any pregnancy complication (such as gestational diabetes mellitus, preeclampsia, severe anemia), and use of medication at time of inclusion.

Experimental procedures

Volunteers visited the laboratory on one occasion for cardiovascular assessment. Prior to this visit, volunteers were asked to abstain from caffeine and/or alcohol for 18 hours and strenuous exercise for 24 hours prior. Volunteers' freestanding stature was measured, body mass was determined

using an electronic scale and BMI was calculated. Blood pressure was manually measured on the left arm after 5 minutes of seated rest using the auscultatory method. Two measurements of systolic and diastolic blood pressure (SBP and DBP) were taken and averaged. Mean arterial pressure (MAP) was calculated as 1/3 SBP + 2/3 DBP.

Echocardiography

One trained sonographer (VLM) acquired cardiac images in all volunteers after 15 minutes of quiet rest in the left lateral position, following standard echocardiographic procedures. Echocardiography was completed using a commercially available ultrasound system and 1.5 – 4.6 MHz phased array transducer (Vivid E9 and MS5, GE Medical Systems, Horten, Norway) with a three-lead electrocardiograph that enabled the gating of images to HR.

Echocardiographic images were collected to measure LV structure and function in accordance with current guidelines (17). Two dimensional (2D) parasternal long axis and short axis views at the base (mitral valve), mid (papillary muscle) and apex levels and apical 4- and 2-chamber views were collected. Tissue Doppler imaging (TDI) of the septal mitral annulus and pulsed wave Doppler of mitral inflow velocities were measured from the apical window. 2D images were acquired within a range of 70-90 frames per second, whereas TDI images were collected with frame rates >100 frames per second. Five consecutive cardiac cycles were recorded at end expiration to limit displacement of the heart and changes in intrathoracic cavity pressure during respiration. Data were stored for later offline analysis (EchoPAC, GE Medical, Horton, Norway). Measurements were made in triplicate from different cardiac cycles and averaged.

Standard measures of cardiac structure and function

Linear dimensions including intraventricular septal wall thickness (IVS), LV internal diameter (LVID), posterior wall thickness (PWT) were measured from a 2D parasternal long axis view. LV length was measured at end-diastole (d) in an apical 4-chamber view. LV mass was calculated using the area-length method. Relative wall thickness (RWT) was calculated as (2xPWTd)/LVIDd. Sphericity index, as a measure of left ventricular geometry was also calculated as LV length d/LVIDd.

Cardiac volumes, including SV, EDV and end-systolic volume (ESV) were derived via the Simpson's biplane method using 2D apical 4- and 2-chamber views. This allowed the subsequent calculation of cardiac output as the product of HR and SV. The influence of body size on cardiovascular structure and function is well established; therefore, comparisons between independent groups must be conducted using scaled data. To compare between groups with known changes in body mass as a result of pregnancy, cardiac parameters were scaled to height in this study. Previously published exponents for allometric scaling to height were used for cardiac output (1.83), SV (2.04) (18) and LV mass (2.70) (19), whilst EDV and ESV and internal dimensions were scaled using predicted exponents (2.00 and 1.00, respectively) determined by the theory of dimensionality (20). The coefficient of variations for measurement of cardiac output, stroke volume and end diastolic volume were 3.2, 3.0 and 3.0%, respectively. Systemic vascular resistance (SVR) was calculated as MAP/cardiac output.

Traditional measures of systolic and diastolic function were also measured. Using the volume measurements above, EF was calculated as

(SV/EDV) x 100. Peak systolic (S'), early (E') and late (A') diastolic septal velocities were measured to determine tissue displacement across the cardiac cycle and were scaled to LV length (21). The intra-observer coefficient of variations for measurement of S', E' and A' were 5.8, 7.1 and 5.5%, respectively. Trans-mitral blood flow velocities (E and A) were also measured and the E/A ratio calculated.

Evaluation of LV mechanics

Speckle-tracking echocardiography (STE) was used to measure longitudinal, basal and apical circumferential strain, as well as basal and apical rotation to calculate LV twist. STE is an offline analysis technique that provides local displacement information by tracking natural acoustic markers within myocardial tissue, known as speckles, as previously described (22). The data presented were an average of myocardial segments identified through STE. Longitudinal strain was measured through tracing the LV endocardial border in the apical 4-chamber view. Apical and basal circumferential strain and rotation were derived from parasternal short axis apical and basal views. Twist was calculated by subtracting time-aligned basal rotation from apical rotation and scaled to LV length to calculate torsion (°/cm). Strain and rotation curves for three cardiac cycles were generated. The raw frame-by-frame data was transformed using software (2D Strain Analysis Tool, Stuttgart, Germany) that applied a cubic spline interpolation to separate systole and diastole into 600 data points each. This enabled time alignment of data, allowing for inter- and intra-individual variability in HR and individualized frame rate at image acquisition. Cardiac cycles with insufficient tracking were excluded from the analysis and are noted in each dataset affected. Peak and time to peak (%)

strain, rotation and twist were calculated. Systolic and diastolic strain, and twist and untwist velocities were also measured. The intra-observer coefficient of variations for measurement of longitudinal strain, basal and apical circumferential strain and twist were 7.7, 11.7 and 10.5, and 24.3%, respectively.

Outcome of pregnancy

Gestational outcomes, including gestational age at delivery, infant birthweight, and development of gestational complications, were self-reported and collected using a questionnaire. Women in the pregnant group completed the questionnaire via email or telephone interview within 6 months of delivery. Postpartum women completed the questionnaire during their visit.

Statistical analyses

Data are presented as mean ± standard deviation (SD). Statistical analyses were conducted using either SPSS (Version 22.0 IBM SPSS Statistics for Macintosh, IBM Corp., Armonk, NY) or GraphPad Prism software (GraphPad Prism for Mac, Version 7.0a, Dan Diego, California, USA). Alpha was set at 0.05. One-way analyses of variance (ANOVA) and independent T-tests were used to detect differences between volunteer characteristics. In all cases, data were checked to ensure statistical assumptions were met. Tukey-Kramer *post hoc* test comparisons were completed if the main effects of ANOVA were statistically significant.

Analyses of covariance (ANCOVA) were used to determine differences in cardiac parameters after incorporation of covariate parameters (including age, as well as HR, EDV and SBP in the analyses of LV mechanics).

Assumptions of ANCOVA were checked: linear relationships and homogeneity of regression slopes between parameters were assessed by visual inspection of scatterplots. Standardized residuals for groups and the overall model were assessed by Shapiro-Wilk's test (P> 0.05) for normal distribution. Homoscedasticity and homogeneity of variance were assessed by visual inspection of a scatterplot and Levene's test of homogeneity of variance, respectively. If statistical significance between groups was identified, *post hoc* analyses were performed with a Bonferroni adjustment. Effect size, specifically η_p^2, was estimated for all analyses using a full factorial univariate model within SPSS. Effect size was interpreted as 0.01 = small effect, 0.06 = medium effect and 0.14 = large effect.

In order to investigate the influence of hemodynamic load on LV mechanics, Pearson's correlation was used to identify the relationships to indices of hemodynamic load (HR, SBP, EDV). Linearity and outliers were confirmed by visual assessment of scatter plots. Outliers were included in analyses without transformation if identified, as above. Normality was assessed using Shapiro-Wilks test (> 0.05). The correlation coefficient (r) was interpreted as $0.1 < r < 0.3$ small correlation; $0.3 < r < 0.5$ moderate correlation and $r > 0.5$ strong correlation. The coefficient of determination (r_2) was calculated to determine the variance between variables.

RESULTS

Forty-seven women volunteered to participate (non-pregnant women = 19, pregnant women between 22-26 weeks gestation = 15, postpartum women 12-16 weeks after delivery = 13). Based upon self-report, volunteers were healthy non-smokers, free from cardiovascular and/or metabolic diseases and

were not taking any medication at the time of inclusion. All pregnant and postpartum women had uncomplicated, singleton pregnancies and were primiparous, although women who had suffered one previous miscarriage before 12 weeks gestation were included (pregnant n = 2; postpartum n = 2). The average time point of assessment for pregnant women was 25.4 ± 0.6 weeks gestation, and for postpartum women 15.1 ± 1.3 weeks after delivery. The distribution of infant sex and method of delivery (vaginal, elective and emergency Caesarean section) were similar between pregnant and postpartum groups. Non-pregnant women were nulliparous and had never tried to conceive.

Two individuals withdrew from the study after recruitment; therefore, 45 Caucasian women completed data collection and were included within the final analyses (recruitment flow diagram and reasons for withdrawal included in supplementary material, Figure S1). Characteristics of the study population are presented in Table 1. As non-pregnant women were significantly younger than pregnant and postpartum women, age was included as a covariate in all statistical analyses.

In accordance with the current knowledge, pregnant women had significantly higher cardiac output compared with non-pregnant and postpartum women (Figure 1; unscaled and numerical data included in supplementary material Table S1). This was a result of both greater HR and SV (Figure 1). The significantly greater SV was underpinned by a significantly greater EDV in pregnant women versus non-pregnant women (Figure 1). Pregnant women also had significantly lower SVR compared to non-pregnant and postpartum

women (Figure 1). Non-pregnant women had significantly higher blood pressures compared to postpartum women (Table 1).

There were no significant differences in LV structure (supplementary material, Table S2), traditional measurements of systolic and diastolic function (supplementary material, Table S3), apical circumferential strain, twist or untwist mechanics (both Figure 2 and supplementary material, Table S4) between groups. In comparison to non-pregnant women, pregnant women had significantly greater peak longitudinal (-22±2 *vs*. -17±3%, *P*=0.002) and basal circumferential strain (-23±4 *vs.* -16±2%, *P*=0.001; Figure 2; additional data in supplementary material Table S4). Postpartum women had significantly greater basal circumferential strain (-24±6%, *P*=<0.001; Figure 2) compared to non-pregnant women, however, there were no significant differences in any other systolic or diastolic parameter between non-pregnant and postpartum women. LV mechanics were not significantly related to HR, EDV or SBP in non-pregnant, pregnant or postpartum women (Figure 3; additional data presented in supplementary material Table S5).

DISCUSSION

The aim of this study was to evaluate whether differences exist in LV mechanics in the second trimester of healthy pregnancy compared to the non-pregnant and postpartum state. We also aimed to determine the influence of underpinning hemodynamics on LV mechanics during gestation. Our hypothesis was partially supported by significantly greater longitudinal and basal circumferential strain, but not apical circumferential strain or twist, in pregnant versus non-pregnant women. Greater LV strain in pregnant women was not significantly related to HR or indices of preload and afterload. These

findings suggest that healthy pregnant women in the late second trimester have greater systolic function, when assessed using speckle tracking echocardiography, which appears not to be related to hemodynamic load.

LV mechanics are not independently related to preload, afterload or heart rate

Changes in hemodynamic load alter LV mechanics in the healthy human heart; however, in this study the greater LV strain parameters were not correlated to EDV, HR or SBP in pregnant women. It could be suggested that the elevated cardiac preload (greater EDV) and lower afterload (maintained SBP with a lower SVR) observed within this study may explain the greater systolic function via activation of the Frank-Starling mechanism and a greater velocity of fibre shortening, respectively. However, there were no associations between hemodynamic load and systolic function parameters in pregnant women. We therefore suggest that the altered HR, preload and afterload of gestation, may only partially contribute to the greater LV strain observed. It is possible that other physiological alterations of pregnancy, such as altered hormonal milieu and/or elevated sympathetic activity, influence cardiac function; however, this hypothesis must be tested in a longitudinal study including such measurements.

Previous work has shown increased sympathetic activity during healthy pregnancy (23, 24) as well as activation of the renin-angiotensin-aldosterone system both of which may exert inotropic effects on the maternal heart (25). Additionally, the increased circulating estrogen associated with healthy pregnancy may also influence cardiac function. Estrogen upregulates the action of L-type calcium ion channels in cardiomyocytes isolated from the base, but not the apex (26), therefore, higher levels of estrogen during pregnancy may

result in greater myocyte contraction at the basal epicardium causing greater deformation, as shown by greater longitudinal and basal circumferential strain in this study. Together, the elevated sympathetic drive and altered hormonal milieu of pregnancy may contribute to altered systolic function observed during healthy pregnancy independent of any changes in overall hemodynamic load.

Enhanced systolic function during healthy pregnancy

In previous clinical studies in non-pregnant populations, a reduction in LV strain has been associated with cardiac dysfunction and pathology (9), in contrast; greater deformation in a physiological state such as healthy pregnancy may reflect a positive adaptation to increased cardiac demand at rest. We interpret the greater longitudinal and basal circumferential strain in pregnant women in this study as an “enhanced” systolic function. However, it is possible that increased resting systolic function may result in a lower capacity to respond to acute physiological challenges (27), and a blunted cardiac reserve. Without the assessment of the dynamic responses to increased cardiovascular demand, we are yet to fully understand if the cardiac reserve is maintained or reduced during the second trimester of pregnancy (28).

Greater LV strain in the late second trimester of pregnancy as shown in this study is discordant with previous literature. Both unchanged (3-6, 12) and decreased (13) longitudinal and circumferential strain have been reported at similar time points of gestation. It is likely that the broad time ranges of assessment in previous studies and the inclusion of heterogeneous cohorts (multigravida, twin and complicated pregnancies) may explain these differences. Our study cohort consisted of healthy, primiparous women assessed during a short gestational window. Therefore, our results cannot be

generalized to multigravida or multiple gestations, or to pregnant women outside of this gestational age. The homogenous cohort included in this study provides strong support that healthy pregnant women do not experience reductions in systolic or diastolic function between 22-26 weeks.

Clinical and research implications

The present data prompt speculation that otherwise healthy women who present with reduced cardiac function, specifically LV mechanics, at this time point in pregnancy may develop cardiovascular complications later in gestation. Disorders such as preeclampsia and gestational hypertension amalgamate with significant cardiac dysfunction (16) including significant reductions in EF. In other populations, previous work has shown that reductions in LV strain precede reductions in EF and the development of overt disease (29). The assessment of LV mechanics, over and above standard echocardiography, completed in the early second trimester could identify women who later develop cardiovascular complications however, this hypothesis requires further investigation.

Study limitations and strengths

Our understanding of LV mechanics in healthy pregnancy would be improved by additional research at different stages of gestation. Previous work by Melchiorre *et al*. has shown significant reductions in diastolic function in otherwise healthy pregnant women from the early third trimester (28 to 32 weeks) to term (37 to 39 weeks) (30), highlighting that dysfunctional change can occur over a short duration and at a critical point of pregnancy. The assessment of LV mechanics at term may provide further insight into

adaptations that lead to the impairments in maternal cardiac function in late gestation. Although not feasible in this study, future work should utilize a longitudinal design with multiple assessments at preconception, during each trimester and at term, as well as during the postpartum period in order to fully elucidate changes in myocardial deformation across pregnancy.

There were several limitations in this study including the small sample size that was powered to achieve the first aim of this study. As such, the results of the correlational analyses may differ with a powered sample size. The cross-sectional nature of this study prevents the understanding of within-individual adaptation, which would provide greater insight into the factors underpinning differences in LV mechanics. Additionally, the clinical relevance of LV mechanics during pregnancy would be better understood if women diagnosed with cardiovascular complications such as gestational hypertension and preeclampsia were also studied. Finally, it must be noted that longitudinal strain is only a proxy of LV contraction due to the double helical, and not longitudinal, arrangement of myocytes (31). However, in this study both longitudinal and basal circumferential strain were significantly greater in pregnant women.

Conclusions

Women in second trimester of healthy pregnancy have significantly greater cardiac contractile function compared to non-pregnant and postpartum women. The significantly greater LV strain observed was not related to preload, afterload or heart rate, and may be result of other physiological adaptations to pregnancy.

DISCLOSURES

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TABLES

Table 1. Volunteer characteristics.

		Non-pregnant	Pregnant	Postpartum	*P*	η_p^2
	n	18	14	13		
Age (years) ‖		28±4 *	32±3	33±2	0.001 ¶	0.360
Body mass (kg) ‖		64±13	73±8	67±11	0.07	0.122
Height (cm) ‖		166±7	167±4	166±4	0.78	0.012
BMI ($kg \cdot m^2$) ‖		23±4	26±4	23±4	0.07	0.118
SBP (mmHg)		113±7	109±8	105±6 †	0.01	0.186
DBP (mmHg)		68±6	63±5	61±4 †	0.002	0.256
MAP (mmHg)		83±6	79±6	75±4 †	0.002	0.264
Birthweight (kg) §		NA	3.46±0.47	3.14±0.50	0.10	0.107
GA at delivery (wks) §		NA	40.3±2.2	39.7±1.5	0.39	0.031

N.B. Data as mean±SD. BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; NA, not applicable; GA, gestational age. *P*-value and effect size (η_p^2) from ANCOVA (age as covariate). Multiple comparisons identified through *post hoc* Tukey-Kramer tests.

‖ indicates statistical analysis completed using ANOVA.

§ indicates statistical analysis completed using independent T-tests.

***** $P < 0.05$ *vs.* pregnant and postpartum, **†** $P < 0.05$ *vs.* non-pregnant.

¶ *P* value is less than 0.0001

FIGURE LEGENDS

Figure 1. Healthy pregnant women in the late second trimester have greater cardiac output (A), heart rate (C), stroke volume (D) and lower systemic vascular resistance (B) compared to non-pregnant and postpartum women.

N.B. Data presented as mean±SD. EDV, end-diastolic volume (E); ESV, end-systolic volume (F). *P*-value and effect size (η_p^2) from ANCOVA with age as a covariate. Statistically significant comparisons identified through *post hoc* Bonferroni procedure. Capped lines indicate significant difference between respective groups ($P < 0.05$), * only indicates significant difference to all groups ($P < 0.05$). ¶ *P* value is less than 0.0001.

Figure 2. Longitudinal (A) and basal circumferential strain (B) were significantly greater in pregnant women compared to non-pregnant women, with no significant differences in apical circumferential strain (C) or left ventricular twist (D) between groups.

N.B. Data presented as mean±SD. *P*-value and effect size (η_p^2) from ANCOVA with age, heart rate, systolic blood pressure and end-diastolic volume as covariates. Statistically significant comparisons identified through *post hoc* Bonferroni procedure. Capped lines indicate significant difference between respective groups ($P < 0.05$), * only indicates significant difference to all groups ($P < 0.05$). ¶ *P* value is less than 0.0001.

Inadequate speckle tracking led to a reduction in the n included in this analysis. Non-pregnant *n* reduced to 17 in all parameters, except basal circumferential strain. Pregnant *n* reduced to 12 in longitudinal strain and 13 in basal circumferential strain analyses. Postpartum *n* reduced to 12 in analysis of longitudinal strain (presented in Supplementary material – Table S5).

Figure 3. Left ventricular mechanics were not significantly related to heart rate, end-diastolic volume (EDV) and systolic blood pressure (SBP) in non-pregnant women, pregnant women between 22-26 weeks gestation and postpartum women 12-16 weeks after delivery.

N.B. r, r^2 and *P*-value determined via Pearson's correlations (presented in Supplementary material - Table S5).

Inadequate speckle tracking led to a reduction in the n included in this analysis. Non-pregnant *n* reduced to 17 in all parameters, except basal circumferential strain. Pregnant *n* reduced to 12 in longitudinal strain and 13 in basal circumferential strain analyses. Postpartum *n* reduced to 12 in analysis of longitudinal strain (presented in Supplementary material – Table S5).