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Short communication

Ventricular efficiency in pregnant women with congenital heart disease

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ABSTRACT

Backgrounds: Pregnant women with congenital heart disease (CHD) are at risk of cardiovascular events during pregnancy as well as postpartum. The aim of our study is to address the feasibility of echocardiography-derived ventricular–arterial coupling during pregnancy and postpartum among women with CHD.
Methods: In 31 pregnant women with CHD, we performed serial echocardiography at the first and third trimesters, early and late postpartum. The indices of contractility (single-beat determined end-systolic elastance, Ees_{ab}) and afterload (effective arterial elastance, Ea) were approximated on the basis of the systemic blood pressure and systemic ventricular volume. The ratio of stroke work and pressure–volume area (SW/PVA) representing ventricular efficiency was also calculated.
Results: Age at the delivery was 28 (24–31) years. ZAHARA score was 0.75 (0.75–1.50). Gestational age and birth weight of newborns were 38 (37–39) weeks and 2.73 (2.42–2.92) kg, respectively. Heart rate, systemic ventricular end-diastolic volume and stroke volume significantly increased from the first trimester to the third trimester and reversed postpartum to the values of the first trimester. Ees_{ab} and Ea significantly decreased from the first trimester to the third trimester (Ees_{ab}; 4.90 [2.86–7.14] vs 3.41 [2.53–4.61] mm Hg/ml, $p = 0.0001$, Ea; 2.83 [1.74–3.30] vs 2.18 [1.67–2.68] mm Hg/ml, $p = 0.0012$), and reversed early postpartum parallelly. Ejection fraction and SW/PVA remained unchanged throughout pregnancy and postpartum.
Conclusions: Echocardiography-derived ventricular–arterial coupling is feasible to understand ventricular function in pregnant women with CHD.

1. Introduction

Pregnant women with congenital heart disease (CHD) are at risk for developing heart failure, arrhythmia, and thromboembolic complications during pregnancy, delivery and postpartum, and they should be appropriately identified and managed [1–3]. The ZAHARA and CARPREG studies revealed that these complications were related to the maternal cardiac function [4,5]. Maternal hemodynamic changes are characterized with a 30–50% increase in cardiac output and plasma volume and a 30% reduction in systemic vascular resistance during pregnancy [6,7]. These changes reversed in the first 2 weeks after delivery and normalized toward preconception values after 3–12 months [8]. Although exercise stress testing and cardiac magnetic resonance imaging are useful to assess hemodynamics, these modalities are not suitable for repetitive cardiac evaluations during pregnancy and postpartum [9,10]. Transthoracic echocardiography is still a mainstay of cardiac evaluation in pregnant women with CHD, but conventional echocardiographic parameters lack the sensitivity to detect early hemodynamic changes [11]. Therefore, a more useful parameter for cardiac evaluation is required to allow more accurate identification of maladapted cardiovascular physiology in pregnant women with CHD.

The end-systolic pressure–volume relation obtained from left ventricular pressure–volume loops provides a useful parameter of cardiac function [12,13]. The ventricular end-systolic elastance (Ees) referred as the slope of the end-systolic pressure–volume relation quantifies

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ventricular contractility and stiffness, and the arterial elastance (Ea) referred as the ratio of end-systolic pressure to stroke volume integrates arterial afterload. To calculate Ees and Ea, the standard method is invasive measurements of ventricular volumes recorded over a range of cardiac loading, but it is not ethically acceptable for pregnant women. Currently, a noninvasive approach has been described to estimate Ees, which is generally referred as single-beat determined Ees (Ees_{sb}) [14,15]. We aim to evaluate the hemodynamic changes in pregnant women with CHD from the aspect of the ventricular energy efficiency.

2. Methods

2.1. Subjects

This study was approved by the institutional ethics committee (approval number 381). Informed content was obtained from all participants. In the present retrospective cohort study, pregnant subjects referred for transthoracic echocardiography were identified using the database of Kyushu Hospital between 2010 and 2017. We identified 54 pregnant women with CHD. We excluded subjects with suboptimal imaging quality, and subjects with the systemic right ventricle or single ventricle physiology. A total of 31 pregnant women with CHD were studied. We obtained maternal and neonatal profiles from the clinical records, and performed echocardiography at the four points: the first and third trimesters, early and late postpartum. The first and third trimesters were defined as 1–12 and 27–42 weeks, respectively. Early and late postpartum periods were defined as within a week after the delivery and around 6 months after the delivery, respectively.

2.2. Echocardiographic assessments of ventricular energy efficiency

All subjects underwent standard transthoracic echocardiography using Philips iE33 or Acuson Sequoia 512 according to the American Society of Echocardiography guidelines [16]. We obtained 2-dimensional images from the apical four chamber view while the subjects were in the left lateral decubitus position. From the acquisitioned images from the apical four chamber views, we measured systemic ventricular volumes using the commercial echocardiographic analysis software TomTec Arena ™ (TomeTec Imaging Systems GmbH, München, Germany). The ventricular end-diastolic and end-systolic volumes were measured by Simpson's method. Validities for volume measurements were evaluated by two observers (J.M. and A.F.). Stroke volume (SV) and ejection fraction (EF) were calculated based on ventricular end-diastolic volume (VEDV) and end-systolic volume. The end-systolic elastance (Ees_{sb}), the index of contractility was determined using a modified single-beat algorithm described and validated by Chen et al. [15]. The effective arterial elastance (Ea), the index of afterload was derived from the end-systolic pressure divided by stroke volume, where end-systolic pressure was estimated as: 0.9 × systolic pressure measured by manual blood pressure cuff measurement at the time of echocardiography. The ratio of stroke work and pressure–volume area (SW/PVA) represents the left ventricular energy efficiency, which was estimated using the theoretic formula; $SW/PVA = 1 / (1 + 0.5 \times Ea/Ees_{sb})$ [17].

2.3. Statistical analysis

Statistical analysis was performed using the Analysis ToolPak in the Microsoft Office Excel™ add-in software. Values were expressed as the median following the interquartile rage. We compared variables between the first and third trimesters, early and late postpartum using the Freidman test and Wilcoxson signed-rank test. For all statistical analyses, a p value <0.05 was considered statistically significant.

3. Results

A summary of maternal and neonatal characteristics is shown in Table 1. Age at the delivery was 28 (24–31) years. All subjects except those with congenital mitral, aortic, and pulmonary valve disease were at postoperative states. There was no patient who underwent mechanical valve replacement and one patient who underwent pacemaker implantation due to postoperative complete atrioventricular block. According to the risk assessment score provided by Zwangerschap bij Aangeboren HARtAfwijkingen (ZAHARA score), there were ZAHARA score ≦0.5 in 7; 0.5 <, ≦1.5 in 21; 1.5<, ≦2.5 in 3, which suggested that our cohort comprised women at relatively low risks for pregnancy [4]. Ten patients were administrated with cardiovascular medicine including digoxin, beta-blocker, angiotensin converting enzyme inhibitor or diuretics. Regarding newborns, the median gestational age and birth weight were 38 (37–39) weeks and 2.73 (2.42–2.92) kg, respectively. There were 7 preterm deliveries and 8 neonatal complications.

Echocardiographic data was shown in Fig. 1. Intraobserver and interobserver correlations were 0.84 ($p < 0.001$) and 0.88 ($p < 0.001$), respectively. There were statistically significant changes in HR, VEDV, SV, Ees_{ab}, and Ea during pregnancy and postpartum. HR, VEDV and SV significantly increased from the first to the third trimester ($p < 0.0001$, $p = 0.0009$ and $p = 0.0019$, respectively). HR remained unchanged early postpartum ($p = 0.141$) and gradually decreased late postpartum ($p = 0.0007$). VEDV and SV promptly reversed to the values at the first trimester after delivery ($p = 0.0213$ and $p = 0.0055$). Ees_{ab} and Ea significantly decreased during pregnancy (Ees_{ab}; 4.90 [2.86–7.14] vs 3.41 [2.53–4.61] mm Hg/ml, $p = 0.0001$, Ea; 2.83 [1.74–3.30] vs 2.18 [1.67–2.68] mm Hg/ml, $p = 0.0013$) and reversed early postpartum (Ees_{ab}; 4.12 [3.16–5.15] mm Hg/ml, Ea; 2.65 [1.98–3.72] mm Hg/ml). Otherwise, EF and SW/PVA remained unchanged throughout pregnancy and postpartum ($p = 0.5344$ and $p = 0.0917$, respectively). Maternal comorbidities, medications and neonatal complications were not related to hemodynamic changes.

4. Discussions

The major finding of our present study is that ventricular energy efficiency is constant throughout pregnancy and postpartum in pregnant women with CHD who have low risks for cardiac events. According to

Table 1
A summary of maternal and neonatal clinical data.

Maternal data	
Age at delivery, years	28 (24–31)
Parity status	
Primary congenital defect	
D-TGA	7
VSD	6
AVSD	5
ASD	4
TOF	3
DORV	2
Isolated valvular disease	4
Mechanical valve	0
Pacemaker	1
ZAHARA score	
≦0.5	7
0.5<, ≦1.5	21
1.5<, ≦2.5	3
2.5<, ≦3.5	0
NYHA function class	
I–II	31
III–IV	1
Other problems	
Blood type incompatible	2
Epilepsy	2
PIH	1
Diabetes mellitus	1
Asthma	1
Scoliosis	1
Cardiovascular medication	10
Neonatal data	
Gestational weeks	38 (37–39)
Body weight at birth, kg	2.73 (2.42–2.92)
Delivery	
Transvaginal	23
Cesarean section	8
Neonatal problems	
Low birth weight newborn	2
Cardiac anomaly	2
Hyperbilirubinemia	2
Asphyxia	1
Pneumothorax	1

VSD; ventricular septal defect, ASD; atrial septal defect, AVSD; atrioventricular septal defect, d-TGA; d-transposed great arteries, TOF, tetralogy of Fallot, DORV; double outlet right ventricle, ZAHARA score; Zwangerschap bij Aangeboren HARtAfwijkingen, NYHA; New York Heart Association, PIH; pregnancy induced hypertension.