BIOMECHANICAL PARAMETER PREDICTS SUCCESSFUL FETAL HEART INTERVENTION OUTCOME BETTER THAN CLINICAL SCANS

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Introduction

Fetal heart interventions aim to resolve mid-gestational cardiac abnormalities, preventing the progression to malformations at birth. Fetal aortic valvuloplasty (FAV) is performed on fetal hearts with critical aortic stenosis and evolving hypoplastic left heart syndrome (CAS-eHLHS), to widen the aortic valve and promote healthier development in gestation, thus reducing the likelihood of a univentricular (UV) birth outcome from ~73% to ~32% [1]. However, a considerable number of cases develop to a UV birth outcome post-FAV, suggesting clinical scans alone lack satisfactory predictive capabilities, and patient selection from scans is not sufficiently accurate. Here, we performed image-based patient-specific cardiac finite element (FE) modelling, to investigate if biomechanical parameters have stronger predictive capabilities of birth outcomes, post-FAV, to improve patient selection.

Methods

Analysis of echocardiographic clinical data for pre-FAV CAS-eHLHS fetal hearts, such as valvular velocities, morphometrics and strains was conducted on 9 diseased fetal cases (4 with UV birth outcomes and 5 with biventricular (BV) birth outcomes). FE modelling was performed on 4D echocardiographic images of fetal left ventricles (LV), using previous methods [2] and was coupled to an age-scalable lumped parameter model. An optimisation algorithm ensured a patient-specific match between the FE models of these cases to clinical measurements. 5 healthy fetal LVs were also analysed and modelled for comparison.

Results

CAS-eHLHS results in reduced circumferential and longitudinal strains, stroke volume and the presence of mitral regurgitation. Pre-FAV echocardiographic parameters such as valvular velocities, morphometrics, and myocardial strain values and Z scores did not distinguish between cases that would go on to be BV or UV (sample plots in Figure 1A-B). However, cases that went on to be BV had significantly larger cardiac measurements compared to healthy cases (example of end diastolic volume (EDV) results in Figure 1B). With FE modelling of diseased LVs, cases with BV outcomes showed elevated peak LV pressure, work done, peak myofiber stress and back-computed myocardial contractility, compared to those with UV outcomes. Diseased biomechanical parameters were normalised by the regression curve of healthy data (Figure 1C-D), which showed peak myofiber stress to be significantly higher in cases with BV birth outcomes compared to UV, with no overlap in group parameters (Figure 1C).

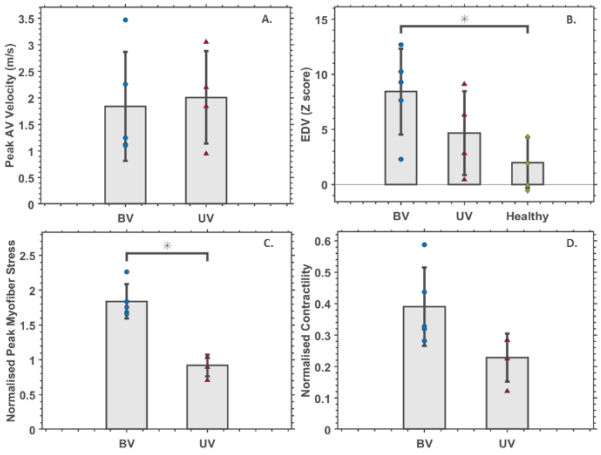

Figure 1: *Bar charts showing mean, standard deviation, and actual data points, with statistical significance at $p<0.05$ indicated by *. [A-B] Example of image-based analysis results, showing no statistical difference between BV and UV outcomes. [C-D] Peak systolic myofiber stress and back-computed myocardial contractility computed through FE computational methods and normalised by the regression curve of healthy data.*

Discussion

Our modelling results suggest that CAS-eHLHS cases that respond well to intervention (go on to be BV at birth, as opposed to UV) tend to be biomechanically "stronger" and larger, with generally larger myocardial contractility and LV size. Peak myofiber stress was able to significantly differentiate between models that would go on to be BV or UV post-FAV. Image-based analysis of the CAS-eHLHS cases, using clinical echocardiographic measurements, was generally unable to distinguish between cases that would go on to be UV or BV as clearly. An improved ability to predict outcomes will allow better patient selection and avoids patients going through procedural risks unnecessarily. Our findings thus demonstrate the benefits of incorporating in-depth computational models to the clinical assessment of CAS-eHLHS patients.

References

1. Pickard S, et al., Circulation, 13:32-41, 2020.
2. Green L, et al., Biomech Model Mechanobiol, 1-15, 2022.

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