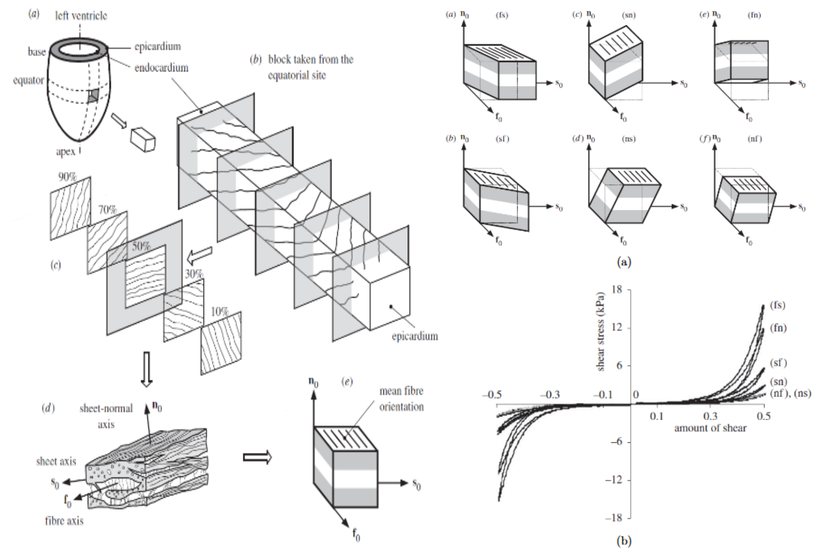
The impact of myocardial fiber orientation on the left ventricle diastolic compliance: an in-silico study

Castaldi B., Angelini A., De Filippi E., Susin F., Cattapan I., Fedrigo M., Boso D., Peruzzo P., Comunale G., Milanesi O.
University of Padua, Italy

BACKGROUND

Left ventricular myocardium is arranged in a complex three-dimensional network of fibers, which forms a counterclockwise helix in the endocardial layer and a clockwise helix in the epicardial layer.
The architecture of left ventricular myocardium is changing over the gestational age.
To build an appropriate in silico model is essential to know the "mechanical response" of the tissue / organ to be studied.
By the histological point of view either the muscle and the extracellular matrix have to be considered.

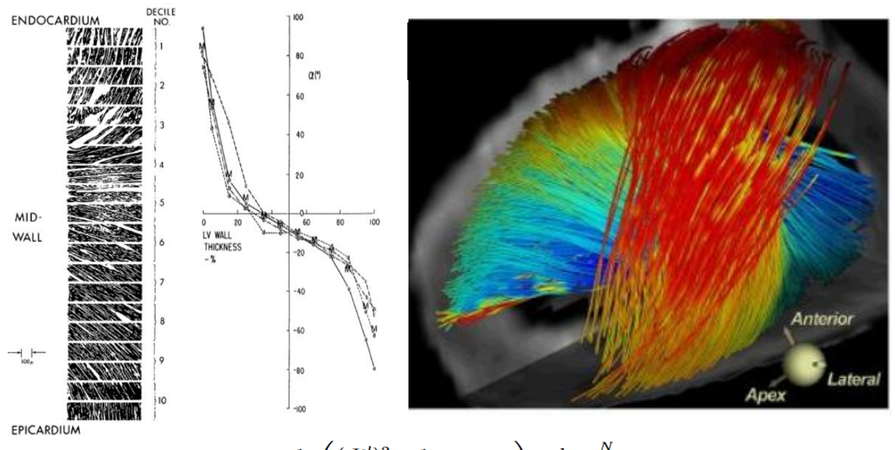


AIM OF THE STUDY

- To evaluate separately by Speckle Tracking Echocardiography endocardial and epicardial functional in human fetuses.
- To combine these data with morphometric observations on histological sections of fetal human hearts, and to compare the development of the different myocardial layers at different gestational ages.
- To verify *in-silico* the influence of different myocardial fibers arrangements on diastolic performance.

METHODS

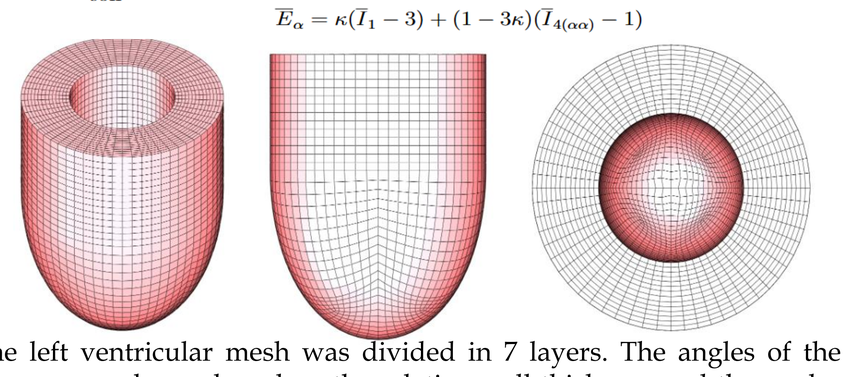
- To study fetal myocardial function, 72 fetuses and 39 premature babies without cardiac pathologies were enrolled. We studied longitudinal endocardial and epicardial strain.
- For the histological section, we studied 20 fetal hearts without cardiac pathologies from fetal autopsy investigation. We determined the single layer's thickness and cardiac fibers orientation in comparison with gestational age.
- Concerning the *in-silico* study, three finite element models of the left ventricular myocardium were developed, corresponding to 20, 30 and 40 GW fetuses. An idealized thick walled ellipsoidal shape was considered, based on the values obtained from fetuses and neonates. Different combinations for the fiber orientations were tested.



$$U = C_{10}(\bar{I}_1 - 3) + \frac{1}{D}\left(\frac{(J^{el})^2 - 1}{2} - \ln J^{el}\right) + \frac{k_1}{2k_2}\sum_{\alpha=1}^{N}\{\exp[k_2\langle \bar{E}_\alpha\rangle^2] - 1\} \quad (4.1)$$

con

$$\bar{E}_\alpha = \kappa(\bar{I}_1 - 3) + (1 - 3\kappa)(\bar{I}_{4(\alpha\alpha)} - 1)$$

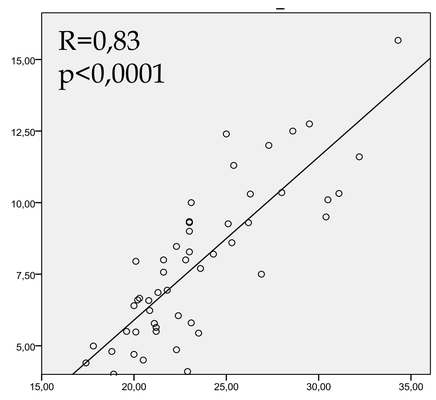


The left ventricular mesh was divided in 7 layers. The angles of the layers were chosen based on the relative wall thickness and the angles found by histology. For 40 GW, alternative models were tested. The model was based on the formula proposed by Holzapfel. Systolic and diastolic pressures were calculated following the algorithm proposed by Peña et al.

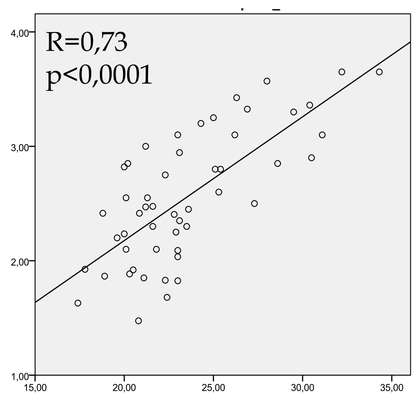
RESULTS

Echo data - LV dimensions

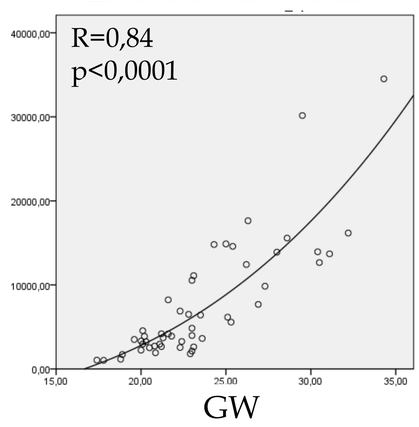
Transverse diameter



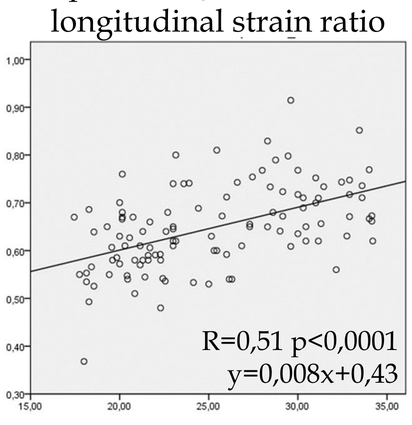
Wall thickness



End diastolic volume

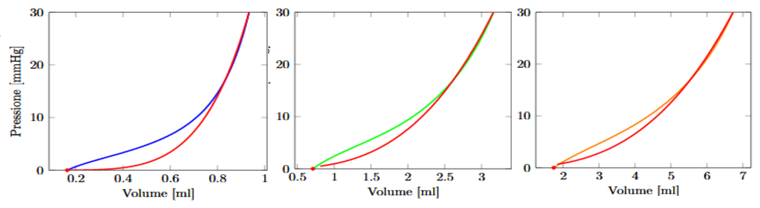


Epicardial /endocardial longitudinal strain ratio

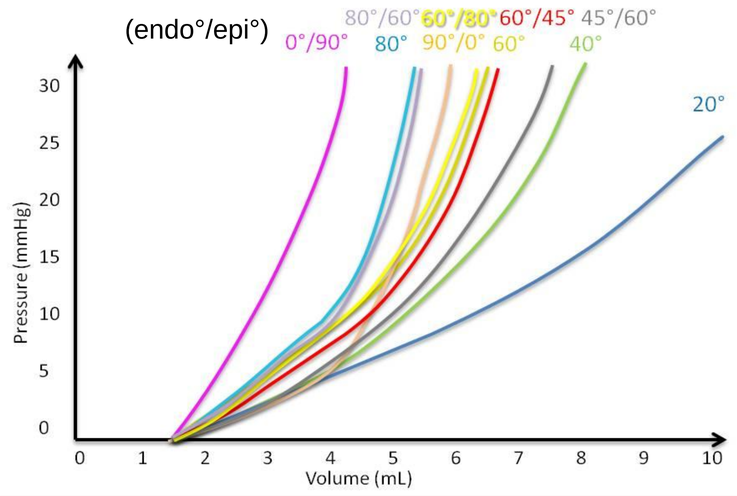


In silico models

20 WoG | 30 WoG | 40 WoG

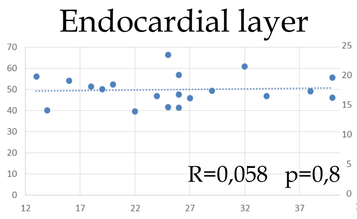


Alternative models of myocardial fibers orientation

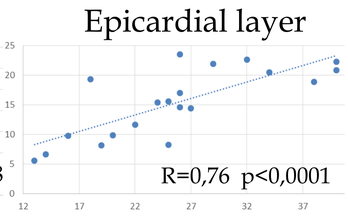


Histology – relative wall thickness of the single layer and % of trabeculae

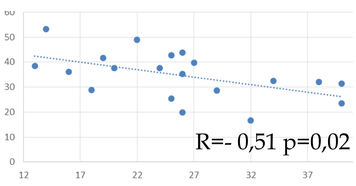
Endocardial layer



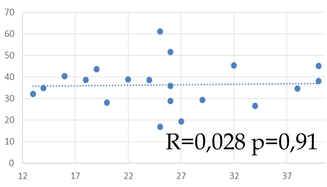
Epicardial layer



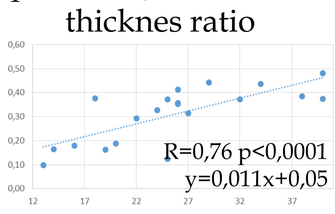
Mesocardium



Trabeculae



Epicardial /endocardial thicknes ratio



CONCLUSION

At early gestational age (<12 GW) the fibers are arranged radially.
From 12 GW the endocardial longitudinal layer develops first. The epicardial layer grows later, the development is completed at the end of the gestation. Histological data confirm the functional data detected by speckle tracking
Computational models showed that a less longitudinal arrangement of the myocardial fibers gives higher diastolic compliance. The endocardial longitudinal fibers are the main contributors for the preservation of the shape of the left ventricle.
Based on these data, the reduction of the fibers' angle in the endocardial longitudinal layer can be a compensatory effect to prevent the increase of left ventricular stiffness. This mechanism is well known in the early phase of diastolic heart failure, by speckle tracking assessment.
Future studies should be addressed to test the systolic efficiency of the different patterns hypothesized.

Disclosure: none.