Asociación Argentina de Mecánica Computacional

Mecánica Computacional Vol XXIX, págs. 35-35 (resumen)
Eduardo Dvorkin, Marcela Goldschmit, Mario Storti (Eds.)
Buenos Aires, Argentina, 15-18 Noviembre 2010

UNDERSTANDING THE MECHANICAL ORIGINS OF CONGENITAL HEART DISEASE

Sandra Rugonyi

Oregon Health & Science University, Portland, OR, United States

Abstract. The development of the heart depends on the interplay between genetic and environmental factors. In developed countries, congenital heart disease affects about 1% of newborn babies and is the leading, non-infectious cause of death among children. Although a few genes that contribute to congenital heart disease have been identified, the majority of congenital heart disease cases cannot be explained by genetic anomalies. Interestingly, blood flow through the heart is a key environmental factor affecting cardiac development, with abnormal blood flow conditions during early development leading to cardiac defects. Anomalous blood flow conditions during fetal development – for example due to placental anomalies – might account for a large proportion of congenital heart defects. However, neither the mechanisms by which abnormal blood flow dynamics lead to cardiac defects nor the dynamics of the normal beating heart and of normal blood flow inside the heart during early development have been fully elucidated.

Shear stresses and pressures exerted by the flow of blood on the walls of the heart are believed to be key mechanical stimuli modulating heart development. Cardiac cells sense and respond to these mechanical stimuli, and in doing so, they modulate cardiac growth and development. Our goal is to quantify flow-induced stresses that result from normal and altered hemodynamics in the heart and predict the effect of these alterations on cardiac development. To this end, we study the heart of chicken embryos, since at very early stages of development the hearts of human and chickens are very similar and developmental processes are highly conserved among vertebrate species. In particular, we focus on a specific heart segment that is very sensitive to hemodynamic conditions, the heart outflow tract, at day 3 out of 21 days of incubation (Hamburger-Hamilton stage 18). During this stage, the heart is tubular, but beats and pumps blood. We use a combination of imaging data, physiological pressure measurements and finite element modeling to better understand the mechanics of the early developing heart, and study the effects of hemodynamics on cardiac development.

To better understand the mechanics of the developing heart, the chick heart is imaged in vivo using optical coherence tomography (OCT). After image reconstruction, 4D images of the heart, which show the 3D cardiac structure as the heart beats over time, are obtained. 4D images are then segmented to get a geometrical model of the heart wall. Blood pressure is measured upstream and downstream of the outflow tract using a servo-null system. Geometrical and pressure data are then incorporated into a finite element model of the developing heart outflow tract, from which flow-induced mechanical stresses can be quantified. Our results show that high shear stresses occur at regions where cardiac valves form, and alterations of these stresses result in valve anomalies.

An ongoing step of our work is the correlation of flow-induced mechanical stresses with gene expression patterns and the morphogenesis of the outflow tract wall under normal and abnormal flow conditions, to enhance our understanding of the origins of congenital heart disease.