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A numerical analysis on the right and left ventricles with circular and elliptical patches

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SOUHRN

Cíl: Při narození existuje komunikace mezi pravou a levou komorou, tato komunikace však po narození zmizí. V některých případech komunikace přetrvává a komory nemohou fungovat nezávisle na sobě. Tato abnormalita působí problémy, například hypertenzi, a komplikuje práci srdečních chlopní. Cílem této studie bylo analyzovat změny v napětí a deformaci stěny způsobené umístěním záplaty na junkci a zajištění optimalizované geometrie záplaty.
Metody: Pro tento účel byly metodou konečných prvků (finite element, FE) vypracovány modely dvou typů kruhových a eliptických záplat se shodnými materiálovými vlastnostmi, následně byly vypočítány a srovnány výsledky těchto dvou různých geometrií.
Výsledky: Při stejných hraničních a zátěžových podmínkách výsledky ukázaly, že eliptická záplata je spojena s menším napětím stěny a je bezpečná pro použití v komorách ve srovnání s kruhovou záplatou.
Závěr: Výsledky této studie mají význam nejen pro stanovení míry napětí a deformace stěny po našití záplaty, ale i pro zajištění optimalizované geometrie spojené s nižší incidencí komplikací.

Keywords:
Circular patch
Elliptical patch
Strain
Stress
Ventricles

ABSTRACT

Purpose: At birth, there is a communication between the right and left ventricles, but this communication disappears after the birth. In some cases, the communication has been continued and ventricles cannot operate independently on each other. This abnormal communication causes problems, such as hypertension and heart valves complications. The purpose of this study was to analyse alterations in stress and strain caused by placement of a patch on junction and offering optimized geometry for it.
Methods: For this purpose, finite element (FE) models of two types of circular and elliptical patches with the same material properties were established and the results of these two different geometries were calculated and compared.
Results: Considering the same boundary and loading conditions, the results revealed that the elliptical patch triggers less stresses and is safe to use in ventricle compared to the circular one.
Conclusion: The results of the concurrent study have implications not only for understanding of the magnitudes of the stress and strain because of a patch but also for providing an optimized geometry which brings about less complications.

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Introduction

In the recent years, the use of computer-assisted surgery design procedures is becoming more popular in the clinical decision-making process to replace empirical and often risky clinical experimentation to examine the efficiency and suitability of various reconstructive procedures in diseased hearts. According to the American Heart Association (AHA), congenital heart defects (present at birth) are the most common type of birth defect. They affect 8 out of every 1 000 newborns.[1,2]

Tetralogy of Fallot (TOF) is a congenital heart defect which is classically understood to involve four anatomical abnormalities. It is the most common cyanotic heart defect and the most common cause of blue baby syndrome.[3] TOF is usually a right-to-left shunt, in which higher resistance to right ventricular outflow results in more severe cyanosis symptoms.[4,5] According to the National Heart, Lung, and Blood Institute (NHLBI), TOF affects roughly five out of every 10,000 babies. The defect is found equally among boys and girls. TOF causes low oxygen levels in the blood, which can cause skin to have a bluish-purple color (cyanosis). Another common sign of TOF is a heart murmur. A heart murmur is an extra or unusual sound that a doctor might hear while listening to the heart. The sound occurs because the heart defect causes abnormal blood flow through the heart. For this purpose, doctors use a material, namely patch, to eliminate this communication.[6] In this study, at first, two ventricles were considered without patch and modeling by using the average pressure, then, two different kind of patches (circular and elliptical) were considered to study and compare to each other.

Methods

In this study the right ventricle (RV), left ventricle (LV), scar tissue, and patch materials were assumed to be hyperelastic, isotropic, nearly incompressible, and homogeneous.[7–11] The governing equations for the structure models are (summation convention is used)[12–16] as follows:

(1)

$$\rho v_{i,tt} = \sigma_{ij,j}\ , \quad i,j = 1,2,3 \qquad \text{sum over } j$$

(2)

$$\varepsilon_{ij} = \frac{(v_{i,j}+v_{j,i}+v_{\alpha,i}v_{\alpha,j})}{2}, \quad i,j,\alpha = 1,2,3 \qquad \text{sum over } \alpha$$

where σ is the stress tensor, ε is Green's strain tensor, v is solid displacement vector, subscript *tt* in *vi, tt* indicates the second-order time derivative, *f i,j* stands for derivative of the function with respect to the *j*th variable, and ρ is material density.

For the sake of simplicity, LV was included as a structure-only model with the same material parameters used for both the LV and RV tissues. The elastic modulus and Poisson's ratio of the right and left ventricles were considered to be 600 kPa and 0.27, respectively. Geometrical modeling for the right and left ventricles was elliptical hollow with height of 13 cm and its cross-sectional diameter was 6 cm. Two types of circular and elliptical patches were considered for analyzing. Diameter of circular patch is considered to be 4 cm. In addition, for elliptical patch large and small diameters were assumed to be 4 and 5.1 cm, respectively. With regard to the materials used for patch which usually was dacron, teflon, bovine pericardium, autologous pericardium, we considered dacron with the modulus of elasticity and Poisson's ratio were taken 8 MPa and 0.32, respectively (Fig. 1).[12,17]

Results and discussions

Heart without patch

In a healthy heart, the pressure in the LV is higher than in the RV,[18–20] hence, in the first model without using patch and while the right and left ventricles work independently, the average pressure in the right and left ventricle were 20 and 120 mmHg, respectively. Contours of stress

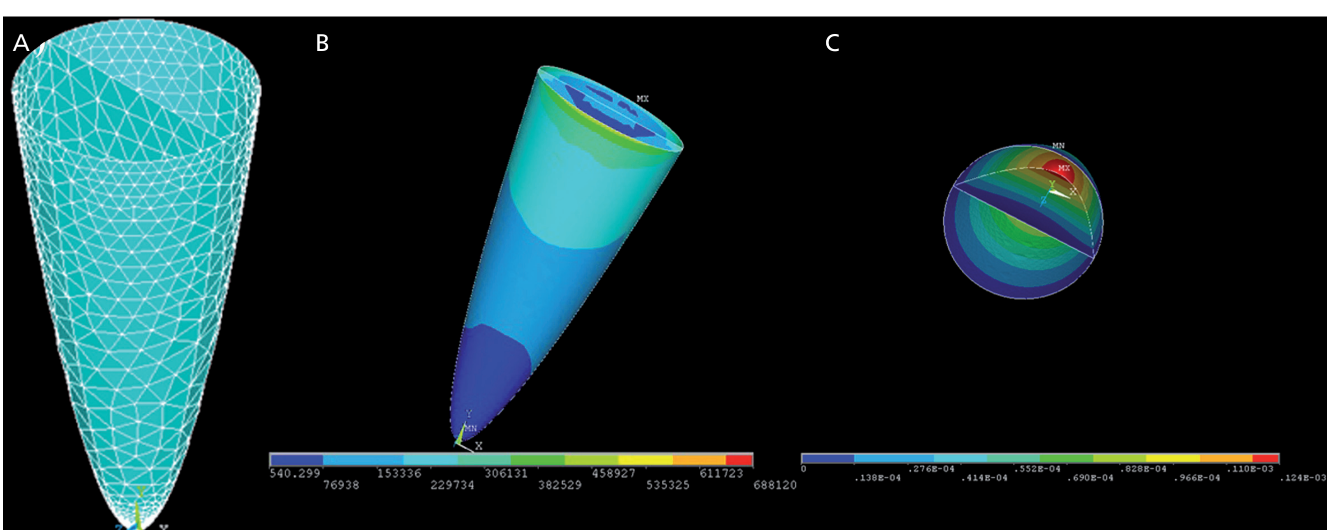

Fig. 1 – (A) The 2D model of ventricles. (B) The stress and (C) strain contours in a healthy ventricle without patch from the side and top views.

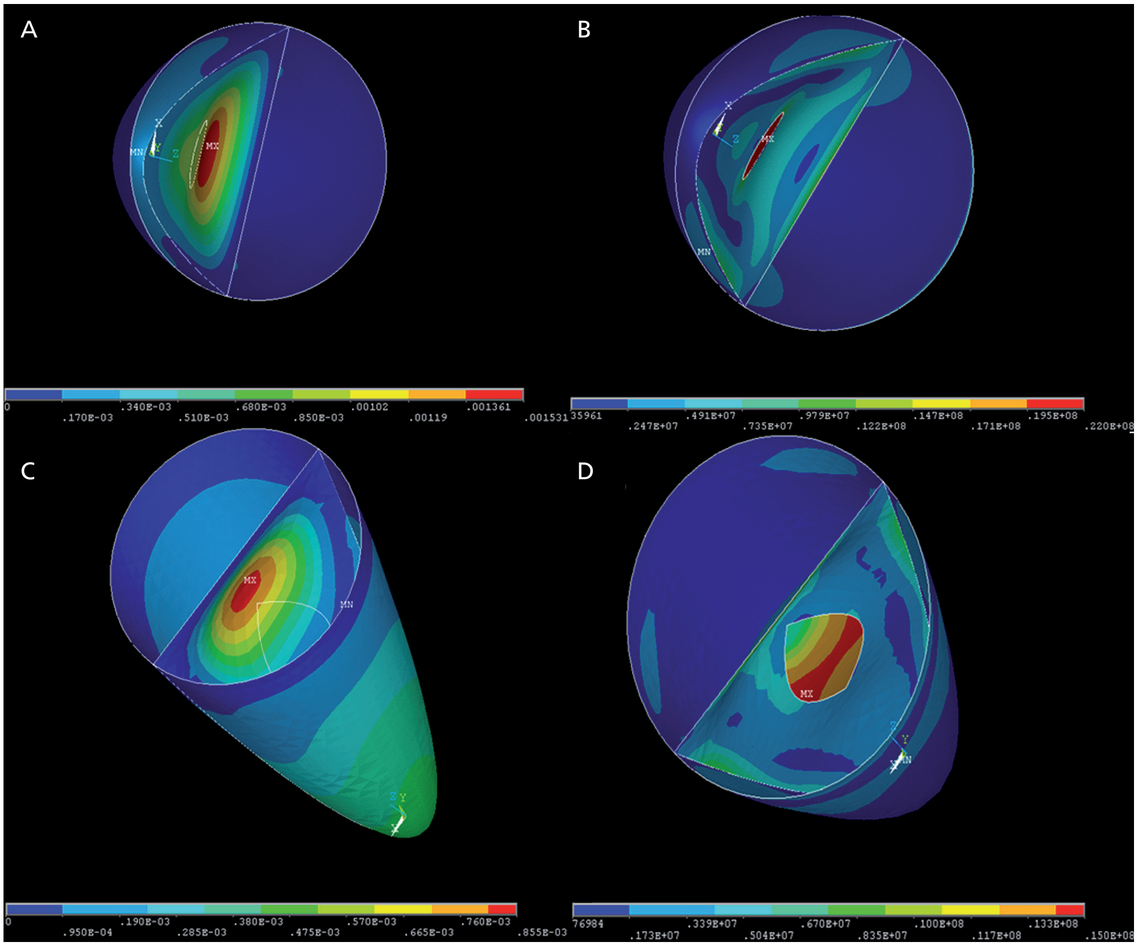

Fig. 2 – (A) Stress and (B) strain contours in a healthy ventricle with a circular patch. (C) Stress and (D) strain contours in a healthy ventricle with an elliptical patch.

and strain are illustrated in Fig. 1B and 1C. Because of the pressure difference, changes of stress and strain in the LV were significant compared to the RV. Fig. 1C indicates wall between the two ventricles which was deformed and distorted because of the effect of the pressure difference as we expected, considering that at the end of ventricles, cross-section is smaller than the rest, and more strain is observed at that area.

Heart with patches

Circular patch: In this case, as already noted, for blocking the communication between the two ventricles we used circular patch with a diameter of 4 cm at the junction. In this case, same as that of the previous case, the average pressure in the RV and LV were set to be 20 and 120 mm Hg, respectively. As shown in Fig. 2 we can understand that because of the shape of the patch, profiles of stress and strain are relatively symmetrical.

Elliptical patch: It is used with a large diameter and small diameter of 5 cm and 4 cm, to prevent contact between the two ventricles. Fig. 2 shows the contours of stress and strain. Although the elliptical patch compared to the circular one induces asymmetric profile, the maximum amount of stress and strain are lower than in the circular one. The maximum stress in the circular patch rises up to 195 kPa, while this value in elliptical patch is 133 kPa. It can be easily seen from the results that by using the elliptical patch, stress and strain created at the junction, is less than in the circular one.

Conclusion

Our research in fact is a preliminary attempt to identify heart with simplified model and considering the patch which located between two ventricles. The changes in the stress and strain caused by placement of a patch on junction were investigated and offered optimized geometry for it. For this purpose, two types of circular and elliptical patch with the same material were used. Finally, the results revealed that by using the elliptical patch, stress and strain induced at the junction, are less than that of the circular one.

Conflicts of interest

None declared.

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