Sensitivity of growth pattern in patch reconstructed arteries with respect to material properties and shape of patch

S.Samaneh Lashkarinia[a], Ye Han[b], Vidhi Upadhyay[b], Gursan Coban[a], Banu Kose[c], Ece Salihoglu[d], Levent Burak Kara[b], Kerem Pekkan[a1]

[a] Koç University, Istanbul, Turkey
[b] Carnegie Mellon University, Pittsburgh, USA
[c] Medipol University, Istanbul, Turkey
[d] Istanbul Bilim University, Istanbul, Turkey

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1. Introduction

Most children who are born with a clinically significant congenital heart defect (CHD) require palliative congenital heart surgeries utilizing native and artificial patch materials for the reconstruction of the heart and great vessels. In an earlier study we presented a pre-surgical patch planning protocol to predict the optimal patient-specific patch shape before the in vivo execution through the surgical palliative repair of pulmonary artery (PA) stenosis in Tetralogy of Fallot patients [1]. In a recent study, to determine the long-term complication of these surgeries we devised a predictive computational tool for volumetric growth of arterial tissue as growing matter in contact with artificial patch tissue [2]. In this study we examine the effect of patch material and shape on the postoperative growth pattern of the patched vessel. Optimized patches provide favorable post-operative cross-sectional enlargement in stenosed vessels. Patches which are less associated with post-operative maladaptation of the live tissue around the stitch line after reaching homeostatic level can be determined in the presented approach.

2. Methods

3D reconstructed models of patient specific Aorta and PA anatomies of newborn patients with severe stenosis are obtained from MRI. Virtual surgery is performed on the diseased anatomy and the stenosis is resolved by patch implantation using our in-house anatomical editing tool. The patched anatomy is pressurized to physiological pressure levels. Our in-house generated elastic-growing material model [3] is utilized as a plugin by means of FEBio software suite to model the native tissue behavior in a patched artery. State of art patch materials including PTFE, Dacron, dehydrated porcine and human pericardium are tested using our planar biaxial test system (BOSE, Framingham, Massachusetts) and extracted material properties [1] are assigned to the patch tissue. Pressure loading data is obtained from the available clinical data for PA and Aorta from birth up to 7 years of age. All models with various patch materials are compared with the baseline model in which the patch is modelled as live tissue sharing the same evolution and material properties as the native tissue. 3D patch shapes predicted by the present approach is developed through a 2D flattenization code.

3.Results and discussion

Figure 1 shows the equivalent stress distribution on the patched aorta of a 1 month old newborn with severe aortic coarctation in early post-operative days and at 60 months.

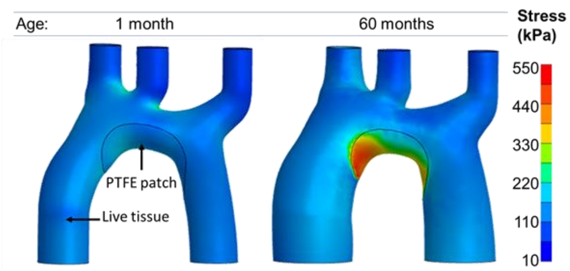

Figure1: stress map on the arterial tissue and patch

Average stress levels on the patch increases from 130 kPa to 435kPa as the aortic pressure increases during growth. However, the stress levels on the live tissue are maintained at a constant level (100-150 kPa) due to tissue growth and volume increase. The results obtained from our computational growth models

[1] Corresponding author. Email: kpekkan@ku.edu.tr

of different patient specific anatomies in this study show that geometrical parameters of the patch and the anatomy have a dominant effect on growth pattern formation. Simulation results of various test patch materials on the same geometry indicate that biological tissues (human and porcine pericardium) undergo higher elastic strains and provide higher enlargement in the stenosed section in the long-term, compared to the stiff synthetic materials like PTFE and Dacron. Cross-section enlargement in the patched region is associated with vessel diameter increase and consequently high elastic stress/strain levels of the live tissue. Therefore, higher growth levels are triggered on the live tissue in the patched region to compensate for the excessive elastic stress/strains. Although soft biological tissues provide favorable outcomes, the patch degradation and wornness due to induction of high strain levels is a factor that should be considered to avoid the need for patch replacement in the long-term.
Figure 2 shows the 2D shape of the patch generated from the implanted 3D geometry in virtual surgery. So, Surgeon can cut 2D shapes from the flat raw patch materials prior to implantation.

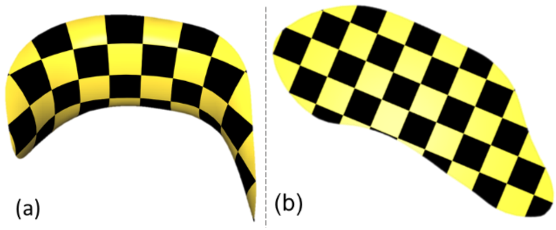

Figure 2: (a) 3D shape of patch, (b) 2D shape of the patch obtained from 3D shape by flattenization

4.Conclusion

Implanted cardiovascular patches in repairing congenital heart defects undergo higher stress levels by the growth of vasculature and native contacting tissue in the years following the surgery. Soft biological patches provide larger cross-section enlargement and higher growth levels in the live tissue. Implemented flattenization approach in generating raw patch shape is useful for surgeon in determining 2D patch shape form complex 3D patch geometry.

5. Acknowledgements

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6. References

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