NUI Galway
OÉ Gaillimh

Computational Characterisation of Bioprosthetic Heart Valve Positioning to Enhance Long Term Performance

McGee, O.M, Gunning, P.S, McNamara, L.M.
Biomedical Engineering, College of Engineering and Informatics, NUI Galway, Ireland

Background

- Transcatheter Aortic Valve Implantation (TAVI) is a minimally invasive alternative to open heart surgery in the treatment of aortic stenosis (Fig.1).

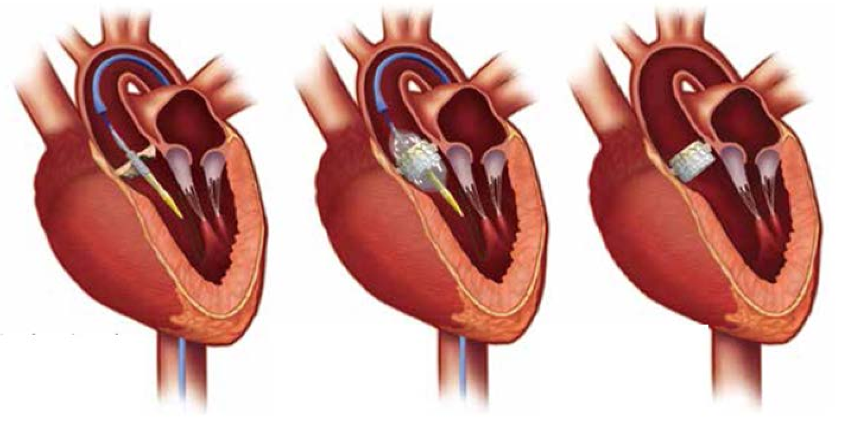

Fig. 1 Transcatheter Aortic Valve Procedure [1]

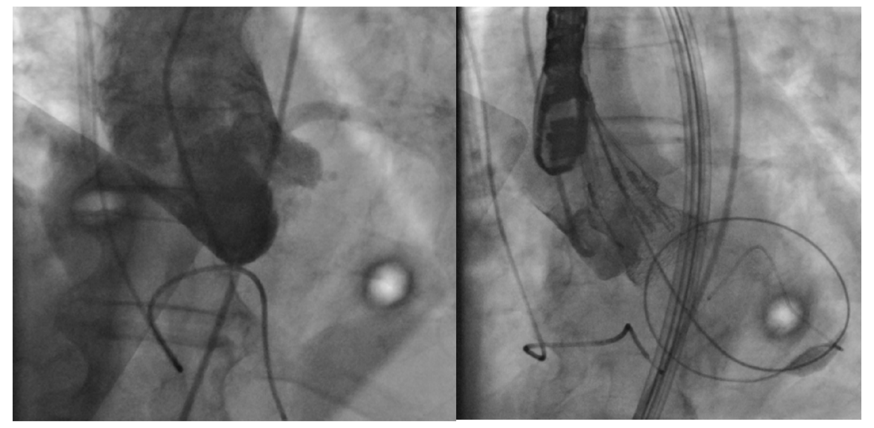

Fig. 2 Positioning a TAV under fluoroscopy

- Studies have shown that incorrect positioning of the TAV's can cause adverse effects as the extension of the heart valve into the left ventricle can lead to mitral insufficiency, arrhythmias, paravalvular leakage, prosthesis embolization or aortic injury [2-4].
- Second generation TAV's have been developed to allow for repositioning of the TAV directly after deployment (TRINITY TA, Evolut R^{TM}, Lotus^{TM}). However, it remains that optimal positioning of TAV's has not been defined.

Objective: To investigate how positioning of TAVs affects stresses in the aortic root and the valve stent

Methods

- A Patient-Specific Aortic Root model was derived from Multi-slice Computed Tomography (MSCT) images of an aortic root of an 86 year old male patient with aortic stenosis using Mimics and 3-Matic (Materialise, Belgium). The geometry was then meshed and modeled as an isotropic hyperelastic material, C10 and C01 were assigned values of 0.5516 MPa and 0.1379 MPa respectively [5, 6, 7].

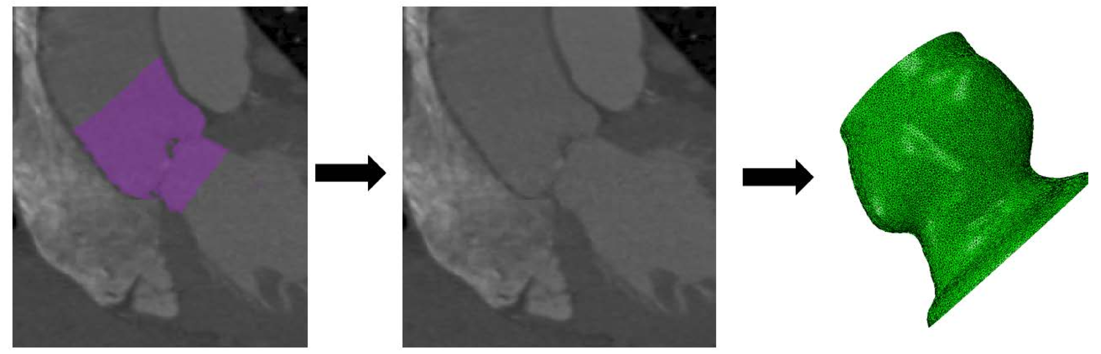

Fig. 3 Thresholding and Meshing of the Patient Specific Geometry

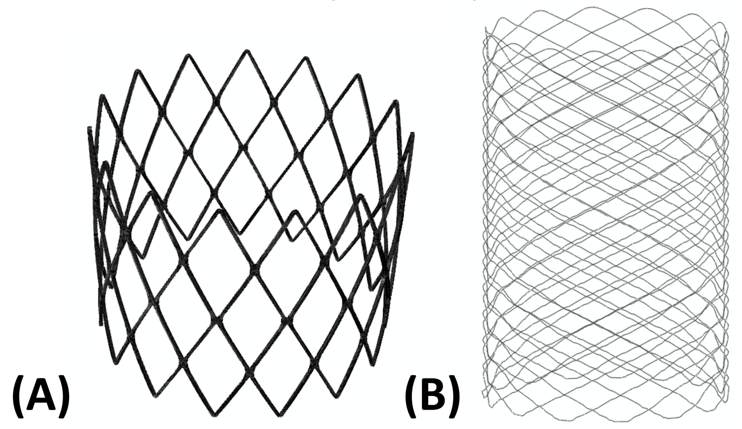

Fig. 4 (A) Laser Cut TAV and (B) Braided Stent Geometry

- A Finite Element model was developed to simulate the crimping and expansion of two self-expanding TAV stent geometries (a laser cut and braided stent (Fig 4)) in three different positions along the aortic root using Abaqus/Explicit (Simulia, Providence, RI). The TAV stents were modeled as superelastic nitinol using an inbuilt Abaqus Subroutine.

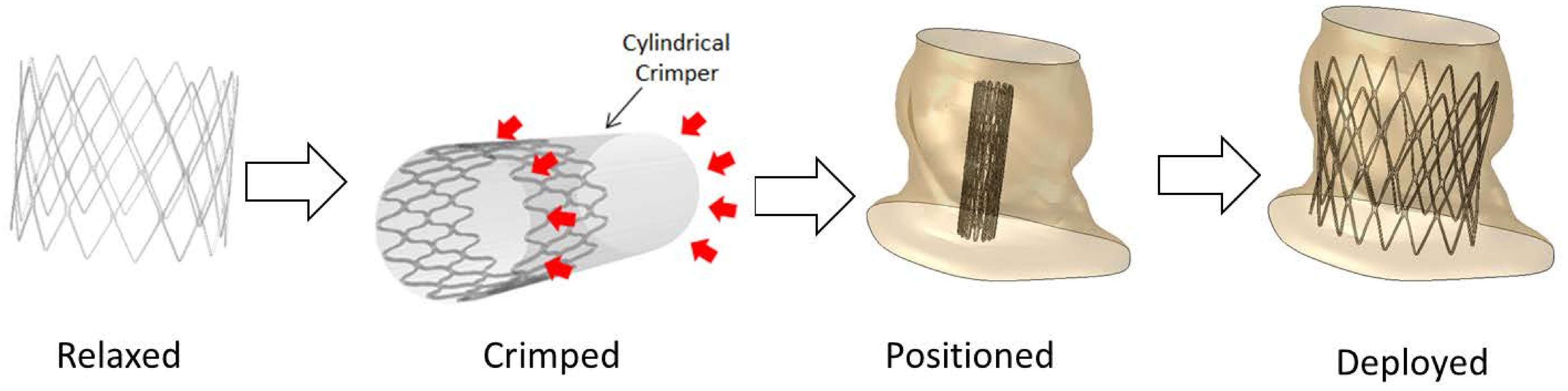

Fig. 5 Crimping and Deployment of the stent

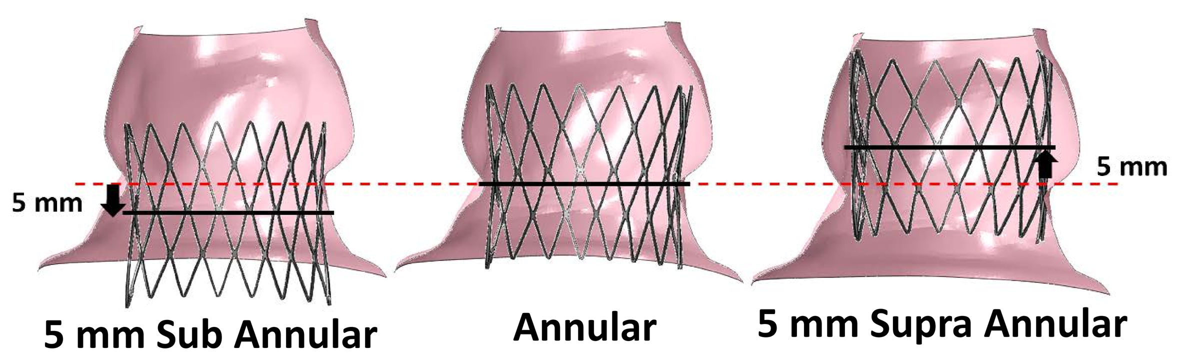

Fig. 6 Deployment of TAV stent in three different positions along the aortic root

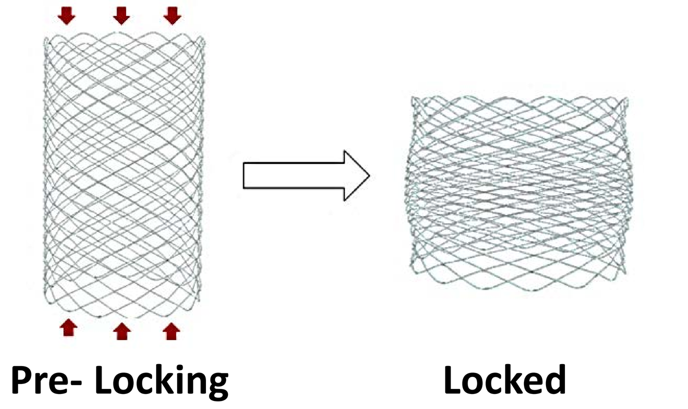

Fig. 7 Locking of the Braided Stent

- The crimping and deployment of the stents were modeled as seen in Fig 5. The crimper was reduced radially inward and non friction contact was used to crimp the stent to a 6mm diameter (18Fr). A friction coefficient of 0.1 was used as contact between the stent and the artery during the deployment of the self-expanding stents [8].
- The stents were deployed in three different positions relative to the aortic annulus (Fig 6).
- An additional locking step was applied to the braided stent. Displacement boundary conditions were used to displace the ends of the stent inward to represent a repositionable locking mechanism (Fig 7).

Results

- The highest stresses in the stent were seen when the stent was deployed 5 mm supra annularly (717.47 MPa) for the laser cut stent and annularly (581.16 MPa) for the braided stent.
- The lowest stresses in the stent were seen when the stent was deployed 5 mm sub annularly for the laser cut stent (471.38 MPa) and 5 mm supra annularly the braided stent (363.92 MPa).

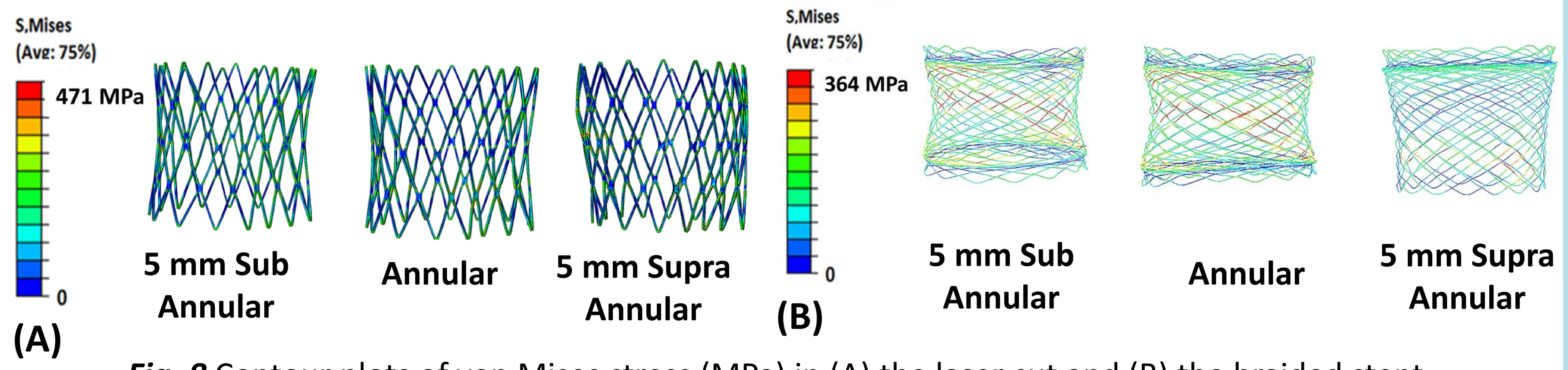

Fig. 8 Contour plots of von Mises stress (MPa) in (A) the laser cut and (B) the braided stent

- The highest aortic stresses were seen when the stent was deployed annularly for both the laser cut stent (0.348 MPa) and the braided stent (0.541 MPa).
- The lowest aortic stresses were seen when the stent was deployed 5 mm sub annularly (0.254 MPa) for the laser cut stent and 5mm supra annularly (0.481 MPa) for the braided stent.

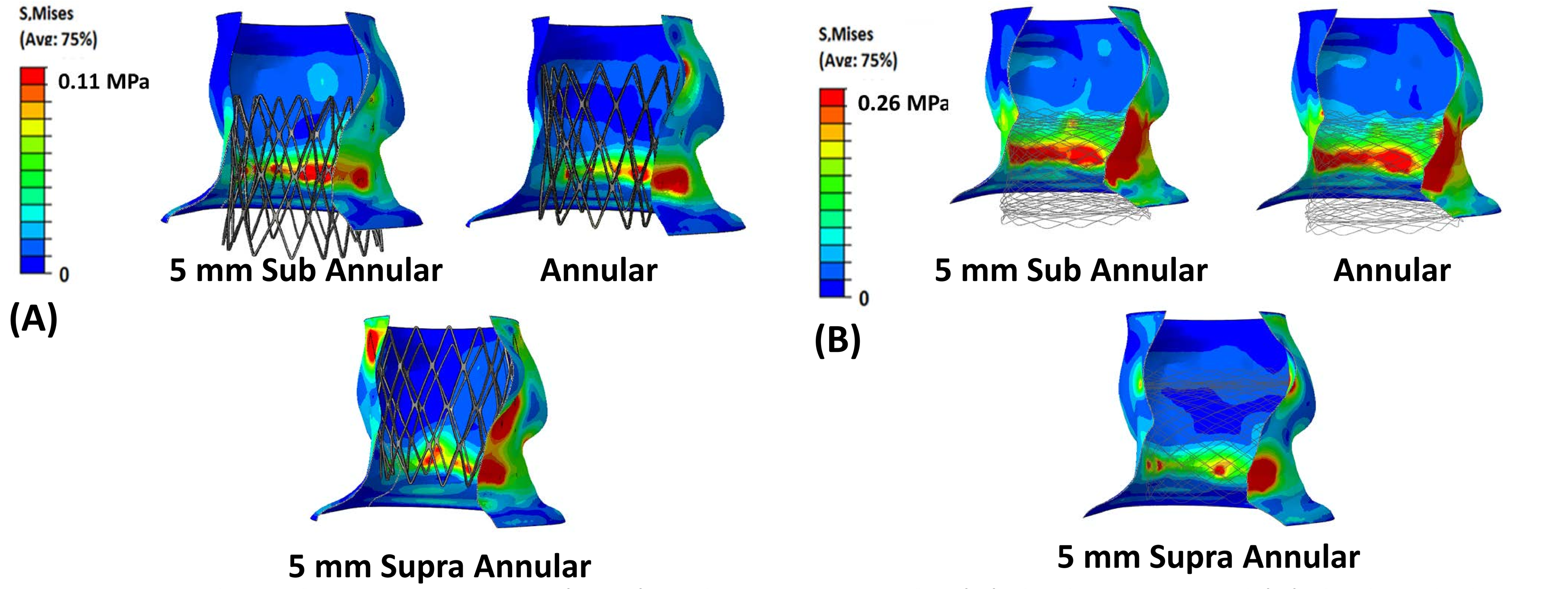

Fig. 9 Contour plots of von Mises stress (MPa) in the aortic root for (A) the laser cut and (B) the braided stent

- Percentage volume graphs (Fig. 10) were used to determine the difference in the distribution of stress throughout the aortic root at the three different positions.

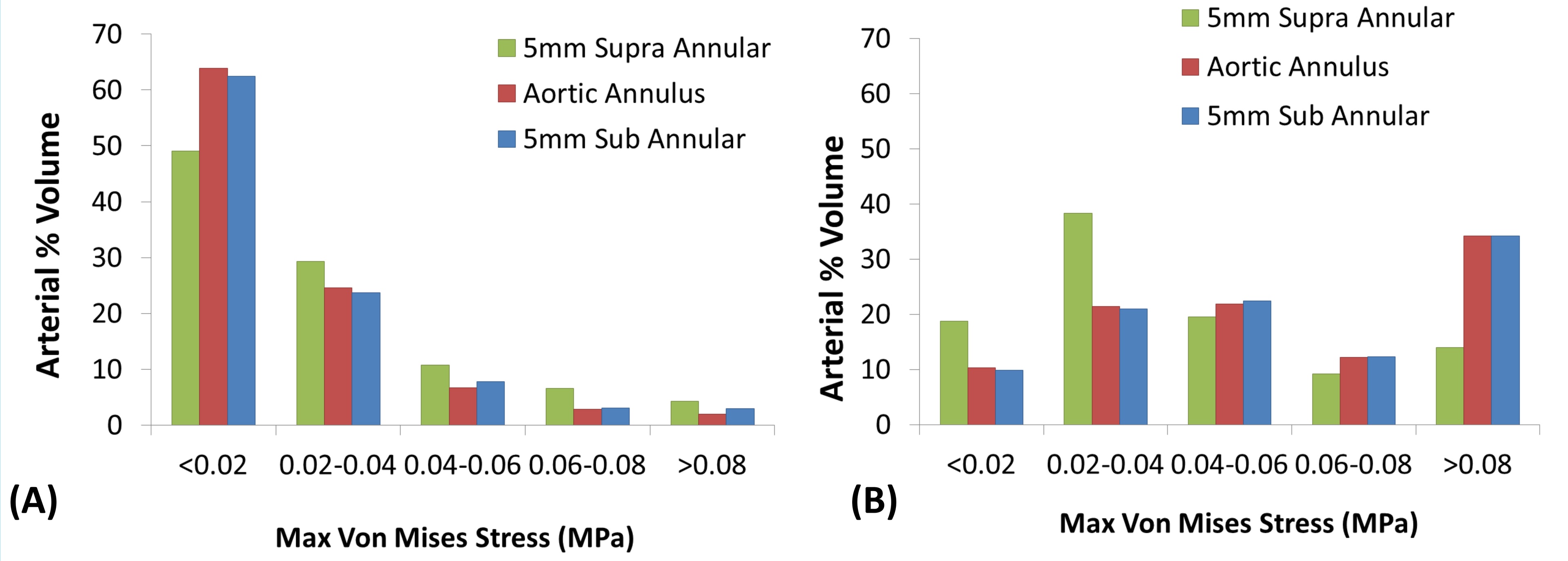

Fig .10 Percentage Volume Graphs for (A) the Laser Cut and (B) the Braided Stent at the three different positions

- Fig. 10 shows similar stress distribution for the laser cut stent in all three positions with the supra annular position showing slightly higher percentage volume at higher stress.
- For the braided stent the supra annular position has lower percentage volume at higher stress.

Table 1. Peak Von Mises Stress (MPa) for the different positions for the Laser Cut Stent

Laser Cut (MPa)	Peak Stress Artery	Peak Stress Stent
5 mm Supra Annular	0.271	717.47
Annular	0.348	474.38
5 mm Sub Annular	0.254	471.61

Table 2. Peak Von Mises Stress (MPa) for the different positions for the Braided Stent

Braided (MPa)	Peak Stress Artery	Peak Stress Stent
5 mm Supra Annular	0.481	363.92
Annular	0.541	581.16
5 mm Sub Annular	0.535	538.53

Discussion

- The maximum Von Mises stresses predicted for all three deployment positions for both the braided stent and the laser cut stent are well below the rupture stress of the aortic tissue (1.75MPa [9]).
- Our results show that stent positioning has an affect on both the peak stress in the stent and the aortic tissue. Positioning also has an affect on stress distribution throughout the aortic root.
- It can also be deduced that optimal positioning is dependent on stent design.
- From this study the optimal positioning for the laser cut stent and braided stent in terms of aortic stress distribution are the annular and supra annular positions respectively.
- Further work will include the native calcified leaflets, an anisotropic material model and examination of the long term fatigue damage.

References

[1] www.wakemed.org [2] J.B. Masson, et al., JACC: Cardiovasc Interv, vol. 2, pp. 811-820, 2009. [3] P. Généreux, et al., J Am Coll of Cardiol, vol. 61, pp. 1125-1136, 2013. [4] P. C. Block, Catheter Cardiovasc Interv, vol. 75, pp. 873-4, May 1 2010 [5] P. S. Gunning, et al Ann Biomed Eng, vol. 42, pp. 1989-2001, 2014 [6] F. Auricchio et al Comput Methods Biomech Biomed Engin, vol. 17, pp. 277-85, 2014. [7] D. R. Einstein et al Computer Methods in Biomechanics and Biomedical Engineering, vol. 6, pp. 33-44, 2003. [8] J. Mummert, Ann Biomed Eng, vol. 41, pp. 577-86, Mar 2013 [9]Vorp, D.A., et al. (2003) The Ann Thorac Surg,. 75(4): p. 1210-1214

IRISH RESEARCH COUNCIL
An Chomhairle um Thaighde in Éirinn