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University of Strathclyde

TERUMO Aortic

Next Generation Design Tools: Full Device Design Modelling Of Aneurysm Repair Stents – Start Date: Aug 2021

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1. The Principle Aims of the PhD

- Extend current modelling techniques to a full device model.
- Assess the accuracy of the model to experimental data, highlighting model limitations.
- Develop and deploy a device model into representative in-vivo conditions to assess mechanical performance and fluid dynamic properties.
- Implement design modifications with the aim of maximising device fatigue life and mitigating fluid flow issues.

2. Modelling Techniques in the Representation of the Nitinol Ring Bundles:

Initial stages of the PhD centred around the modelling of the nitinol ring bundles and the understanding of the interaction between the bundles and the aortic wall. This section of work had 2 main aims: to assess sealing characteristics, and to identify the limitations of each modelling technique for use in future work. Two main modelling techniques were used, a representative continuum element model (fig 1) and a superimposed beam element model (fig 2).

The results showed that:

- The ring bundle is always in contact with the vessel, though the average contact force increases away from the peaks and troughs.
- A beam element model is less computationally expensive than a continuum element but provides no information on the through strains within the wire. Therefor the exact requirements of the designer must be considered when choosing a modelling technique.

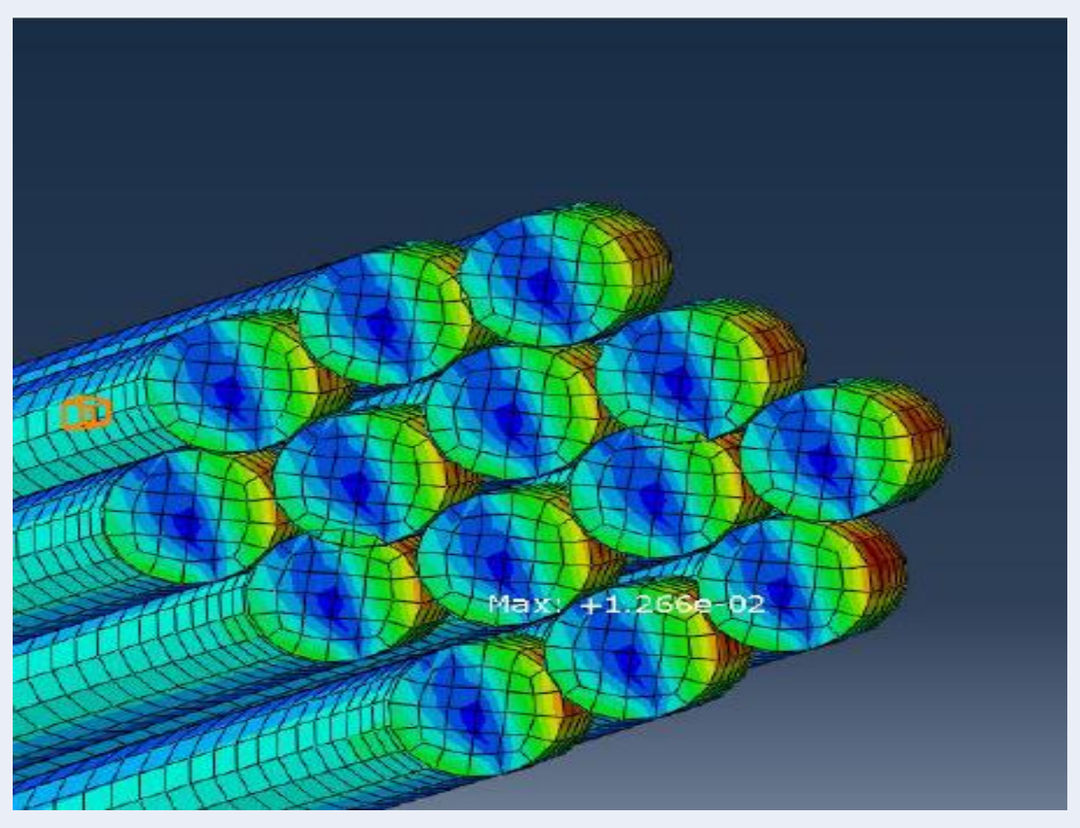

Fig 1: Continuum Element Bundle Model

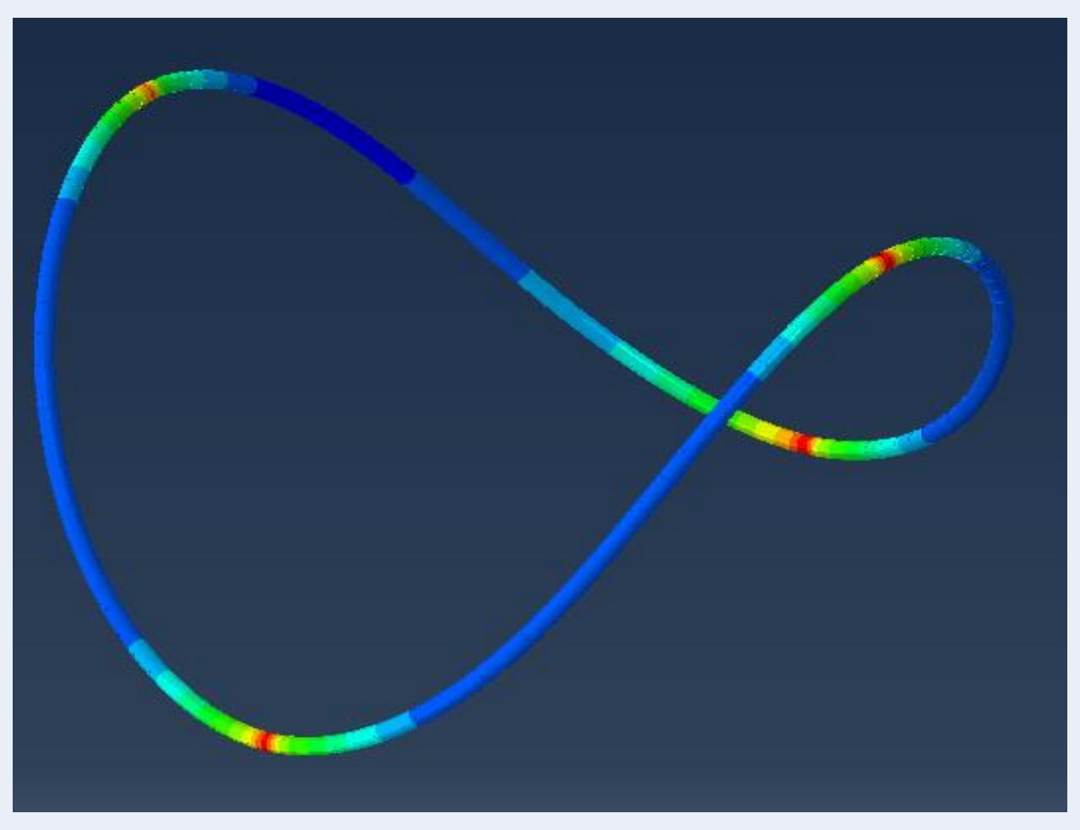

Fig 2: Superimposed Beam Element Bundle Model

3. Hybrid Modelling Technique for Explicit Simulations:

Progressing to the modeling of a multi ring device, several issues were highlighted:

- Larger more complex simulations require an explicit solver.
- During the forming of the ring bundles a pre-strain is created within the wires.
- There is no annealing process in the ring bundles which leads to a further pre strain when the rings are pulled prior to sewing.
- Beam elements with large curvature cannot be used in an explicit solver.

Therefor a hybrid solution which allows for the ring forming process to be carried in an implicit solver before being transferred into the explicit solver was utilized. Sample geometry was used to validate the method with results (fig 3) showing agreeable results. Figure 4 shows the differing strain distributions when the pre-strain is (left) and is not (right) considered.

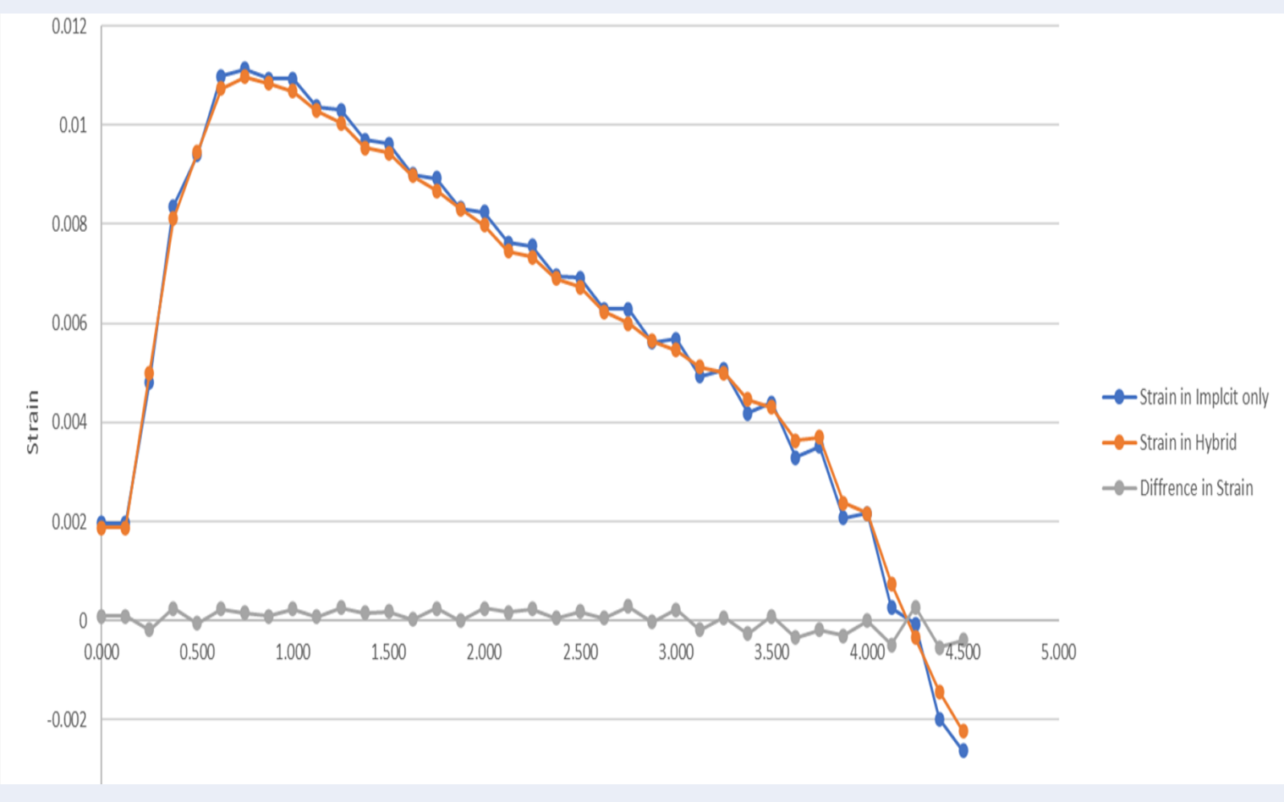

Fig 3: Implicit vs Hybrid Method Strain Distribution on a Dummy Geometry

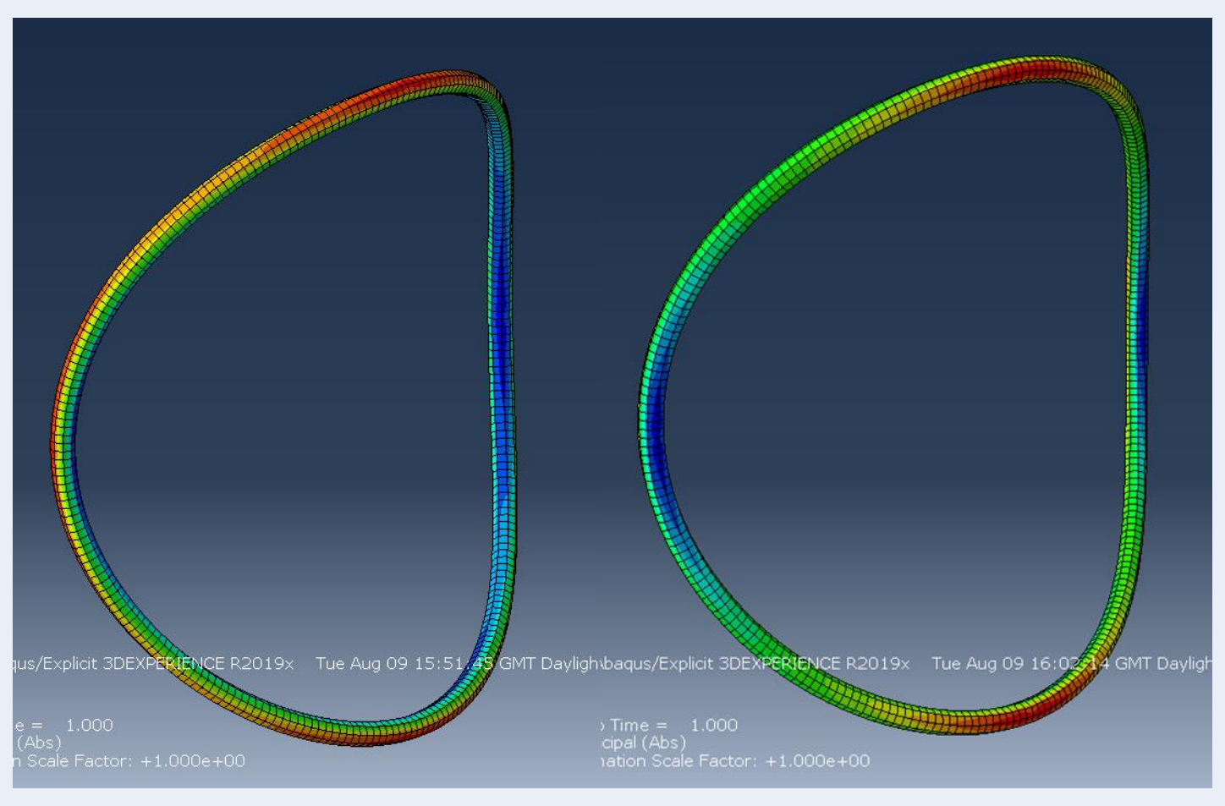

Fig 4: Ring Forming Pre-strain vs no Pre-strain after Pulling into a Saddle

4. The Structural Influence of the Woven Biofabric

When subjecting a device section to basic loading conditions: compression (fig 5), tension (fig 6) and bending(fig 7), the influence of the fabric on the shape of the rings can be viewed.

When the device is in tension, the fabric pulls the rings, further pronouncing the 'saddle' shape. When in compression, the rings move towards a planar deformation. When in bending, the upper end of the rings are in tension and the lower section in compression. Thus, the bottom flattens and the top bends. The influence of the fabric can be seen on the shape of the rings, therefor further investigation into the fabric was required.

Fig 5 Anaconda Leg in Compression

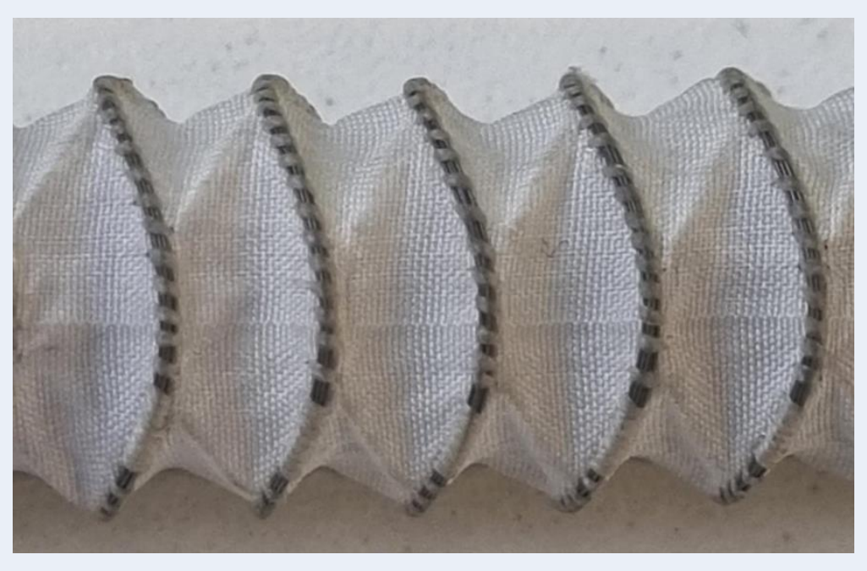

Fig 6: Anaconda Leg in Tension

Fig 7: Anaconda Leg in Bending

5. Fabric Modelling Techniques and Material Models:

- Prior attempts between the University of Strathclyde and Terumo Aortic have used an elastic material model to capture the fabric deformation.
- More recent literature has made use of a Lamina material model which allows for differing properties in the warp and weft directions to be represented and a shear moduli to be directly input.
- A new *FABRIC model within Abaqus allows for an anisotropic material model and considers the non-linearity of the fabric deformation.

6. Material Characterisation through Experimental Testing

- Uniaxial testing showed that the fabric experiences nonlinear deformation when subjected to a uniaxial pull test (fig 8). The testing also highlighted the differing stiffness in the warp and weft directions and the increase in stiffness prior to heat treating the samples.
- Shear deformation testing showed highly non-linear properties and a sudden increase in the gradient of the curve caused by the shear locking of initially perpendicular yarns .
- The bending stiffness of the fabric, found using a load deflection test under self weight showed that the bending stiffness of the fabric was low relative to the axial and shear properties.
- Figures 9 highlights the inability of the elastic and lamina model to accurately capture the fabrics behaviors in shear.

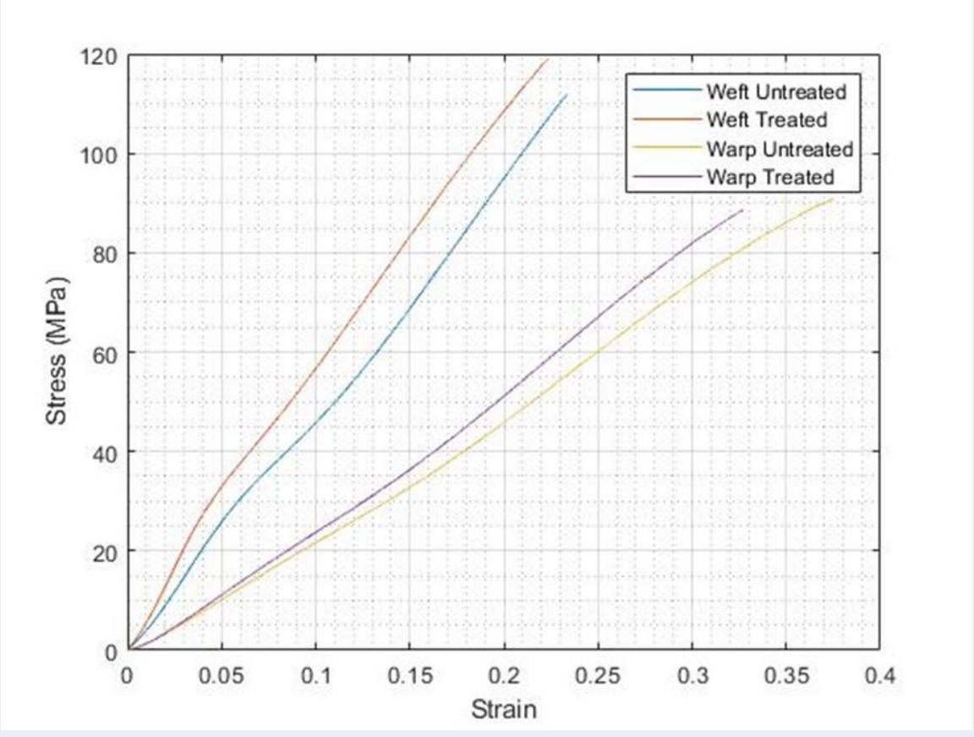

Fig 7: Stress-strain curves for Axial Deformation

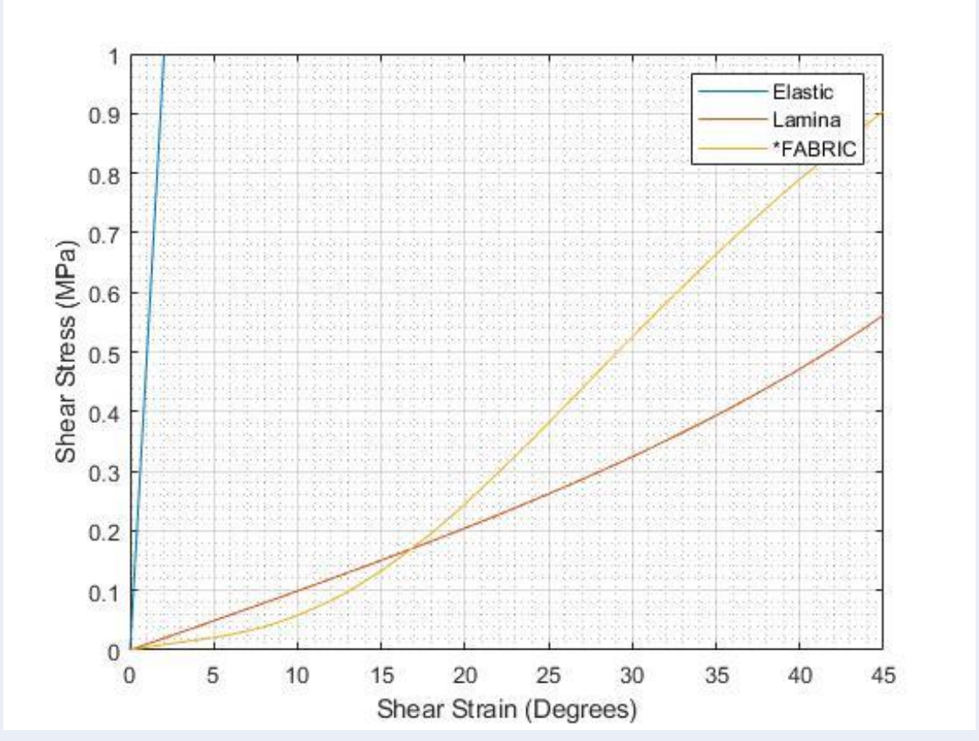

Fig 9: Resistance to Shear Deformation Using Each of the 3 Material Models

8 . Current Work - Validation of the Proposed Material Model:

The validation of the material model integrates the already validated nitinol material model by subjected a section of an anaconda leg device to 3 basis deformations: tension, compression, and bending. The test (fig 10) will scan the position of the fabric and model the deformation on the outer surfaces in a virtual environment. The scans can then be compared to simulations within Abaqus to compare the size and positioning of the fabric folds/deformation.

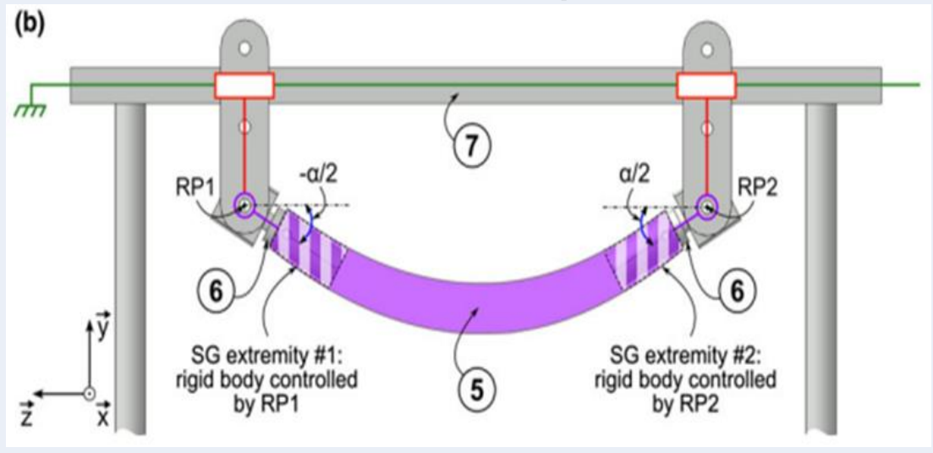

Fig 10: Fabric Validation Test Diagram [1]

9. Future Work

Device Modelling & Validation

- Develop a model which accurately represents the in-vivo conditions and compare this with experimental data.
- Investigate the CFD modelling requirements and quantify the effect of the fabric on the fluid flow though the device.
- Compare experimental data of a pressured device against FEA modelled geometry.

Application of the Device Model

- Investigate geometric variations within the aorta and the subsequent consequences to device behavior.
- Investigate the device design issues of in-vivo deployment.

References

[1] - Demanget N, Duprey A, Badel P, Orgéas L, Avril S, Geindreau C, Albertini JN, Favre JP. Finite element analysis of the mechanical performances of 8 marketed aortic stent-grafts. J Endovasc Ther. 2013 Aug;20(4):523-35. doi: 10.1583/12-4063.1. PMID: 23914862.

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