COMPUTATIONAL MECHANICS OF A COMPOSITE TISSUE-REGENERATING VASCULAR PROSTHESIS

Mazin Sirry, Peter Zilla, Thomas Franz

Cardiovascular Research Unit, Chris Barnard Division of Cardiothoracic Surgery
University of Cape Town, South Africa

INTRODUCTION

In cardiovascular application, radial compliance is a measure of the ability of a vessel to change its diameter in response to blood pressure. One of the main causes of graft failure was reported to be the mechanical mismatch between the graft and the host vessel.

In this study the Finite Element Analysis was implemented to investigate the mechanical behaviour of over-compliant tissue-regenerative porous polyurethane (PPU) vascular grafts when reinforced by Nitinol wire meshes. The main goal was to reduce the radial compliance of the graft to match the native artery (8-10%/100mmHg) in attempt to prevent the graft failure.

METHODS

GEOMETRY: The software ProEngineer Wildfire® 2 (PTC, Needham, MA) was used to develop a 3D model of the tubular knitted wire mesh (ID=3.0mm, wire thickness: 0.05mm). The geometry was imported to Abaqus CAE® 6.8-2 (Dassault Systemes, Providence, RI) in which a cylindrical graft geometry (wall thickness: 0.3mm) was developed. Two versions of 45^0-sector assemblies were developed (*Figure1*) by preserving the inner diameter of the wire mesh at 3.0mm and adjusting the PPU graft internal diameter to 2.40 and 2.84mm such that the wire mesh is placed around and embedded in the graft, forming external-reinforcement (EX) and embedded-reinforcement (EM) grafts, respectively.

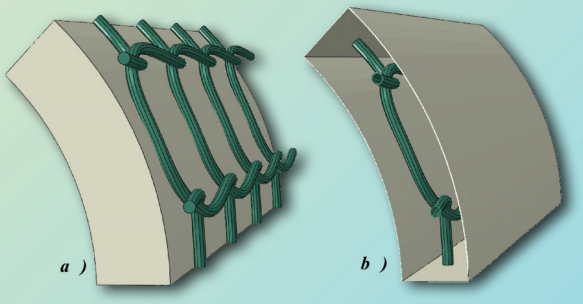

Figure 1: *The two gometries used in the study: external-reinfocement graft (a), and embedded-reinforcement graft (b).*

MATERIAL MODELS: Mechanical properties of Nitinol and PPU were determined experimentally. The Nitinol material was modelled as ABAQUS user-material for superelasticity of shape memory alloy, and the PPU material was modelled as Hyperfoam.

FINITE ELEMENT MESH: Wire and graft structures were meshed using 8-node linear brick elements. 4 and 10 elements were assigned through the graft thickness (8,568 elements) and along the circumference of the wire cross-section (11,487 elements), respectively.

BOUNDARY CONDITIONS: were applied on the circumferential and longitudinal surfaces of the graft and wire-ends such that the assembly moved radially along the planes defined by those surfaces.

LOADING: Uniformally distributed pressure was applied on the luminal surface of the graft up to 200mmHg, covering the physiological BP range.

ACKNOWLEDGMENT

This material is based on work supported financially by the National Research Foundation (NRF) of South Africa.

RESULTS

MAXIMUM STRESS: At 200mmHg, Nitinol\PPU graft recorded 92,000kPa\32kPa (EX model) and 217,000\27kPa (EM model), respectively.

MAXIMUM STRAIN: At 200mmHg, Nitniol\PPU graft experienced 0.4%\20% (EX model) and 0.4%\12% (EM model), respectively.

COMPLIANCE: The EX model showed 7.3 %/100mmHg (70 %/100mmHg was recorded by non-reinforced graft of similar ID). The EM model showed 1.0 %/100mmHg (198 %/100mmHg was recorded by non-reinforced graft of similar ID).

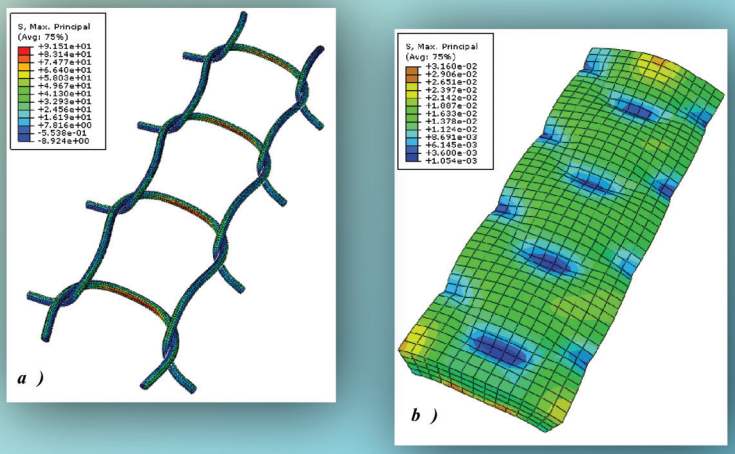

Figure 2: *The maximum principal stress values detected in the Nitinol wire (a) and PPU (b) in the EX model.*

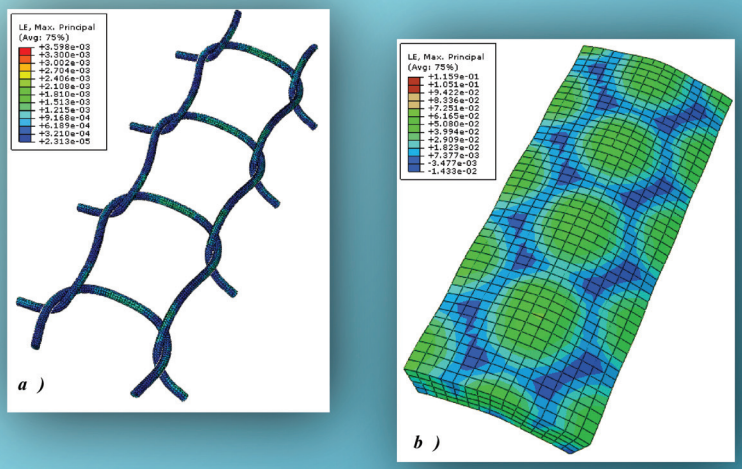

Figure 3: *The maximum principal strain values detected in the Nitinol wire (a) and PPU (b) in the EM model.*

CONCLUSION

The reinforcement helped reducing the overall compliance and excessive dilation of the PPU graft, with the EX design providing more physiological graft compliance. For the Nitinol wires, the maximum predicted stress remined safe at 20% of stress associated with start of Austenite-Martinsite phase transformation (483,000 kPa). The maximum stress and strain exhibited by the PPU graft indicated a non-critical elastic deformation. These outcomes need to be confirmed in further studies and evaluated against physical data.