Assessing modeling assumptions in structural analysis of type B aortic dissections: a study in idealized models

L. Gheysen[a], J. Degroote[a], N. Famaey[b], and P. Segers[a]

[a] *Ghent University, Belgium;* [b]*KU Leuven, Belgium*

Keywords: Aortic dissections, Finite element analysis, Modeling assumptions

1. Introduction

Aortic dissections are characterized by, at least, one tear in the inner layer of the aortic wall, which leads to the formation of a parallel blood path (the false lumen), next to the normal path (the true lumen). A common treatment in type B aortic dissection (involving the descending thoracic aorta) is the placement of a stent-graft at the location of the entry-tear in order to trigger thrombosis of the false lumen and therefore remodeling of the dissection. Although this treatment has been shown effective, re-intervention and aortic expansion within one year is still seen in, respectively, 20% and 30% of the patients [1,2]. These observations together with the large interpatient variability of the disease, emphasizes the need for a patient-specific approach. To assist clinicians in assessing the benefit of the stent-graft placement for a particular patient with a type B aortic dissection, computational models of the aortic wall, the blood flow, the stent-graft deployment and their interaction, able to predict the acute and long-term treatment outcome in the individual patient, would be very helpful.

Up to now, quite some effort has been done to model the blood flow dynamics in type B aortic dissections using computational fluid dynamics [3,4]. The dissected aortic wall has been modeled before too [5,6]. The aim of most of these models, however, was to study the blood dynamics in a more accurate way, rather than focusing on the wall stresses itself. Moreover, each model is subject to multiple modeling assumptions, while the impact of these assumptions is often not thoroughly discussed. The aim of this study is therefore to consider the effect of some of the important modeling parameters, i.e. the degree of geometrical idealization, the thickness of the dissected membrane and aortic wall and the inclusion of prestresses on the predicted stresses and deformations.

2. Methods

Finite element analyses, using Abaqus, will be performed for three geometries that will be created, using the in-house developed software pyFormex. The geometries will range from an idealized dissection model (figure 1) up to a patient-inspired parametric model. Each model will be meshed using hexahedral elements. The aortic wall is assumed to be anisotropic hyperelastic following Gasser et al. [7], with material properties obtained during a biaxial test of a diseased aortic tissue sample (FIBEr, KU Leuven) and exposed to the systolic blood pressure of 120 mmHg. For each geometry a default model will be set up, using:

(1) a wall thickness of 1.75 mm, estimated based on Iliopoulos et al. [8]
(2) a dissected membrane equal to 45% of the total wall thickness, assuming that the dissected membrane consists of the complete intima and half of the medial layer [9]
(3) an axial prestretch of 20% [10]

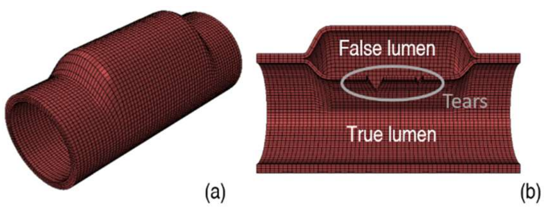

Figure 1: (a) Idealized model of a type B aortic dissection, including (b) the true lumen, false lumen and two tears.

Starting from this model, the total thickness of the aortic wall will be varied between 1.5 mm and 2.0 mm. Moreover, the thickness of the dissected membrane will be varied between 35% (intima and 3/8th of media) and 55% (intima and 5/8th of media) of the total wall thickness [9]. Finally, the required complexity of the used prestressing algorithm will be taken into account (no prestresses; axial prestress; axial prestress in addition to residual stresses using the deposition stretches algorithm of Famaey et al. [11]). In order to assess the influence, the maximal circumferential Cauchy stress ($\sigma_{Circ,Max}$) and the maximal radial displacement ($U_{Rad,Max}$), obtained using a global cylindrical coordinate system, will be considered. Table 1 gives an overview of the planned simulations.

	WT (mm)	MT (% of WT)	Prestress
Default	1.75	45	20% Axial
PS no	1.75	45	No
PS dep	1.75	45	Deposition
WT min	1.50	45	20% Axial
WT max	2.00	45	20% Axial
MT min	1.75	35	20% Axial
MT max	1.75	55	20% Axial

Table 1: Overview of the planned analyses. WT: wall thickness; MT: membrane thickness, PS: prestress

3. Results and discussion

This study is ongoing, and therefore only preliminary data on the idealized model is presented (figure 2).

Prestress: The inclusion of axial prestresses strongly influences $U_{Rad,Max}$, while the effect on $\sigma_{Circ,Max}$ is limited. It is, however, important to consider that, even with inclusion of the axial prestress, the physiological situation is still largely simplified as no zero-pressure configuration and no deposition stretches are calculated. Therefore, the implementation of the prestressing algorithm of Famaey et al., is expected to largely improve the accuracy of the finite element analysis [11].
Wall thickness: As expected, an increasing wall thickness leads to a decrease in $\sigma_{Circ,Max}$. The observed differences in $U_{Rad,Max}$ were limited.
Membrane thickness: An increasing thickness of the dissected membrane strongly increases the observed $\sigma_{Circ,Max}$ and $U_{Rad,Max}$. This is explained by the fact that an increasing thickness of the dissected membrane directly influences the assumed thickness of the remaining aortic wall in the false lumen, as the total wall thickness is kept constant.

This study aims at gaining insight in the importance of making particular assumptions, rather than giving an exhaustive overview of all possible changes. Some important parameters are included in this study, but parameters as e.g. the size of the true and false lumen, the tear size, material properties, … have to be taken into account as well to obtain the full picture.

4. Conclusions

The preliminary results, obtained with the presented idealized dissection model, indicate that $U_{Rad,Max}$ is mainly influenced by taking into account the axial prestress. Besides, $\sigma_{Circ,Max}$ is sensitive to the chosen wall and membrane thickness. As these parameters are often not visible on CT scans, which are often used as a basis for patient-specific modeling, caution should be taken when making modeling assumptions regarding the tissue thickness.

5. Acknowledgements

L.G. is funded by a doctoral grant strategic basic research (1S48920N) of the research foundation-Flanders FWO-Vlaanderen.

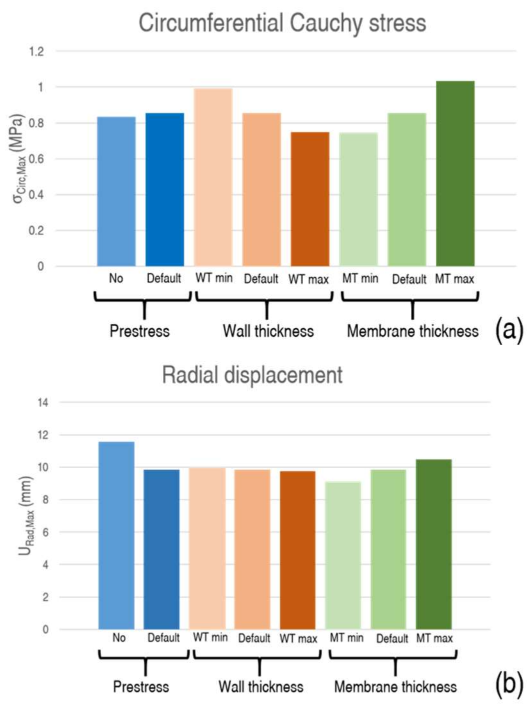

Figure 2: Influence of variations in prestress (PS), wall thickness (WT) and membrane thickness (MT) on the (a) $\sigma_{Circ,Max}$ and (b) $U_{Rad,Max}$ obtained with the idealized model.

6. References

[1] P. Mastroroberto et al., Journal of Cardiothoracic Surgery **5**, 23 (2010).
[2] R. Fattori et al., Jacc-Cardiovascular Interventions **6**, 876 (2013).
[3] H. Xu et al., The Journal of the Biomedical Engineering Society **46**, 927 (2018).
[4] C. Menichini et al., Journal of Biomechanics **66**, 36 (2018).
[5] M. Alimohammadi et al., BioMedical Engineering OnLine **14** (2015).
[6] K. Bäumler et al., Biomechanics and Modeling in Mechanobiology, 1 (2020).
[7] T. C. Gasser et al., in *J. R. Soc. Interface*2006), pp. 15.
[8] D. C. Iliopoulos et al., Journal of Thoracic and Cardiovascular Surgery **137**, 101 (2009).
[9] J. D. Humphrey, Journal of Vascular Research **50**, 1 (2013).
[10] P. B. Canham et al., Cardiovasc. Res. **23**, 973 (1989).
[11] N. Famaey et al., ZAMM-Zeitschrift fur Angewandte Mathematik und Mechanik (2018).