MCB, vol.16, supplemental 2, pp.148-149, 2019

The Effect of the Elongation of the Proximal Aorta on the Estimation of Aortic Wall Distensibility

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Introduction: The proximal aorta accommodates approximately half of the total compliance of the arterial tree. The loss of the aortic wall distensibility leads to a deleterious increase in the cardiac afterload and is an independent predictor of all cause mortality [1]. Accurate estimation of the aortic wall compliance is, therefore, key for correct risk stratification. The distensibility of the aortic wall can be precisely calculated by measurement of the volumetric change of the aortic geometry over pressure changes, i.e. the aortic volume compliance. However, researchers often estimate the aortic distensibility by examining lumen area changes in the cross-sectional plane. This simplification presumes that the principal strain is in the radial direction and neglects the effect of the deformation of the proximal aorta along its long axis. However, a number of investigations have shown that the proximal aorta significantly elongates during the cardiac cycle [2]. Motivated by the aforementioned, the aim of the current study was to investigate both *in silico* and *in vivo* how the elongation of the proximal aorta during the cardiac cycle might compromise the accuracy of the estimated wall distensibility.

Methods To achieve this, we first developed a computational framework to simulate the deformation of the 3-D proximal aortic geometry during the cardiac cycle, adopting a quasi-static approach. More specifically a structural model was built based on the MR images of the aorta of a healthy 30-year-old male. The 3-D geometry was reconstructed; an appropriate hex mesh was created and imported in Abaqus. The constitutive material model used assumes an incompressible anisotropic arterial wall reinforced by families of collagen fibers [3]. The zero-pressure configuration was reconstructed from the *in vivo* measured geometry following the methodology of [4]. Appropriate boundary conditions were set along the aortic wall to mimic the viscoelastic support provided by the surrounding tissues. Aortic root motion was also imposed at the proximal boundary based on the aortic root displacement measured from 2-chamber and 4-chamber view cine cardiac MR data of a healthy young adult. We applied a physiological pressure profile to the lumen wall, which was calibrated according to the carotid pressure measured via applanation tonometry, and simulated a full cardiac cycle. From the simulations, we were able to extract the actual volume changes over the pressure changes, which serves as the precise measure of aortic distensibility –as imposed by the material properties. Consequently, 7 cross-sections were tagged along the aorta and were used to calculate the respective area compliances. We then estimated anew the aortic distensibility by integrating the area compliances over the length of the centerline of the aortic segment. To assess the effect of neglecting the elongation, we assumed for the integration that the length of the aortic segment did not vary significantly during the cardiac cycle and was equal to its diastolic value.

To corroborate our findings with *in vivo* measurements, we acquired MR images of the proximal aorta of two healthy young subjects (one male and one female) in two timeframes: once during peak systole and once during diastole. The 3-D aortic geometries were reconstructed from the level of the right coronary artery until above the celiac trunk for each timeframe and the real volume compliance was calculated, as described above. Subsequently, we tagged 8 cross-sections along the diastolic and systolic aortic geometry: the proximal and distal end, before the brachiocephalic artery, before the left common carotid artery, before and after the left subclavian artery and at the level of the 3rd and 7th intercostal arteries. The area compliance of these cross-sections was calculated and aortic distensibility was anew estimated by integration over an invariant centerline length, as before.

DOI: 10.32604/mcb.2019.07346

Results and Discussion

Fig.1 shows a comparison between the real wall distensibility and the estimated value after integrating area compliances over an invariant centerline length, as calculated by the computational model. The error was approximately -33%. Tab.1 summarizes the results from the *in vivo* investigation. We note that the error for the female subject was significantly higher than the one of the male subject. For both *in vivo* and *in silico* approaches, the respective errors were in the same order of magnitude.

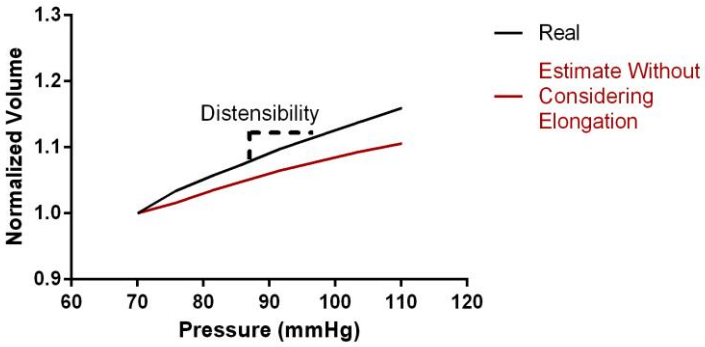

Figure 1. Real against estimated distensibility after neglecting aortic elongation (*in silico* model).

Table 1. Results from the *in vivo* investigation.

	Real Distensibility (10^{-3} mmHg^{-1})	Distensibility estimate without considering elongation (10^{-3} mmHg^{-1})	error
Male subject	6.41	3.74	-41.6%
Female subject	5.65	2.69	-52.4%

We conclude that neglecting the elongation of the proximal aorta when deriving the aortic wall distensibility leads to an overestimation of wall stiffness. In light of this evidence, area compliance as assessed in a cross-sectional plane might not be sufficient for the estimation of the proximal aortic wall distensibility. Although this finding is rather intuitive, it has been overlooked by the community, which might have serious implications in our understanding of pathogenesis.

Keywords: Longitudinal stain; proximal aorta; compliance; finite element analysis

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