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Applicability of simplified models of abdominal aortic aneurysms

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Introduction: Credible calculation of stresses in the wall of abdominal aortic aneurysm (AAA) depends not only on its patient-specific (PS) geometry but requires also inclusion of the unloaded geometry and residual stresses which results in rather complex models giving nearly constant stress distribution through the wall thickness. Although obtained by a time-consuming calculation, this stress distribution resembles membrane stress state being independent of material if the deformed geometry is taken into consideration. In the paper stress distributions calculated on the basis of different finite element (FE) models of AAAs are compared to assess the acceptable simplifications.

Methods: Stresses in a shell can be calculated on the basis of Laplace law under assumption of their constant magnitude through the shell thickness. This is the case for thin shells made of linear elastic materials, while the stress gradient throughout the wall increases with the wall thickness and nonlinearity of the stress-strain dependence [1]. Recently FE models of AAAs have confirmed their credibility if unloaded PS geometry is used (obtained by backward incremental method) and residual stresses (RS) are introduced (on the basis of assumption of homogeneous stress distribution through the wall thickness) [2]. Here this model is denoted as model A when Vande Geest-like (VG) constitutive model is applied and as model B when quasi-linear 2nd order Yeoh (QL) constitutive model with high stiffness (corresponding to the slope of the stress-strain curve under high strains) is used. Both of these models induce membrane-like stress states in shells with regular geometric shapes (cylinder, sphere, ellipsoid). For both cylindrical and PS geometries, the results are then compared with a much simpler model C without residual stresses, based on the loaded geometry and QL constitutive model, to test a hypothesis that this simplification could offer acceptable results. If this was true for PS models of AAAs, the comprehensive finite element models (A or B) could be replaced by the much simpler model C.

Results: Stresses in a shell with simple geometry are illustrated with a cylinder. While without residual stresses the results are highly dependent on constitutive models, here models A, B or C give similar stress distributions corresponding to membrane stress obtained by Laplace law applied on the deformed geometry (see figure 1). For model C (without residual stresses) this can be explained by the high stiffness of the model causing negligible differences between the deformed and undeformed dimensions. Then models A, B and C were applied with a PS geometry (recorded under mean blood pressure). As locations of peak wall stresses (PWS) can be different for these models, the results are compared on node-to-node basis. The error rates (figure 2) show differences comparable with the calculated PWS for all combinations of models.

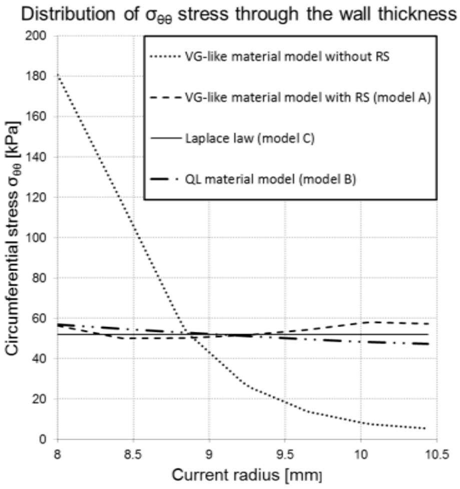

Figure 1.: Comparison of circumferential stresses for cylindric shape and different models

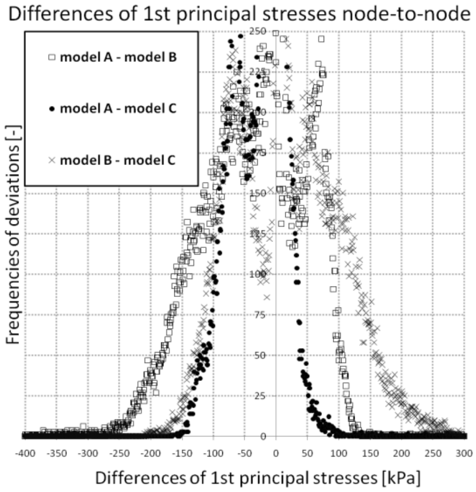

Figure 2.: Frequencies of deviations in 1st principal stress for different model pairs with PS geometries

Discussion: For simple geometrical shapes the sophisticated FE models give PWS similar to the Laplace law. Consequently, results of the simple model C are acceptable here, if radial deformations of the model are constraint sufficiently by the high stiffness of the constitutive model. However, for the PS geometry considerable differences (comparable with the magnitude of stresses) occur. This can be explained by bending of the shell caused by changes in local shell curvature between unloaded and loaded shapes; because of this effect the calculated stresses depend highly on the constitutive model (in contradiction to Laplace law) and the simplified model C is not acceptable.

Conclusion: The simple quasi-linear constitutive model without residual stresses and without taking unloaded shape into account can offer acceptable results for simple geometrical shapes but is not applicable for credible evaluation of stresses in patient specific models of AAAs.

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