DEFORMATION AT BRANCH POINTS IN HUMAN CEREBRAL ARTERIES

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INTRODUCTION

Head injury frequently involves damage to the cerebral blood vessels. Even when the vessels are not damaged, they may contribute to the overall response of the brain (Zhang et al., 2002). While previous work in our laboratory has focused on the mechanical properties of unbranched segments of cerebral vessels (Monson et al., 2003, 2005), the cerebrovascular network contains many branch points.

To our knowledge, the only study testing the susceptibility of human cerebral branch points to failure considered the effects of internal pressurization only (Mitchell and Jakubowski, 2002). We have recently compared the response of human branched arterial vessels to axial deformation with that of unbranched segments. Only 3 of the 12 vessels tested failed in branch regions, but none of the specimens failed at midsection locations not associated with a branch. Non-branch failure always occurred at the attachment points of the vessel to the testing apparatus, indicating the likelihood of tissue damage during the vessel attachment process.

We have investigated our experimental observations further through the use of a finite element model of a branched cerebral vessel. The data reported here characterize the behavior of an idealized branched vessel to axial deformation comparable to that used in our experimental testing.

METHODS

The non-linear finite element solver LS-DYNA (LSTC, Livermore, CA) was used for the finite element analysis of the branched vessel. Geometry and mesh were constructed using TrueGrid (XYZ Scientific Applications, Livermore, CA). Following an approach similar to that of Thubrikar et al. (1990), the arterial branch was modeled as the intersection of two cylindrical tubes. The nodes near the intersection were modified to create a transition region between the branch and the main vessel using two methods (denoted A and B).

The radius r_m and thickness t_m of the main vessel were taken from experimental measurements. The radius r_b and angle θ of the branch were varied to test the sensitivity of stress concentrations at the branch point to these factors. Because of the large displacement applied to one end of the main vessel, a neo-Hookean strain energy function was assumed with material properties taken from previous studies (Monson et al., 2006; Zhang et al., 2002). Following our experimental testing, idealized branched vessels were simultaneously subject to an axial stretch of 1.4 and an internal pressure of 20 kPa.

RESULTS AND DISCUSSION

Figure 1 shows the maximum principal stress contours for the case when $r_m / r_b = 2$ and $\theta = 45°$. There is an increase in the stress on the inside of the vessel wall in the transition region between the main vessel and the branch. Furthermore, there is a stress concentration on the outside of the main vessel, probably due to the thinning of the vessel wall in that area resulting from our algorithm to generate the smooth transition region. This outer stress concentration is not observed in specimens with branches that are more perpendicular to the main vessel, but is larger than the internal stress concentration in vessels with branches of 30°.

Figure 2 shows the maximum principal stress as a function of the branch angle and the branch radius. For branches that are relatively perpendicular to the main vessel, we see that the maximum principal stress actually increases as the size of the branch decreases. This is contrary to both our experimental observations and simulations of non-branched vessels having a simple hole of various sizes in its wall. Furthermore, changes in transition geometry specifically designed to reverse the unexpected branch-size trend were only partially successful.

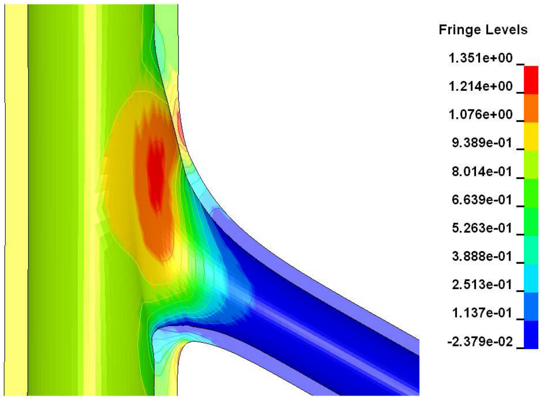

Figure 1: Maximum principal stress (MPa) in a 45° branched vessel under an internal pressure of 20 kPa and axial stretch of 1.4.

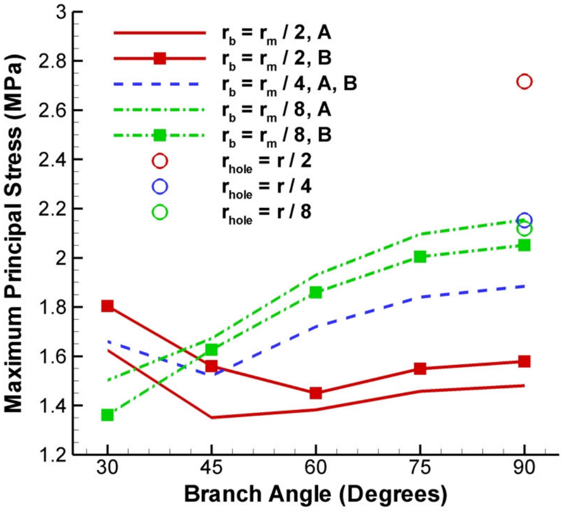

Figure 2: Maximum principal stress in a branched vessel as a function of branch angle and transition region geometry and in a non-branched vessel with a hole.

SUMMARY/CONCLUSIONS

The stress concentration at branch points is sensitive to the geometry of the transition region between the main vessel and its branch, suggesting that more study of the geometry is necessary. The fact that geometry changes do not resolve differences in simulated trends in comparison to experimental findings suggests that material properties may also vary across the transition region.

REFERENCES

Mitchell, P., Jakubowski, J. (2002). *Brit. J. Neurosurg.*, **16**, 578—582.

Monson, K.L. et al. (2003). *J. Biomech. Eng.*, **125**, 288—294.

Monson, K.L. et al. (2005). *J. Biomech.*, **38**, 737—744.

Monson, K.L. et al. (2006). *Proceedings of 2006 ASB Annual Conference.*

Thubrikar, M.J. et al. (1990). *J. Biomech.*, **23**, 15—26.

Zhang, L. et al. (2002). *Stapp Car Crash J.*, **46**, 145—163.

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