DETERMINATION OF RESIDUAL STRESS IN ARTERIES: A COMPUTATIONAL APPROACH

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Determination of residual stress distribution in arteries from recorded opening angles is typically performed analytically by assuming that the radially cut artery forms a segment of a circular annulus in its zero-stress state and a complete circular annulus of lesser inner/outer radii in its residually stressed unloaded state. Such studies have consistently shown that circumferential residual stress is compressive in the intima, and increases nonlinearly across the wall to become tensile in the adventitia. Further, they also show that accounting for residual stress in stress analyses of arteries under physiologic pressure substantially reduces the transmural variation in circumferential and axial stress across the arterial wall. However, the analytical approach to determining residual stress distribution in arteries is based on two assumptions. One, the residual stresses are calculated at the central section of a long tube by imposing an a priori constant axial stretch while deforming the artery from the experimentally recorded stress-free state to its unloaded state. Two, the artery configuration is assumed to be a partial or complete circular annulus. Arteries photographed in their stress-free state show some deviation from circularity in our experiments and hence this may be another source for error. Further, as interest moves to diseased arteries, the deviation from circularity is likely to be substantial and hence alternative ways to calculate residual stress need to be explored. We performed FEA to assess the implication due to the former assumption (i.e., constant axial stretch) and the source for error from the latter (i.e., circularity). The former assumption holds only when the central section of the artery segment is away enough from its ends – that is, when the segment is long enough for the edge-effects to subside. We used 3D cylindrical geometries and an isotropic material model to study how long the segment length must be in relation to the thickness for the analytical solution to be accurate. We then harvested a porcine femoral artery, determined its unloaded and stress-free configurations and performed FE analysis to determine the residual stress distribution using the realistic geometry without making the circularity assumption. We then performed FE analysis on a hypothetical circular annulus of ‘similar’ configuration and compared their residual stress distributions. Our findings suggest that segments length may need to be at least about five times (preferably 10 times) the wall thickness before the constant axial stretch assumption for the central region is reasonable. We also found that the circularity assumption may be a reasonable approximation for typical arteries even if they exhibit some non-circularity in their open segments.

References

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