AN INVESTIGATION ON THE USE OF SILICONE TO MODEL ARTERIAL TISSUE BEHAVIOUR IN THE TUNING-FORK MODEL OF THE CAROTID BIFURCATION


INTRODUCTION
The development of atherosclerosis in the carotid bifurcation of the cardiovascular system has been the subject of much investigation. The carotid bifurcation is a prevalent area for atherosclerotic plaque build-up (Sakata et al., 1988). The performance of minimally invasive treatment of this plaque build-up has been below expectations. There is an increased need to analyse the poor performance of this treatment by numerically and experimentally replicating the diseased carotid bifurcation geometry with realistic material behaviour. This paper presents the investigation of an analogue material to represent arterial tissue behaviour. The aim of this study is to computationally set up an idealised carotid bifurcation model and compare the mechanical behaviour of arterial tissue to a silicone material model.

Experimentally, silicone material is used primarily to replicate the mechanical behaviour of arterial tissue. Many studies have used silicone as a mimetic material of the arterial behaviour i.e. Zidi and Cheref, (2003), O'Brien et al., (2005) and Corbett et al., (2010). This study aims to evaluate how representative the use of such silicone materials are of the arterial tissue behaviour in the carotid bifurcation by comparing the mechanical behaviour of silicone material to arterial tissue using finite element analysis (FEA). This evaluation is carried out using an idealised carotid bifurcation geometry.

Bharadvaj et al., (1982) dimensioned an idealised ‘Y’ shape model of the carotid bifurcation, which is the gold standard of dimensions for the carotid bifurcation in numerical studies i.e. Delfino et al., (1997) and Hariton et al., (2007). However, Smith et al., (1996) developed an updated carotid bifurcation idealised geometry that better represents the carotid bifurcation; the ‘tuning fork’ model. Studies by Ding et al., (2001) and Thomas et al., (2005) illustrated and validated the improvements in this model. The Thomas et al., (2005) study proved that the tuning fork model, with its curved apex feature, occurs more commonly than the original Y shaped model. Therefore this tuning fork bifurcation geometry will be used in this study.

MATERIALS AND METHODS
The idealised tuning fork carotid bifurcation geometry was modelled using dimensions from the Ding et al., (2001) study and the apex curvature from the Thomas et al., (2005) study, see figure 1. The numerical setup was developed using FEA and two material models of silicone and arterial tissue were applied individually to the tuning fork carotid bifurcation geometry. The silicone material, a commercially available two-part silicone, was modelled using a reduced polynomial strain energy function (SEF), as seen in eqn. 1. The coefficients used can be seen in table 1.

The arterial tissue material model was applied using a SEF (eqn. 2) developed by Gasser et al., (2006) (HGO). This HGO SEF is a histological and phenomenological SEF that includes the effect of collagen fibres within the tissue. In this study two collagen fibre orientations were applied to the carotid bifurcation. These orientations were based off a cylindrical coordinate system with an angle of 39° (for all values see table 2). To ensure that the results developed from varying the SEF in the tuning fork model were not geometry dependent, the same HGO SEF was also employed to the Y geometry from Bharadvaj et al., (1982).

To determine if the HGO SEF does represent the mechanical behaviour of the carotid arterial tissue, and whether silicone behaves similarly, the numerical results are compared to the biaxial mechanical properties of common carotid arteries from Sommer et al., (2010).
RESULTS
This HGO SEF is compared to experimental data on the mechanical properties of carotid tissue from Sommer et al., (2010) as seen in figure 2. This was carried out to validate the HGO SEF and confirm that it predicts the arterial tissue behaviour.

Figure 2 illustrates that it is comparable to experimental data under the same pressure loads. There is a difference in material behaviour after a 7% circumferential stretch but this can be attributed to the iterative process of matching the HGO SEF values (table 2). A better understanding and characterisation of the experimental data could lead to a better demonstration of the accuracy of the HGO SEF.

Figure 3 compares the HGO SEF material behaviour to the silicone model showing a significant difference in mechanical behaviour and circumferential deformation between the material models. The HGO SEF material model has a J-type curve whereas the silicone increases almost linearly, illustrating that silicone is a poor mimetic material of the carotid arterial tissue.

DISCUSSION
The results demonstrate the difference in mechanical behaviour between the silicone and arterial tissue materials. The arterial tissue model is more elastic under a pressure load and its circumferential deformation behaves in a significantly different manner.

The results from this study confirm that the HGO SEF is a good representation of arterial tissue to published experimental material properties, even when applied to a complex geometry such as the carotid bifurcation. Conversely silicone does not represent arterial tissue mechanical behaviour undergoing a pressure load. Therefore questions arise as to whether silicone is truly an analogous material of arterial tissue in the carotid bifurcation and therefore instigating the question of what material is a good representation of the mechanical behaviour of arterial tissue.

REFERENCES