MODELLING MIDDLE MENINGEAL ARTERY RUPTURE MECHANISM: A PRELIMINARY STUDY

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Introduction

Epidural hematoma (EDH) is a traumatic accumulation of blood between the inner table of the skull and the dura membrane; EDH includes about 2-3% of pediatric head injuries, and the majority of them are temporal or temporoparietal due to the location of the Middle Meningeal Artery (MMA) [1]. The source of bleeding in most cases is due to rupture of MMA [2]. EDH is mostly associated to the skull fracture reported by 60%-70% cases [1]. On the other hand, some cases have been reported EDH without skull fracture [3]. In this work, it has been tried to investigate a possible injury mechanism of MMA, based on temporal bending-like skull deformation.

Material and method

A simple finite element model including a skull-artery contact model has been studied through simulation using ABAQUS (figure 1). The simulation includes one step explicit analysis of 0.1s, in which the artery has been pressurized up to 20 kPa and carried the time-varying radial displacement of the skull with the maximum value of 0.578 mm at the middle.

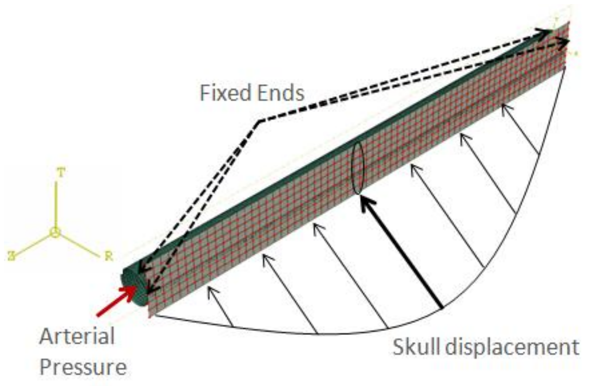

Figure 1: Finite Element Model of Skull in contact with the artery, showing the loading and boundary condition.

The artery as a cylindrical tube membrane with 8000 M3D4R elements and the skull as a cylindrical tube membrane with 469 M3D4R elements have been modeled. The diameter of the artery model is considered to be 0.63 mm. The thickness of 0.11 mm and the length of 10 mm have been also assumed in the simulation. A cylindrical coordinate system has been created to define the corresponding orthotropic material properties in axial, circumferential and radial directions. As there are no studies until now which characterize the mechanical response of MMA experimentally, the existing Fung hyperelastic material of the middle cerebral artery reported by Monson et al. [4] has been slightly calibrated with respect to MMA geometry to C1=5.14, C2=2.66, C3=111.25, C= 0.00288. For the skull, the elastic properties of E=16.7 MPa and $\nu = 0.42$ have been taken [5].

Conclusion and discussion

As noted by Holzapfel et al. [6] and Monson et al. [4], the arteries show anisotropic behavior under biaxial loading. The simulation result (Figure 2) also represents this kind of behavior, indicating stiffer response in the axial direction in comparison to the circumferential direction. However, the stress range is not as high as the typical failure stresses observed by some other arteries [4, 6].

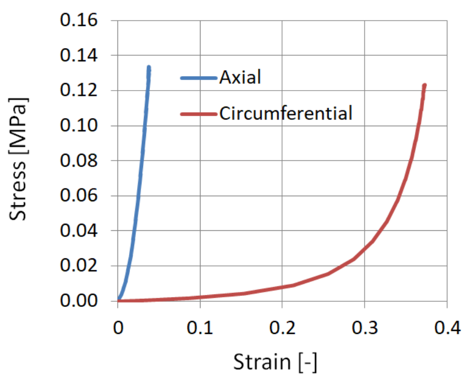

Figure 2: Stress-strain behavior of the artery in axial and circumferential directions

In conclusion, to model potential failure, the mechanical properties of MMA should be determined experimentally in the next step. More critical skull deformations should be obtained from different skull impact simulations. Furthermore, other possible injury mechanisms should be studied through simulation such as artery rupture in conjunction with dura detachment due to impact forces [3].

References

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