Assessment of bridging vein rupture associated with acute subdural hematoma through finite elements analysis after biofidelic position adaptation

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I. INTRODUCTION

Acute subdural hematoma (ASDH) is one of the most frequent traumatic brain injuries (TBIs) in bicycle-related accidents, with mortality rates ranging from 30% to 90% [1]. Next to head contusion and laceration of cerebral veins and arteries, rupture of a bridging vein (BV) is a major cause of ASDH [1-2].

Most of the FE head models include a mechanical representation of bridging veins (BVs). The SIMon model [3] has BVs modelled as cable discrete beams with a Young's modulus of 0.275 MPa. The KTH FE head model [4] has discrete beam elements with a stiffness of 1.9N, while the UCDBTM [5] and the WSUBIM [6] also have similar BV representations. The only study investigating the reliability of head models on BV ruptures known to the authors was that by Cui *et al*.[7], where data from whole body cadaver experiments were used to assess the predictability of the KTH head model by testing different reported material properties. Another factor that can significantly affect the outcome, and that has not been investigated so far, is the BV positioning within the models.

Musigazi *et al.* [8] performed a study on BV anatomy based on CT angiogram data to determine the relative position of the BVs and their entrance angles along the superior sagittal sinus (SSS), referring to conventional anatomical landmarks. These data were then used to reposition the elements in a biofidelic way.

This study evaluates the representation of BVs in the KTH head model when the mean position and the mean entrance angles of BVs are used, and makes a direct comparison with the results of [7], where the original KTH model was used to assess if positioning could improve the predictive capability of the model.

II. METHODS

A detailed description of the KTH FE head model can be found in [4]. The original model has the BVs positioned according to the findings reported by Oka [9]. The discrete beam elements are connected to a node on the SSS and a node on the cortical surface. The adapted BV model has the same number of BVs on different locations within the cortical segments, as has been reported by [8]. Each of the ten segments is a cortical region of 18° from nasion to inion. From the same study, the entrance angle of the BVs to the SSS has been modified to match the reported mean angle. In order to achieve these exact angles, the beam elements are connected to free nodes placed on the cortical surface. These nodes are connected to nodes of the cortical surface by constrained interpolation. With this constraint type, the motion of a single dependent node is interpolated from the motion of a set of independent nodes[10]. To assess if the adapted BV configuration is an improvement on the original model, the cadaver impact comparison is used in the same way as described by [7]. The commercial FE solver LS-DYNA was used. Boundary prescribed motion was used to apply the same translational and rotational accelerations as those recorded in the Depreitere *et al.* [1] experiments.

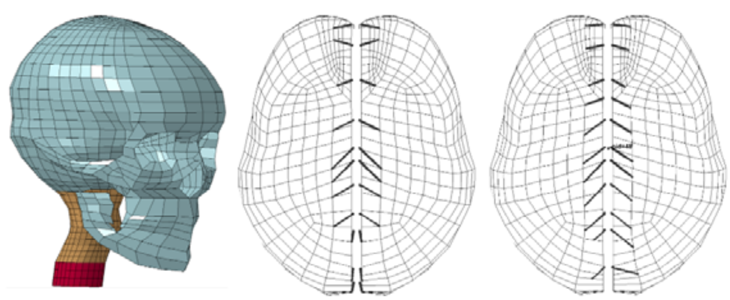

Fig. 1. From left to right: KTH head model, original model BV configuration, adapted model BV configuration.

In these experiments whole body cadavers were impacted by a pendulum on the back of the head. The acceleration was captured by three uniaxial accelerometers fixed on the left side of the cadaver head. After each

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blow the cadavers were checked for BV ruptures by means of fluoroscopy. From the original 18 cases, six were discarded due to insufficient information.

To simulate the cadaver experiments, the recorded accelerations of each of the cases were applied on the adapted KTH head model. Three different sets of BV material properties have been used in the same way as in [7]. The aim is to determine how many successful predictions of either rupture or non-rupture this adapted model can yield, with a maximum of 12. The linear and rotational accelerations were given as an input. The maximum BV strain was used as a rupture criterion. The engineering strain of all the BVs was calculated and compared to BV failure strain reported in literature [7].

III. INITIAL FINDINGS

The results are shown in Table I. The success rate is the percentage of the correct predictions to the total number of experiments. The unsuccessful predictions are further separated into false positive or false negative rupture predictions, with false negative being less desirable from a head protection point of view. All three parameter sets yield a prediction of 67%, which is similar to the prediction rate reported by [7].

The location of the maximum BV strains in the adapted model is mainly at the middle cortical segments (4,5,6), which correspond to the location reported by Depreitere *et al*. [1]. Instead, the original head model from the study of [7] yields the maximum BV strains almost completely at the back of the cortical segments (8,9).

TABLE I
THE RESULTS OF THE CADAVER EXPERIMENT SIMULATIONS WITH THE ADAPTED KTH HEAD MODEL (FP: FALSE POSITIVE, FN: FALSE NEGATIVE, SP: SUCCESSFUL PREDICTION) AND HIGHEST BV STRAIN LOCATION (F: FRONT, M: MIDDLE, B: BACK)

	01-3_1		**01-3_2**		**21-2_2**		**21-3_1**		**22-3_1**		**25-2_1**		**25-2_2**		**28-2_1**		**29-3_1**		**30-2_1**		**32-2_1**		**33-2_2**	
Age	80 yo		80 yo		82 yo		93 yo		70 yo		65 yo		65 yo		93 yo		80 yo		86 yo		55 yo		88 yo	
Delye	FP	M	FN	M	FN	F	SP	B	SP	M	SP	F	SP	F	FN	M	SP	M	SP	M	SP	M	SP	M
Monea	FP	M	FN	M	FN	F	SP	B	SP	M	SP	F	SP	F	FN	M	SP	M	SP	M	SP	M	SP	M
Monson	FP	M	FN	M	FN	M	SP	M	SP	M	SP	M	SP	F	FN	M	SP	B	SP	M	SP	M	SP	M

IV. DISCUSSION

Even though there is no improvement in successful predictions, the improvement in maximum strain location is a step forward. Furthermore, there are a number of factors that need to be considered. Four out of 12 cases come from a second impact on the same cadaver when the first did not produce a rupture. All of the ruptures occurred on cadavers with an age of 80yo+. Even if the beam elements are placed in the mean position and angle, there is a considerable inter-specimen variation. Subject-specific angles could be another possible approach. The BV material used is linear elastic, which does not show the anisotropic nature of the tissue, and also the vein geometry is oversimplified. Finally, the mean ultimate strain was used as a failure criterion even though the reported standard deviations of ultimate strain are also significantly large. Future work will include developing a BV rupture risk assessment by taking into account the whole ultimate strain distribution.

V. REFERENCES

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