Finite Element Analysis for Understanding Trauma Brain Injury in Judo

Daisuke Ito, Koji Mizuno, Masahito Hitosugi, Haruo Murayama, Katsuhiro Koyama

I. INTRODUCTION

Head injuries are frequent in judo, which is a famous martial arts in Japan. Acute subdural hematoma (ASDH) often occurs when participants fall and are thrown. In Japan, at least 30 cases of severe head injuries in judo were reported from 2003 to 2010 [1] and 28 of 30 people suffered from ASDH. Another research study also showed that 76 head trauma injuries were involved in 110 cases of fatal judo accidents in school (1983-2011) and 51 of 76 cases were related to ASDH.

In this study, head impact conditions in judo were reproduced with a human FE model, and brain kinematics and injuries were examined in order to understand head injury mechanisms in judo. A head FE model reflecting anatomical and mechanical characteristics was used. Experimental data of translational and rotational acceleration were input to the FE model. The brain strain distribution and some injury measures were investigated.

II. METHODS

The Simulated Injury Monitor (SIMon) FE head advanced model developed by the National Highway Traffic Safety Administration (NHTSA) [2-3] was used in this study. The model consists of the cerebrum, cerebellum, brainstem, ventricle, falx, tentorium, parasagittal blood vessels (bridging veins) and combined pia arachnoid complex (PAC) and the cerebro-spinal fluid (CSF) layer. The mass of the head and brain models were 4.5 and 1.5 kg, respectively, which corresponds to size of the 50th percentile male.

In this study, three experimental data obtained by dummy experiments were used for the FE analysis shown in Fig. 1. The experimental studies reported by [4] are briefly described as follows. The POLAR dummy with a height of 175 cm, mass of 75 kg and high biofidelity was used as the Anthropomorphic Test Device (ATD). An expert judo athlete threw the dummy on the tatami, which is a Japanese mat, by throwing techniques called Osoto-gari, which has the highest risk of any throwing technique [1]. The dummy fell backward and the occipital area of the head hit the tatami. The dummy reproduced kinematics of a thrown judo player who could not perform proper protective measures to prevent head contact. Translational and rotational accelerations of head in impact were measured by accelerometers installed in the dummy head. These translational and rotational accelerations were given to the rigid skull of human head model as prescribed motion.

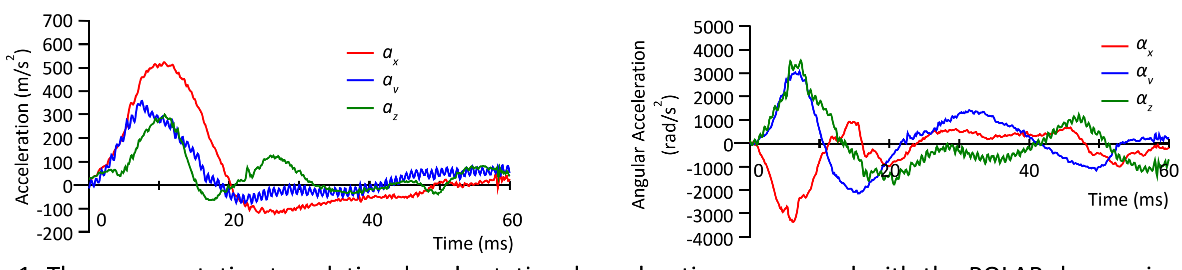

Fig. 1. The representative translational and rotational accelerations measured with the POLAR dummy in an Osoto-gari throwing test [4].

Some injury measures were evaluated. In order to evaluate the deformation of the brain, the maximum principal strain (MPS) in the brain was examined with the FE model at impact. The MPS is associated with brain tissue damage, such as haemorrhagic cortical contusions and axonal damage. The Cumulative Strain Damage Measure (CSDM) was examined in order to evaluate injury risk of diffuse axonal injury. Elongation of superior cerebral veins, so called

D. Ito is an Assistant Professor in the Department of Mechanical Science and Engineering at Nagoya University in Japan (+81-52-788-6233, ito@mech.nagoya-u.ac.jp). K. Mizuno is a Professor in the Department of Mechanical Science and Engineering at Nagoya University, Japan. M. Hitosugi is a Professor in the Division of Legal Medicine in Shiga University of Medical Science, Japan. H. Murayama is an Associate Professor in the Department of Sports Science in Dokkyo Medical University School of Medicine, Japan. K. Koyama is a Professor in the Graduate School Department of Interdisciplinary Research, University of Yamanashi, Japan.

"bridging veins", was also measured. Elongation of bridging veins, which is one of the most common factors in ASDH, was examined by using beam elements representing parasagittal blood vessels.

III. INITIAL FINDINGS AND DISCUSSION

Distribution of MPS in the brain is shown in Fig. 2. As shown in Fig. 2, large strain occurred on the surface of the brain (at 10 ms). The strain started to concentrate on the callosum region at 15 ms. The MPS was observed in the right lateral surface region in all cases. From this result, it was found that brain injury risk is high in the lateral region and the callosum.

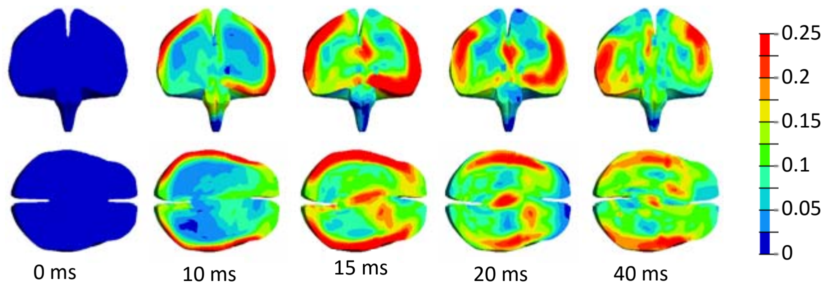

Fig. 2. Distributions of MPS. The upper row represents the distribution in the coronal plane and the lower row in the transverse plane.

Elongation of bridging veins, one of the most important factors for ASDH, was examined by using beam elements representing parasagittal blood vessels. Fig. 3 show the elongation time histories of these elements. At about 20 ms, the beam elements in the right frontal lobe and the left parietal lobe were elongated due to brain rotational behaviour in the transverse plain. Their maximum strain was about 0.1, which is lower than the failure threshold of bridging veins [5]. After that, the rotational direction of the brain was reversed and these beam elements were compressed.

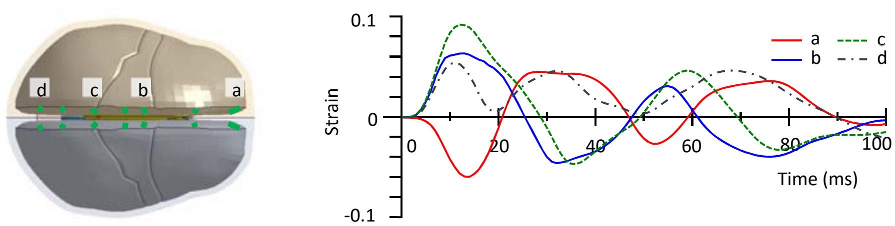

Fig. 3. Representative strain time histories of the beam elements representing bridging veins.

Table I shows injury measures in each impact simulation. The probability of trauma brain injury (TBI) and diffuse axonal injury (DAI) were estimated based on injury risk curves [3]. The results show that although severe concussion with the loss of consciousness for 1-6 hours was predicted based on MPS, the risk of diffuse axonal injury was low in judo impact.

TABLE I
VALUES OF INJURY MEASURES IN THREE SIMULATIONS

	Test 1	Test 2	Test 3	Average (± 1 S.D.)
Maximum Principal Strain (prob. of TBI (AIS3))	0.614 (0.348)	0.707 (0.472)	0.681 (0.437)	0.667 ± 0.048
CSDM (Threshold = 0.25) (prob. of DAI)	0.156 (0.047)	0.234 (0.083)	0.298 (0.131)	0.229 ± 0.071

Our results implies the possibility that injury risks of rupture of the bridging veins is low in judo and the previous criteria cannot predict ASDH because of low rotational acceleration. However, the strain in the surface of brain was high and this may result in cortical veins rupture. The results may support the hypothesis in [6] that almost all ASDH's from non-penetrating impacts are due to the rupture of cortical vessels in the dural/arachnoid complex, not including the bridging veins. Further research is needed in order to clarify injury mechanisms of the brain in judo.

IV. REFERENCES

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