Finite Element Analysis and Experimental Study on Mechanism of Brain Injury Using Brain Model

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Abstract – The aim of this study is to discuss the occurrence mechanism of the brain injury analytically and experimentally. In this paper, first, an experimental system to do an impact experiment was presented. The pressure changes inside a brain agar phantom were measured. Second, a three-dimensional FEM model of the impact experiment was constructed. From the results of the fundamental analysis, the transmitted pressure inside the brain agar phantom could be presented. The comparison of the computer simulation and experimental results showed that the negative pressure values, same as the positive pressure occurred in the coup side region of the agar, also appeared in the contrecoup side region of the agar.

I. INTRODUCTION

Annually, motor vehicle crashes in the world cause over a million fatalities and over a hundred million injuries [1]. The head is identified as the body region most frequently involved in life-threatening injury. To understand how the brain gets injured during an accident, the mechanical response of the contents of the head during impact has to be known. The damage of the brain is divided into the pressure damage and the acceleration damage roughly. In the case of the both damages, there are two types of injuries, one is coup injury caused in the direct hit region, and the other is contrecoup injury caused in that diagonal position. However, the occurrence mechanisms of the latter injury have not been explained yet. Since this response can not be determined during an in-vivo experiment, numerical finite element method (FEM) is often used to predict this response.

In this study, first, a system to do a basic experiment was built, and an impact experiment was conducted for the purpose of making the occurrence mechanism of the brain injury clear. Second, a simple three-dimensional FEM model was constructed, and the fundamental analysis of the brain damage mechanism was completed. From the comparison of simulation and experimental results, it was found that computer simulation method was useful to investigate the mechanical response of the head.

II. METHOD

Fig. 1 shows the schematic drawing of impact experiment. In Fig. 1, we assign that the acrylic resin, agar and water to be head bone, brain tissue and cerebrospinal fluid (CSF), respectively. Pressure sensors were embedded at the three positions inside the agar. The signals from these sensors were transmitted to the computer and analyzed. When combined with a general strain amplifier, the pressure sensor detects the unique distribution of spot pressures. Experimental setup is shown in Fig. 2. Acrylic resin container used in these experiments was 10.0cm in inner diameter, and 8.0cm in height. The agar was 8.0cm in diameter, and 4.0cm in height. The pressure sensor, comes with a foil strain gage and Wheatstone bridge in an incredibly small and thin mainframe, which is 6.0mm in diameter and 0.6mm in thickness (Fig. 3). Fig. 4 shows a three-dimensional finite element mesh for calculating pressure distributions.

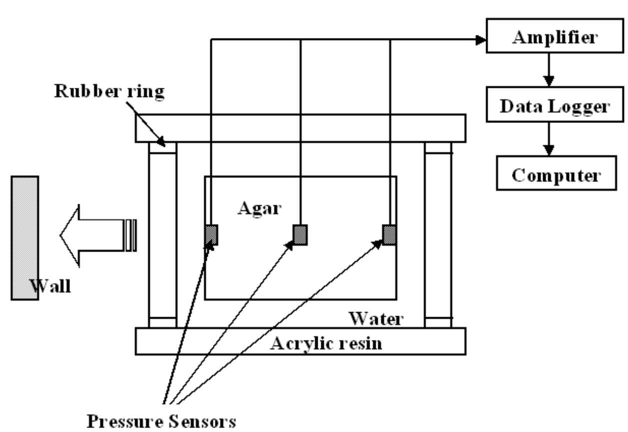


Fig. 1 Schematic drawing of impact experiment.

Fig. 2 Experimental setup.

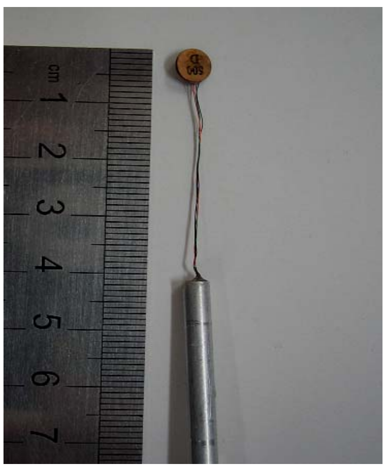


Fig. 3 Pressure sensor used in the experiments.

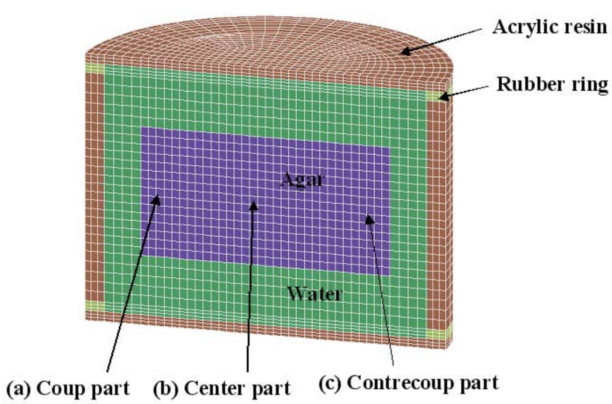


Fig. 4 Finite element mesh for calculating pressure distributions.

Table I Typical values of acrylic resin and agar parameters.

	Density (kg/m^3)	Young's modulus (MPa)	Poisson ratio	Yield stress (MPa)
Acrylic resin	1190	2900	0.23	71
Agar	1040	17	0.49	2

Table II Typical values of water parameters.

	Density (kg/m^3)	Bulk modulus (MPa)	Kinetic viscosity (m^2s)
Water	1040	2250	1×10^{-6}

Table III Typical values of skull bone and brain parameters.

	Density (kg/m^3)	Young's modulus (MPa)	Poisson ratio	Yield stress (MPa)
Skull bone	2600	5540	0.23	71
Brain	1040	17	0.49	2

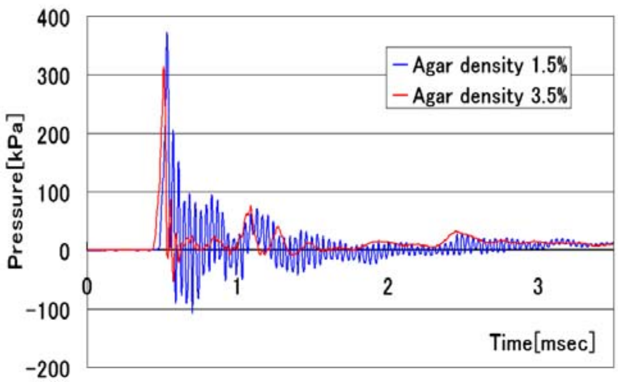
Table IV Typical values of water parameters.

	Density (kg/m^3)	Bulk modulus (MPa)	Kinetic viscosity (m^2s)
CSF	1040	2250	1×10^{-6}

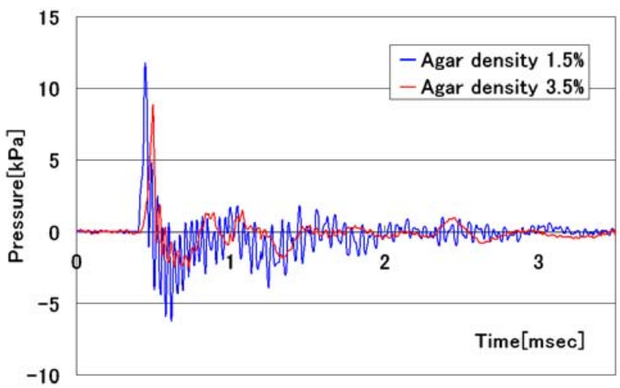
Here, the acrylic resin and the agar were treated as the elastoplastic material. On the other hand, the water was treated as the fluid material. The physical parameters used in the calculation shown in Fig. 6 (simulation A) are listed in Tables Ⅰ and Ⅱ. The physical parameters of human head shown in Fig. 6 (simulation B) are listed in Tables Ⅲ and Ⅳ [2], [3]. Here, LS-DYNA was used in computer simulations.

III. RESULTS AND DISCUSSIONS

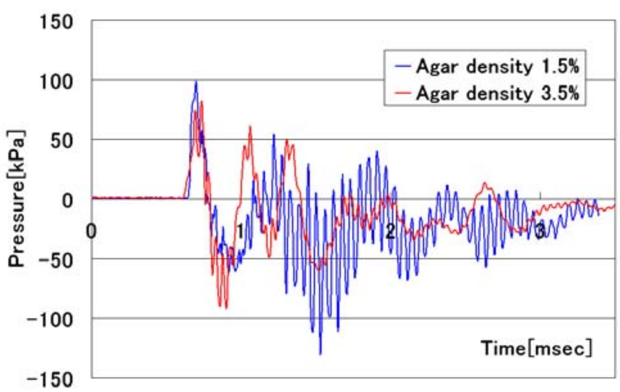
Fig. 5 shows the results of the measurement pressure at the three points shown in Fig. 1 by impact experiment. In the experiments, the two kinds of agars used were 1.5% and 3.5% concentrations. Fig. 5(a) shows the pressure fluctuation near the coup side region of the agar. In Fig. 5(a), the maximum pressure values just behind impact are 310kPa and 370kPa to the 1.5% and 3.5% concentrations, respectively. In Fig. 5(b), at the center region of the agar, the maximum pressure values are less than 15kPa. In Fig. 5(c), near the contrecoup side region of the agar, it is found that, in addition to its maximum pressure value of 80kPa, the



(a)



(b)



(c)

Fig. 5 Experimental result of pressure changes,
(a) coup side region, (b) center region,
(c) contrecoup region.

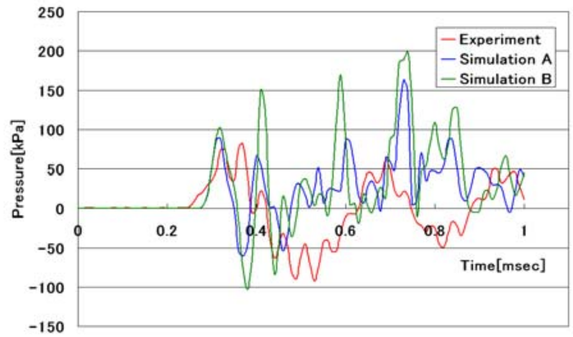
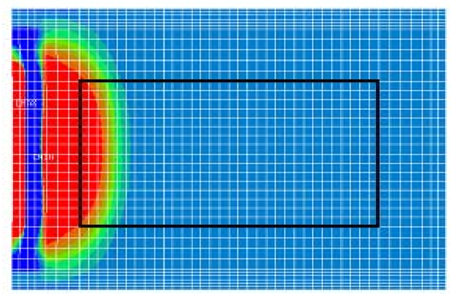
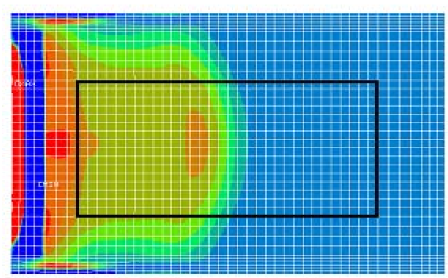


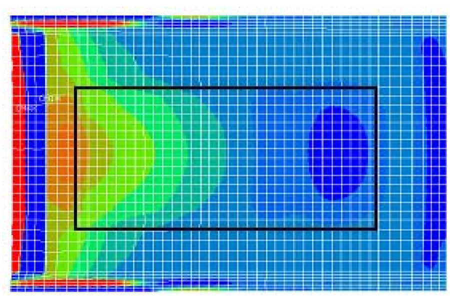
Fig. 6 Estimated and measured pressure changes.



(a)



(b)



(c)

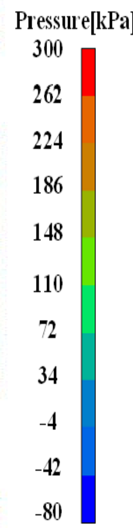


Fig. 7 Estimated pressure distributions after impact,
(a) time=0.19msec, (b) time=0.25msec, (c) time=0.37msec.

negative pressure value of more than –100kPa is caused. Fig. 6 shows the comparison of experimental and analytical results near the contrecoup side region of the agar. Here, normalized pressure P_n is given by

$$P = \frac{(P - P_{max})}{(P_{max} - P_{min})} \qquad (1)$$

where P_{min} is the minimum pressure value, P_{max} is the maximum pressure value, P is the pressure value at the point (c) shows in Fig.4. In Fig. 6, both the experiment and computer simulations confirm that the negative pressure, same as the positive pressure occurred in the coup side region of the agar, appeared in the contrecoup side region of the agar. Fig. 7 shows the time course changes of the pressure distributions inside the agar after impact. We find that, from Fig. 7(a), in the coup side, the high pressure region spreads to the surface of the agar just after impact (time=0.19msec). In Fig. 7(b), the high pressure is transferred to the contrecoup side region of the agar. In Fig. 7(c), we can see that the negative pressure appears in the contrecoup side because of the reflected pressure.

IV. Conclusion

The results of basic impact experiments and its computer simulations were described. According to our numerical results by using FEM, it can be seen that the negative pressure values, same as the positive pressure occurred in the coup side region of the agar also appeared in the contrecoup side region of the agar because of the reflected pressure.

We are now trying to measure the pressure changes inside an animal brain under the impact experiment.

References

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