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# Basic Study of Brain Injury Mechanism Caused by Cavitation

Y. Kurosawa, K. Kato, S. Saito, M. Kubo, T. Uzuka, Y. Fujii, and H. Takahashi

*Abstract*—**The purpose of this study is to discuss the mechanism of brain injury experimentally, with respect to the pressure changes on the surface of a brain agar phantom by cavitation. First, an experimental system to perform an impact experiment is presented. We present some images taken by a high-speed camera of the behavior of a simple physical head model with and without the brain agar phantom during impact. From the photographs of the high-speed camera, we can confirm that cavitation bubbles occur at the contrecoup side, irrespective of the usage of the brain agar phantom. Second, two experimental systems to perform impact and strike experiments are presented. The pressure changes on the surface of the brain agar phantom at contrecoup side were measured by two kinds of experiments and impact velocities. Frequency analysis of the measured pressure changes was conducted by FFT software. From these results, we found that the collapse of cavitation bubbles at the contrecoup side can strongly affect the characteristics of pressure changes on the surface of the brain agar phantom.**

## I. INTRODUCTION

FROM the latest statistics, while death toll of traffic accident has been reduced in some countries , there have been over a million fatalities and over a hundred million injuries world wide[1]. The largest cause of death in traffic accidents is brain injury and the human brain is the most important part of the human body. Therefore the brain has to be protected from strong impacts. Types of the brain damage are roughly divided into pressure damage and acceleration damage. There are two sides of brain damage. One is coup injury caused at the directly hit region, the other is contrecoup injury caused at the opposite side. Although many researchers studied the mechanism of contrecoup injury, it is not sufficiently satisfied results of the mechanism.

In previous works, we presented the computer simulation by the three-dimensional (3-D) finite element method (FEM). FEM were performed to predict the mechanism of contrecoup injury. We found that the high pressure is generated in the acrylic container at the time of impact and spectrums are generated in some frequency bands.

First, in this paper, an experimental system to take pictures of the mechanism is presented. We recorded the behavior of the simple physical head model, with and without a brain agar phantom, at the contrecoup part using a high-speed camera at 2000fps.

Second, two experimental systems to perform impact and strike experiment are presented. The pressure changes on the surface of the brain agar phantom at contrecoup part were measured at two different speeds. Also, frequency analysis of the pressure changes were measured by a Fast Fourier Transformation (FFT).

## II. METHOD

Fig. 1 shows the cross section of simple physical head model used in the impact experiments. To discuss the basic mechanism of brain injury, we assume that the head model consists of a skull, cerebrospinal fluid (CSF) and brain tissue to be represented by the acrylic resin, water and agar, respectively. Acrylic resin container used in the experiments was 18.0cm in diameter, and 17.6cm in height, which is approximately the same size of a human head. The agar was 14.0cm in diameter and 12.0cm in height. The agar was placed in the center of the acrylic container and the inside of the container was filled with water.

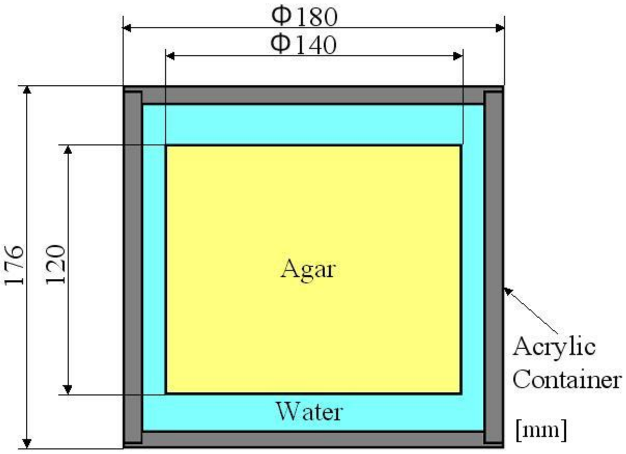

Fig. 1. Cross section of simple physical head model

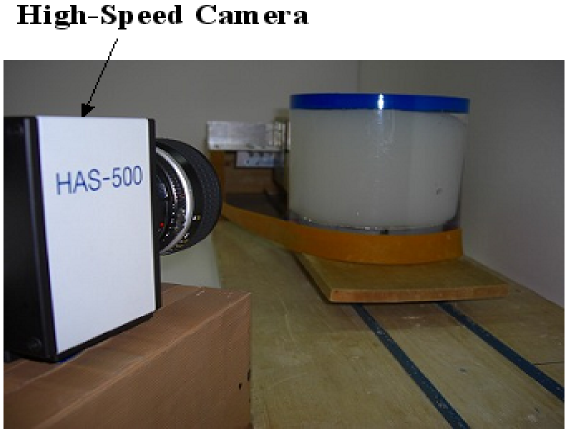

Fig.2. Experimental setup for taking pictures

Y. Kurosawa, K. Kato, and S. Saito are with Dept. of Mechanical Engineering Informatics, Meiji University, Kawasaki, Japan. (e-mail: ce82024@isc.meiji.ac.jp)

M. Kubo is with Future Creation Laboratory, Olympus Co., Ltd., Tokyo, Japan.

T. Uzuka and Y. Fujii are with Dept. of Neurosurgery, Brain Research Institute, Niigata University, Niigata, Japan

H. Takahashi is with Niigata Cancer Center Hospital, Niigata, Japan

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The structure of the container is equal to a sudden pressure increase at the time of impact. Even small air bubbles cannot enter the acrylic container, because of a plastic seal. Since the acrylic container is sealed tightly, when bubbles are observed inside the container we can be fairly certain that the cavitation phenomenon occurs in the acrylic resin container. Fig. 2 shows the experimental setup to take pictures at the contrecoup part. We made this head model collide with a wooden wall at 10km/h using a precise elastic band. The high-speed camera used in the experiments was a HAS-500 (Ditect), which can capture 2,000 frames per second. The camera was set to observe the whole contrecoup part behavior of the head model. Fig. 3 and Fig. 4 show two kinds of experimental setup. In the traffic accident, we assume some cases that an impacter collides to the human head and the human head collides to the impacter. Therefore we used two kinds of experimental setups that are for impact and strike experiments. Fig. 5 shows the pressure sensor to measure the pressure changes on the surface by the contrecoup part of the agar. The diameter of the sensor is 6.0mm, and thickness is 0.6mm. The specifications of the pressure sensor are listed in Table Ⅰ. The pressure signal from the sensor was transmitted to the computer and analyzed. Combining the strain amplifier and data logger with the pressure sensor, it detects the unique distribution of spot pressure. The pressure sensor was fixed on the surface of agar, which causes small initial pressure, so the measured pressure means differential pressure in the experiments. We installed the pressure sensor in contrecoup part of each experimental setup and measured pressure changes. The agar used in the experiments is 2.0% concentration, and its Young's modulus is 224kPa.

## III. RESULTS AND DISCUSSION

First, the impact experiment was conducted by using the acrylic resin container without agar. Fig. 6 shows the selected four frames from the film shot at the impact speed of 10km/h. In Fig. 6(a), t=0.0 is the time just after impact. The bubble is not generated inside the acrylic container. In Fig. 6(b), small bubbles begin to spread from the both side to contrecoup part of head model at t=1.0msec. In Fig. 6(c), the bubbles of both sides fade away and the size of the bubbles of contrecoup part becomes big. In Fig. 6(d), most bubbles concentrate on contrecoup part and bubbles become biggest. Next, we conducted the impact experiment with agar. Fig. 7 shows the selected four frames from the film shot at the same impact speed with no agar. In Fig. 7(a)~(d), it can be seen that bubbles occur inside the acrylic container clearly same as Fig. 6. From Figs. 6 and 7, we can find that the cavitation phenomenon occurs at the contrecoup part, and it is not dependent on existence of the brain agar phantom. Fig. 8 shows the results of the measured pressure changes on the surface of the contrecoup part. From the past experiment with the high-speed camera, we found that the marginal speed in which the cavitation occurs is 6km/h. We choose 5km/h and 10km/h as collision speed to examine influence on pressure changes by having cavitation bubbles. In Fig. 8(a), the negative maximum pressure generated by collision

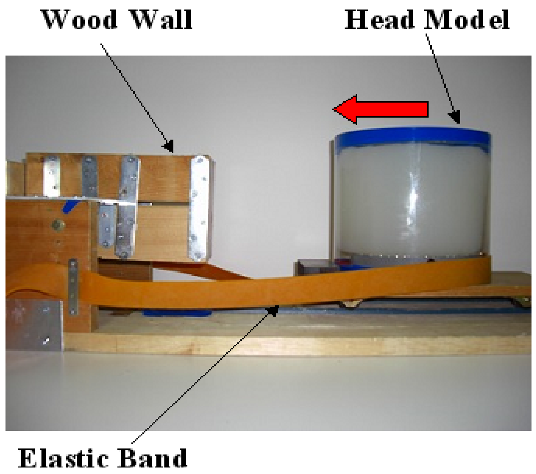


Fig.3. Experimental setup (Collision)

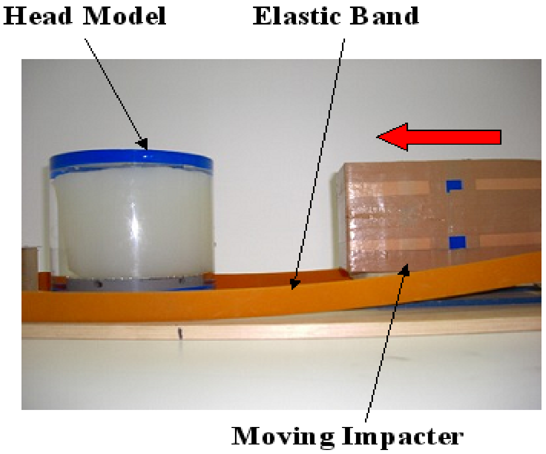


Fig. 4. Experimental setup (strike)

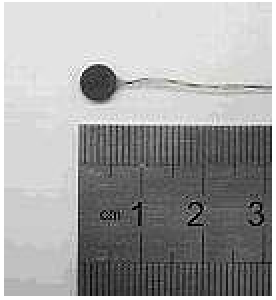
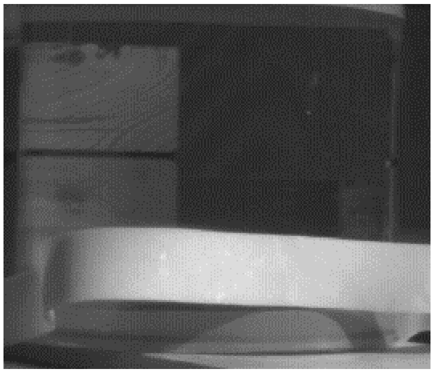


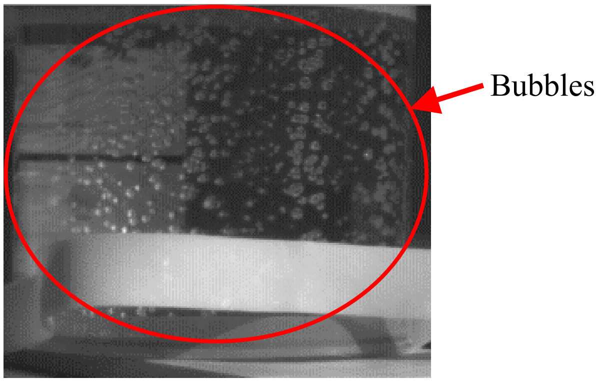
Fig. 5 Pressure sensor

Table Ⅰ Specifications of pressure sensor

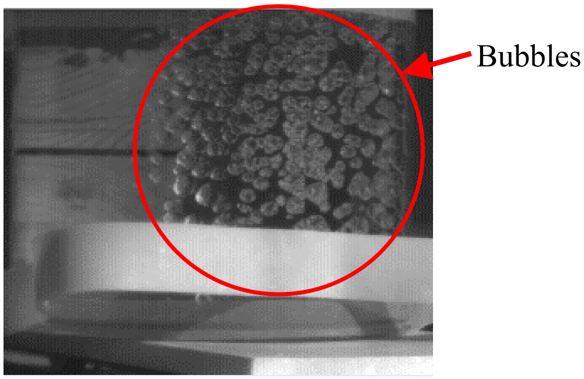
| | |
|---|---|
| Rated capacity | 200kPa |
| Rated output | 0.856 |
| Safe excitation voltage | 3V |
| Bridge resistance | 120Ω |
| Natural frequency | 14kHz |
| Sampling time | 10 μ sec |
| Diameter | 6mm |
| Thickness | 0.6mm |



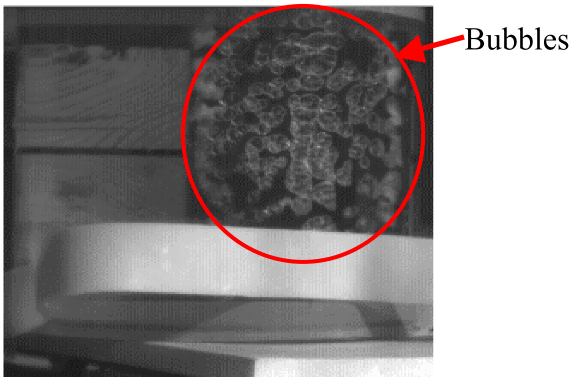
(a) t=0.0[msec]



(b) t=1.0[msec]

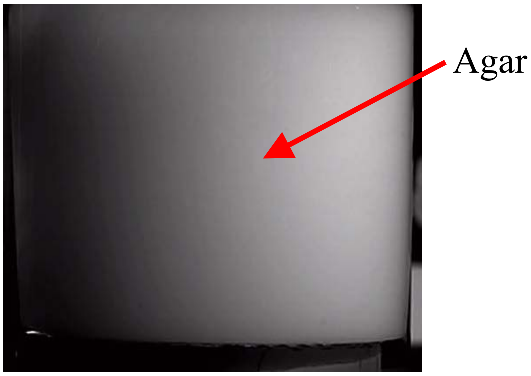


(c) t=2.0[msec]

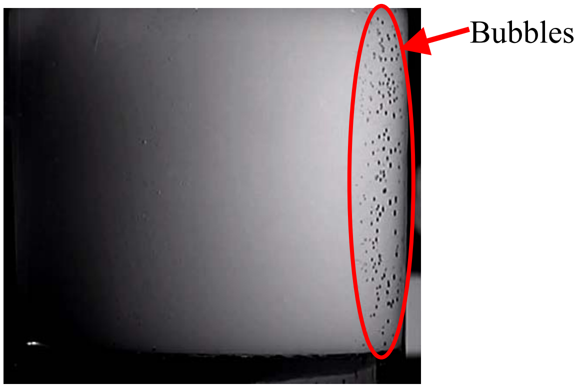


(d) t=3.0[msec]

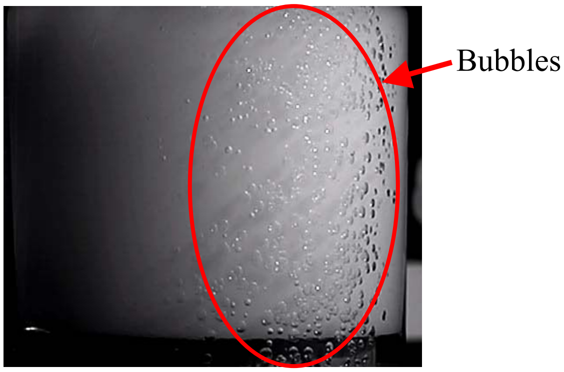
Fig. 6. Four frames from the film shot at 10km/h (no agar)



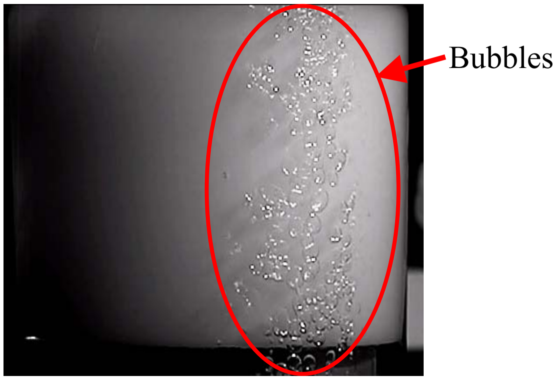
(a) t=0.0[msec]



(b) t=1.0[msec]



(c) t=2.0[msec]



(d) t=3.0[msec]

Fig. 7. Four frames from the film shot at 10km/h

experiment appeared over 3msec period immediately after the impact. On the other hand, the negative maximum pressure by the strike experiment appeared over 2.5msec period immediately after the impact. The outbreak time of negative pressure was different, but the maximum absolute pressure was 80kPa each other. In Fig. 8 (b), both of experiments generated the negative pressure over about 3msec period immediately after the impact, and the big pressure vibration at 4msec also appeared. This time for the pressure vibration to occur is well in agreement with time when cavitation bubbles concentrates on contrecoup part. This fact expresses that the collapse of cavitation bubbles has much effect on pressure changes at contrecoup part. The pressure vibration, that the margin of the positive maximum pressure and negative maximum pressure becomes 500kPa, may be related to the contrecoup injury.

Fig. 9 shows the results of the frequency analysis of the pressure changes by using the FFT program [2], [3]. Here, the normalized amplitude $x_n$ is given by the following equation:

$$x_n = \frac{(x - x_{\min})}{(x_{\max} - x_{\min})}$$

where, x is the amplitude of pressure change, $x_{\min}$ is the minimum amplitude, $x_{\max}$ is the maximum amplitude.

From these results, some big peaks are seen in frequencies of up to 3,000Hz in Figs. 9 (a) and (b). Over 3,000Hz shown in Fig.9 (a), we coudn't find the peak of characteristic frequency band. But in Fig.9 (b), we found that it includes high frequency component over 3,000Hz comparing with Fig. 9 (a). Especially the pressure changes contain over 14,000Hz to 18,000Hz period frequency component.

## IV. CONCLUSION

We discussed experimentally about the cavitation phenomenon generated in the collision and the pressure fluctuation generated in the case. The photographs of the behavior at the contrecoup side were presented using a high-speed camera. We could detect the cavitation phenomenon in the simple physical head model. The pressure changes on the surface of the agar at the contrecoup side were measured. We found pressure vibration caused by the collapse of bubbles. It may be possible that the cavitation causes brain injury.

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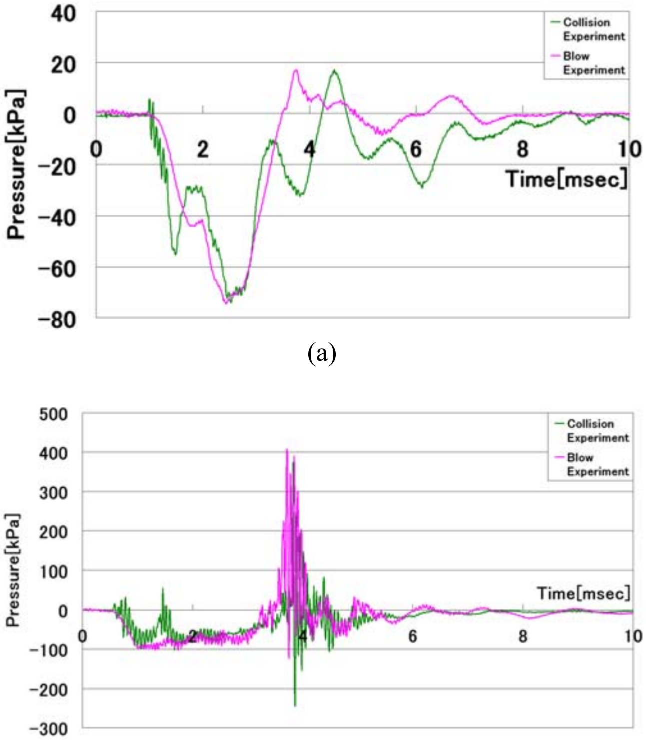
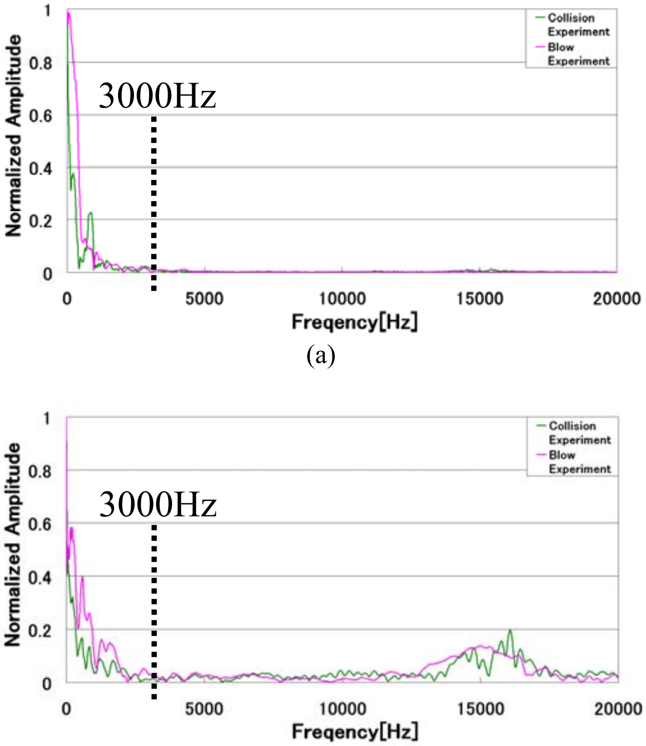


(a)

(b)

Fig. 8. Measured pressure changes on surface of the contrecoup part agar at the impact velocities: (a) at 5km/h (b) at 10km/h



(a)

(b)

Fig. 9. Amplitude spectrum of measured pressure changes at the impact velocities: (a) at 5km/h (b) at 10km/h