Single underwater spark discharge-induced shock wave used for physical gene transfer method

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1. Introduction

High pressure underwater shock waves which are generated by explosive process such as electrical discharge or microexplosive explosion have been successfully applied to a clinical use of extracorporeal shock wave lithotripsy1-3. Shock wave mediated gene transfection4 has also attracted much attention as a physical method with high survival rate and high transfer efficiency. In order to introduce the foreign substances into human primary cultured cells, we have used single shock wave generated by underwater spark discharge5. In this study, the acoustic characteristics of single underwater spark discharge induced shock wave were investigated using a polyvinylidene difluoride film-based hydrophone sensor which is known as a detector of underwater shock waves6.

2. Experimental procedure

2-1. Shock wave generation

Single shock wave was generated by underwater spark discharge using an impulse voltage generation circuit. This circuit is composed of a charging circuit and a discharge circuit including a gap switch (GS). The basic operation of this circuit is as follows: The sinusoidal AC voltage (60 Hz) reduced by a variable autotransformer is boosted 150 times with a neon transformer. The boosted AC voltage is half-wave rectified by 40 series-connected-diodes. The boosted and rectified AC voltage is charged in five parallel-connected capacitors (each capacitance of 1700 pF) through a 50 kΩ resistor. The charging voltage is applied to the needle electrode in water through GS. In this experiment, the electrode distance fixed at 1 mm and 2 mm were used for the GS interval set to 2 mm and 3 mm, respectively.

The applied voltage, the discharge current, and the shock wave were measured using a high voltage probe (Nissin Pulse Electronics, C0701) and a current transformer (PEARSON ELECTRONICS, 110), and a hydrophone sensor with rise time of 50 ns (Muller, Platte Needle Probe), respectively. These temporal waveforms were measured using a digital oscilloscope (Iwatsu, DS-5414).

2-2. Shock wave measurement

Figure 1 shows an illustration of the positional relationship between the needle electrode and the hydrophone sensor in the shock wave measurement. The tungsten needle electrodes (tip radius: 25 µm) were placed in a tank (61 × 61 × 85.5 mm) filled by pure water (conductivity 1 µS/cm). The needle electrodes were fixed at a height of 40.5 mm from the bottom of the tank. The hydrophone sensor was installed upward the needle electrodes and its position was adjusted precisely by using the three-axial ball slide stages (SIGMAKOKI) and a precision labjack (SIGMAKOKI). In this experiment, the distance between the electrode and the tip of hydrophone sensor was set to 6 to 12 mm.

3. Experimental results and discussions

3-1. Discharge and pressure waveforms

Figure 2 shows the discharge power and the pressure waveforms when the distance from the needle electrode to the hydrophone sensor is set to 10 mm. The results in the distance between needle tips of 2 mm and 1 mm are shown in Fig. 2(a) and 2(b), respectively. In these figures, the time of the peak power was set to 0 s. The discharge energy calculated from the power waveform of Fig. 2(a) and 2(b) were 0.429 J and 0.135 J, respectively. The each observed pressure waveform was composed

Table 2

<table>
<thead>
<tr>
<th>Center freq (kHz)</th>
<th>Max dB at 1 MHz</th>
<th>Max dB at 285 kHz</th>
<th>Max dB at 359 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68.6</td>
<td>65.2</td>
<td>62.5</td>
</tr>
<tr>
<td>2</td>
<td>69.2</td>
<td>66.3</td>
<td>63.5</td>
</tr>
<tr>
<td>3</td>
<td>69.8</td>
<td>66.7</td>
<td>63.8</td>
</tr>
</tbody>
</table>

3-2. Attenuation coefficients

The attenuated sound wave s have maximum transmitted pressure and center frequency, transmission through human skull cadaver variation in the future studies. It also needs to minimize the laser output further investigation is required for higher pressure geometrical differences and skull density ratio.

References

[2] Xiaofeng Fan., et al., Proceedings of...
mainly of positive pressure components and shows steep rise in pressure. The maximum values of the pressure shown in Fig. 2(a) and 2(b) were 11.9 MPa and 7.52 MPa, respectively. As can be seen from these figures, the each peak pressure was changed by changing the discharge energy, whereas, its waveform shape was unchanged. The full width at half maximum of pressure shape was 0.27 μs.

3-2. Pressure gradient and impulse

The relationship between the waveform shape and gene introduction has been already investigated by several researchers.  Mulholland et al. reported the effect of high stress gradient of the laser-induced stress wave (LISW) on the permeabilization of the plasma membrane7).  Kodama et al. showed that the impulse of shock wave was dominant factor for uptaking the molecules into the cytoplasm of human cells8).  In this study, therefore, the pressure gradient and pressure impulse of underwater spark discharge-induced shock wave were calculated from the pressure waveforms.

Figure 3 shows the peak pressure dependence of the pressure gradient (closed black circles) and pressure impulse (closed red circles). The closed blues squares and open green triangles indicate the pressure gradient and pressure impulse estimated from the results of LISWs, respectively.

4. Conclusion

The acoustic characteristics of single shock wave generated by underwater spark discharge were investigated in detail. As a result, the generated shock wave consists mainly of the positive pressure component and has an ability used for gene transfer, even when the discharge energy is less than 0.5 J.

Acknowledgments

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References

7)  S. E. Mulholland, S. Lee, D. J. McAuliffe, and A. G. Doukas, Pharm. Res. 16[4], 514 (1999).