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Experimental study and mechanism analysis on bioeffects by nanosecond electromagnetic pulses*

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Abstract The athermal bioeffects caused by nanosecond electromagnetic pulses with body cells was studied by using a broad band transverse EM-wave cell (BTEM CELL). The experimental system and preliminary mechanism analysis were presented.

Keywords: nanosecond electromagnetic pulses, athermal bioeffects, mechanism analysis, BTEM CELL.

1 Introduction of biological effect on transient electromagnetic pulses (TEMP)

The bioeffects of the TEMP on biological bodies are very different from that of continuous wave, which is a newborn subject in bioelectromagnetism. The thermal and athermal biological effects on interaction of continuous wave with biont were widely studied during the past half century, while the interaction of transient electromagnetic field to biological bodies was seldom reported[1—5]. The reasons are as follows.

For continuous wave, biological features in bionts are relative to frequency, average power density and interactive time of incident wave. When incident EM field is a transient narrow pulse, the average power density becomes meaningless and almost zero. The biological effects are only relative to TEMP waveform, amplitude and duration of pulses. Their dosage standards are much different.

For TEMP incidence, the interaction process of pulses with bionts is instable and nonlinear. The duration of transiently induced current in bionts is much shorter than that of continuous wave. The experiment requires an ultra wide band-width measurement system. Because TEMP possesses a very wide spectrum (the frequency component extends almost from direct current to giga hertz), continuous wave experimental system of single frequency cannot be used[6].

To determine the effects on the cell membrane potential produced by an impulse field (TEMP) we consider the ANSI C 95.1 1974 standard[7]. The power density is limited to be 100 W / m^2, and the time interval is set to be 6 min. According to this limitation, an impulsive EM

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field with a total energy density of 36 000 J/m^2 is admissible.

We have found that the above-mentioned standard does not involve the athermal bioeffects of the impulsive EM field on cell membrane of a biont. The transmembrane potential produced by TEMP would be two orders of magnitude greater than that by continuous wave. Owing to the existence of athermal bioeffects, one cannot only calculate the thermal effects.

The athermal bioeffects of the TEMP on biological bodies usually occur on cell membrane.

For TEMP incidence, the cell membrane will generate a new potential on the basis of the original normal transmembrane potential. The new potential will affect the structures and functions of cells in biont.

According to our experimental results, the TEMP will strongly destroy the body's cell compared with continuous wave. So it is very important to study the interaction mechanism.

2 Methods and results

The experiments were conducted in the BTEM CELL. Fig. 1 shows the experimental system.

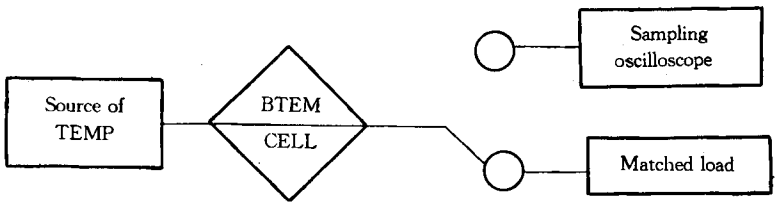

Fig. 1

A homogeneous field of quasi-plane wave was established in the BTEM CELL. The parameters of the BTEM CELL are as follows: range of frequency DC was 17.0 GHz; transmission constant $T>0.9$; standing wave ratio $\rho<2.0$; the bandwidth of sampling oscilloscope SQ-27 was 1 000 MHz. The biological samples included foetus's umbilical blood, sheep red cell and Hela cell. The parameters of TEMP source of Gaussian type were: rising time of pulse 1.2 ns, duration time 2.4 ns, and amplitude 80—100 V.

We put the samples at different positions in the BTEM CELL. There were different intensities of field at different points. The samples were radiated for 1, 1.5, 2 and 3 h, respectively (table 1, figure 2).

Table 1 The effects of TEMP on body's lymph cell (‰)

Time of radiation/h	Number of nucleus	Ratio of mini cell	t	Ratio of mini nucleus	t	Ratio of broken nucleus	t	Ratio of dyskaryosis	t
0	3 000	0.33		0.33		0.00		2.67	
1.0	3 000	0.33	0	1.33	0.776	0.67	0.819	23.3[a)]	4.075
1.5	3 000	0.33	0.581	2.33	1.222	2.00	1.415	24.7[a)]	4.24
2.0	3 000	3.00	1.464	4.33	1.855	1.67	1.293	35.0[a)]	5.318
3.0	3 000	1.33	0.776	3.67	1.672	2.33	1.527	39.7[a)]	5.75

a) $P<0.01$. Noticeable symbol. t-test.

(a) (b) (c)

Fig. 2. (a)Minicell; (b) broken nucleus; (c) dyskaryosis.

The ability of forming rosette of T-lymph cells was decreased very much. The longer the radiation time, the less the rosette, indicating that the immunity ability of cells had been destroyed (table 2).

Table 2 Percentage of the E-rosette

	Normal	1.0 h	1.5 h	2.0 h	3.0 h
Total number	135	135	135	135	135
Number of E-rosette	97	73	50	30	18
Percentage (%)	72	54	37	22	13
t		3.029	5.714	8.176	9.72
P		<0.01	<0.01	<0.01	<0.01

The ability of anti-hypoosmosis of cells declined, especially when the concentration of normal saline was 0.35%—0.55%.

3 Discussion

(1)Using a ball model, the thickness of a cell membrane of lipid bilayer is about the order of 10 nm. To hold on the normal physiological function, the cell membrane has an electrostatic transmembrane potential of about 70 mV, with inner field intensity of 10^5 V/cm. Under the radiation of continuous wave, at power density 10 mW/cm^2, the additional membrane potential of several mV/cm is generated. In the case of TEMP incidence with the outer field strength of 10^5 V/cm, a new transmembrane potential of 100 mV will be generated and the inner field strength in the cell membrane will be 10^7 V/cm. The interaction of TEMP to cells is much stronger than that of continuous wave[8,9].

(2) For the TEMP incidence, the cell membrane functions as a power collector. It makes the inner field intensity of the cell two orders of magnitude higher than that of the outer field. At such a high field intensity, irreversible change of configuration happens to some large molecules in the cell membrane.

(3) The interaction mechanism of the new transmembrane potential induced by TEMP, which generates the athermal bioeffects on a biont, is the effect of "electroporation"[10,11]. Under radiation of electric field pulses, many pores will be formed on lipid membrane, resulting in rapid changes in membrane potential and exposure of the cytoplasm to the extracellular medium. The electrostatic conductance of lipid bilayers is due to very small pores spontaneously formed and destroyed. Application of pulsed fields at high intensity provides energy for enlarging these natural pores and may result in formation of electroporation. The opening or closing of many protein channels with electroporation formation is dependent on transmembrane potential. The gating potentials of these channels are in the range of 50 mV, which is considerably smaller than the dielectric strength of a lipid bilayer. Many voltage-sensitive protein channels will open before the trans-

membrane potential reaches the breakdown potential of the lipid bilayer. However, opening of these channels may not be sufficient to prevent a continuous increase of transmembrane potential from reaching the breakdown potential of the lipid bilayer. Protein channels once opened may experience a much larger current. As a result these channels may be irreversibly denatured by Joule heating or electric modification of their functional groups.

The athermal bioeffects mechanism of TEMP in biological cells is not clear yet. Much work has to be done.

4 Conclusion

The effects of transient electromagnetic pulses on biological cells are much stronger than that of continuous wave. The cell membrane plays an important role in gathering energy. A high field intensity inside cell can generate irreversible breakdown to cell membrane and nucleus. The ANSI C 95.1 1974 standard should be modified.

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