Does the successful ventricular defibrillation decide by energy or charge?

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Abstract

Objective: This paper investigates the main electrical parameters which influence the results of the ventricular defibrillation. The research is the foundation of low energy defibrillation.

Methods: According to the cell electrophysiology, the change of charge is the main reason of the change in transmembrane potential. In this paper, the effect of the energy especially charge to defibrillation is studied through 7 animal trails by an appropriate defibrillator designed by ourselves.

Results: The defibrillation energy is the main parameter which determines the dysfunctions to the patient and the defibrillation charge is the main parameter which determines whether ventricular defibrillation is successful. According to the defibrillation energy threshold curve and charge threshold curve gained from the animal trials, the shock pulse can be optimized in order to decrease the body dysfunctions as well as defibrillating successfully. The decisive infection of charge to defibrillation is brought forward in this paper for the first time.

I. Introduction

A widely accepted viewpoint \cite{1,2} about the electric defibrillation is that most of the myocardium cells can be enforced to depolarize and enter refractory period at the same time when electric field of the shock interacts with myocardium cells. In this case, all the propagation of the depolarization waves will be terminated and the ventricular fibrillation will stop also. For a long time, the electric shock energy is thought to be the most important parameter for defibrillation \cite{3}. In the recent years, some researchers think the shock currents that flow through the heart are the main factor for defibrillation \cite{4}.

The cell electro-physiology tells us that the electric characteristic of the cell membrane is like a capacitance in certain aspect. So the change of the transmembrane potential is just like the charge or discharge of the capacitance that determined by the amount of the electric ion – charge.

\[ \Delta V = \frac{\Delta Q}{C} \] (1)

\[ Q = I \times t \] (2)

Where \( \Delta V \) is the change of the cell membrane voltage; \( Q \) is the charge; \( C \) is the capacitance; \( I \) is the current and \( t \) is the time.

II. Method

The multifunctional defibrillator

A novel multifunctional defibrillator has been designed for this research. The output waveform of this defibrillator is biphasic truncated exponential, the duration of any pulse and the interval between to pulses can be adjusted optionally (the minimal adjusting unit is 0.1ms). The threshold of defibrillation energy or charge corresponding to the certain duration of the pulse can be measured easily.

Animal trails

Seven animal trails have been done. The animal is domestic swine, weigh 25-40kg and 12-20 weeks of age. The animal was medicated with pentobarbital to maintain anesthesia. One of the defibrillation electrodes (a ICD defibrillation electrode catheter was used) was put into the right ventricle transvenous and the other electrode (a 9cm wide and 12cm long square copper defibrillation electrode) was affixed to the left thorax’s surface after this area was grained.

Six kinds of pulse’ duration was setting: 0.3+1+0.3 (that means the duration of the first pulse of the biphasic truncated exponential is 0.3ms, the interval between two pulses is 1ms and the duration of the second pulse is 0.3ms, the expressions below have the same meanings), 0.5+1+0.5, 1+1+0.5, 1+1+1, 2+1+2, 3+1+3, 4+1+4, 5+1+5 and 6+1+6.

A 50Hz/30V alternating current was delivered to the defibrillation electrode inside the right ventricle for approximately 1-2s to induce ventricular fibrillation (VF).

The defibrillation would put in practice with one of the output waveforms mentioned above (for
example 1+1+1) after the VF was induced for 10s. Three times defibrillation at a certain voltage would actualize at most, if the defibrillation was not successful in this case, the saving defibrillation with the highest voltage of the defibrillator would bring into effect. The lowest defibrillation voltage corresponding to the lowest energy and lowest charge that could defibrillate successfully was the defibrillation threshold.

II. Results

The energy threshold curve of defibrillation

Fig.1 A is the energy threshold corresponds different shock pulses duration; B is charge threshold corresponds to different shock pulse duration.

Fig.1 (A) shows that the average defibrillation energy threshold corresponding to different pulses duration of 7 animals and the standard difference of the average value is about 15%. It reveals clearly that there is a minimum value in the middle of the curve.

The electric charge threshold curve of defibrillation

Fig.1 (B) shows that the average defibrillation charge threshold corresponds to different pulse duration of 7 animals and the standard difference of the average value is also about 15%. We can see that the charge threshold varies little when the pulse duration is short but it increases quickly at certain pulse duration (in this example the pulse duration is 3ms-3ms).

III Conclusion AND discussion

The infections of shock energy and charge to the defibrillation

It goes without saying that, the degree of the shock dysfunction is decided by defibrillation energy. It is also one of the reason that why a low energy defibrillation method should be investigated. So the optimal defibrillation energy is the lowest energy that can ensure the successful defibrillation.

The results of animal trails show that the charge threshold of defibrillation changes little when shock pulse duration is short. The curve is showed in Fig.2. It means that the charge is the main factor in defibrillation. But along with the prolongation of the pulse duration, the shock voltage must be lower and lower to keep the low shock charge until reaching the voltage threshold.

That means we cannot keep the charge threshold only by means of prolonging the pulse duration. This phenomena can be explained by the opening or closing of the ion channels on the cell membrane. It means that if the pulse duration is too long, the excrescent time is not only wasteful but also increasing the defibrillation and damnifying the body.

The red curve in Fig.2 represents the energy threshold of defibrillation and the blue curve represents the electric charge threshold of defibrillation. The optimal shock pulse duration can be selected considering the energy factor and the charge factor synthetically. That means selecting certain pulse duration with both low energy threshold and charge threshold. From our experimental results, this pulse duration is 2+1+2.

The decisive infection of charge to defibrillation is brought forward in this paper for the first time. This point of view may help us to understand the mechanism of electrical defibrillation.

The limitation of this research was the small quantity of animal trails.

Reference