Recordings of Impedance and Communication Between Defibrillator and Pacemaker Electrodes

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ABSTRACT

External defibrillation involves short electric shocks of several thousand volts applied to the chest of patients suffering from heart stop. The shock coordinates disorganized muscle fibers of the heart which then can resume normal activity. Implanted pacemakers monitor the natural electrical activity of the heart via electrodes mounted permanently on the inside of the heart. If this activity is insufficient, the pacemaker stimulates the heart muscle by applying a short electrical impulse of a few volts. During the period of defibrillation, voltage differences arise simultaneously between various locations of the body preventing recordings of the heart’s natural activity. In order to quantify parameters determining voltage and current in a conductive medium or in a myocardium when defibrillator and pacemaker electrodes are present simultaneously, impedances between electrodes positioned on conductive materials were recorded in laboratory set ups, and the methods were tested using a porcine heart in vitro.

KEYWORDS
Analogue Models, Defibrillation, Demand Pacemaker, Physiological Models, Tissue Conductivity

INTRODUCTION

External defibrillation is performed in order to resuscitate patients suffering from cardiac arrest by applying an electric shock of several thousand volts to the patients thorax for a number of milliseconds giving rise to currents in the order of several amperes passing through the tissues of the thorax and through the myocardium. This throws the heart into refractoriness for a few seconds initiating normal myocardial function according to e.g. Sperilakis, N. (1989) and Hall, J. E.(2016). Defibrillation of the exposed heart is in principle performed in the same way using in the order of hundreds of volts according to Schwarz B et al. (2003). External and internal defibrillation are also used to eliminate arrhythmia of the heart (Thakor,N.V.1984). Internal defibrillation involves the application of cardiac catheters with electrodes in the distal end. These are applied to the inside of the atrium and electric stimuli of different time courses and strength are used as described by Cooper, R.A.S., Johnson, E.E. and Wharton, J. M. (1997).

External defibrillation, involving energy levels up to 400 Joules, may cause tissue damage in the form of burn marks to the skin (Patriciu,A. et.al.2005) and injuries to underlying tissues such as imbalance of the ion concentration inside the cells and in the body fluids e. g. the interstitial and

DOI: 10.4018/IJBCE.2019070103

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intercellular fluids dealt with by Patel & Roth (2001) and Kim,Y., Zieber,H.G.and Wang, I.E.(1990). This may have an unfavorable influence on the electrical potentials between the inside and the immediate outside of the cardiac nerve fibers which normally are of the order of -80 to -95 mV (Sperilakis,N.1989). Biphasic and damped sine wave shocks are dealt with by Schwarz, B. et al (2003). Internal atrial defibrillation is dealt with by Cooper,R.A.S., Johnson, E.E., & Wharton,J.M.(1997) using monophasic and biphasic stimulation and by Patel,S.G. & Roth,B.J.(2001) demonstrating polarization of tissue in the vicinity of surface electrodes in an electric field. Defibrillation of the exposed heart using a single mono phasic shock has been chosen as a scenario for the experiments to be accounted for in the following.

Pacemakers are electric stimulators that can monitor electric activity (ECG) of the heart and intervene in cases of arrhythmia by supplying electric stimuli in the order of a few volts and of a duration of a half to one millisecond to the heart muscle (Escher,D.1973). Implanted pacemaker electrodes are generally fastened to the inside of the heart ventricle (Starr, D. et al,1981, Reade,M.C.2007 and Schaldach,M.1971). Flexible cords connect the electrodes to the pacemaker itself, which is placed subcutaneously in the chest of the patient. Implanted pacemakers can be controlled from the outside regarding “On-Off” as well as amplitude and frequency of stimulus and can work for a number of years.

To determine the correlation between defibrillation voltages and currents in conductive media and the influence of these on the voltage between implanted bipolar pacemaker electrodes, recordings of voltage and impedance between sets of stylized electrodes placed on conductive media was performed in the frequency range from 25cps to 2000cps. The results were compared to results retrieved from an empirically derived formula (Jarlov,A.&Jensen,T.T.,2017) determining the electrical impedance between the electrodes. Defibrillator shocks as well as pacemaker stimuli were afterwards applied to a porcine myocardium in vitro and the electrode voltages were recorded by a four-channel oscilloscope. The experiments and procedures described in the following are meant to illustrate measuring principles and the application of analogue models of the electrical circuits used in the experiments and are in no way recommended for clinical use. The designations “Pacemaker” and “Defibrillator” are used freely to cover commercially available instruments as well as laboratory set ups used as their substitutes.

Methods and Materials
Two circular electrodes, 1cm in diameter, made of polished sterling silver and two similar electrodes made of 24 carat gold were used as defibrillator electrodes. Silver and gold with a position at the top of the electrochemical series were chosen as specific reference electrodes and because they are tolerant to biological tissues. The electrodes were placed in pairs on a conductive medium and the numerical value of the impedance, \( Z \), between the electrodes was recorded using the voltage clamp method as accounted for by Jarlov,A & Jensen,T.T.(2017) at 1000cps as a function of the thickness \( h \) of the conductive medium. This consisted of goatskin of the type “chamois” with an admixture of 0.9% NaCl solution. The results are shown in Figure 1 together with graphs derived by formula (1) as dealt with by Jarlov & Jensen, (2017).

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Z = \left( \frac{a - d}{\sigma h} \right) + \left( \frac{a - d}{\sigma ad} \right) + Rk
\]

The parameters used are explained in the insert upper right in Figure 1.

Stylized pacemaker electrodes designed as polished pins with diameter 0.1cm made of either sterling silver or 24 carat cold as outlined in the insert Figure 2 were inserted \( b \) cm into the conductive medium. The impedance between the electrodes was recorded at 1000 cps as function of \( b \) as shown in Figure 2. The electrodes were solely used to demonstrate measuring procedures and are not recommended for clinical use.
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