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Electrostimulation by time-varying magnetic fields

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Despite several investigations and publications on possible effects due to time-varying magnetic fields, the question remains as to the magnitude of the field, or its derivative with respect to time, that is capable of stimulating the human heart. It is quite surprising how little information on cardiac stimulation has entered the discussion to date. If the law of induction and the fundamental law of stimulation, both in their field forms, are combined, the result is quite different from what has been published: (1) It is the amplitude of the gradient field that is responsible for stimulation and not dB/dt. (2) The shape of the time-varying pulse has no influence on stimulation but only its mean value. (3) Owing to different rheobase and chronaxie values for cardiac tissue and peripheral nerves, the threshold for magnetostimulation of the myocardium is up to 200-fold higher than that for nerves. These results allow for the determination of safety limits that are certainly above those proposed to date. Based on these limits, technological advancement can be achieved without neglecting the patient safety requirement.

Keywords: electrostimulation, magnetostimulation, neurostimulation, cardiac stimulation, electrical safety, magnetic field, electric field.

INTRODUCTION

Although there have been several investigations and publications on possible effects due to time-varying magnetic fields in the last decade [1–7], the question remains open as to the strength of the magnetic field required to excite the heart during NMR imaging. Is a possible hazard associated with the rate of change dB/dt of the magnetic field, or is the peak value of rectangular stimulus fields responsible for excitation of nerves or cardiac muscle? What is the threshold value for cardiac excitation in relation to peripheral nerve thresholds? The IRPA/INIRC Guideline on MRI [4] warns that electric field strengths exceeding 5 V/m may cause ventricular fibrillation, suggesting that the thresholds for nerve and cardiac muscle stimulation are very close.

Reading the articles discussing magnetic stimulation, it is surprising to note how little information on cardiac pacing has entered the discussion so far, and, furthermore, that discrepancies between the levels of proposed and measured electric fields obviously require further investigation [6]. It is the intent of this article to apply the enormous knowledge of cardiac pacing compiled during the last three decades to the special problem of magnetic stimulation of the heart.

INDUCTION OF ELECTRIC FIELDS BY TIME-VARYING MAGNETIC FIELDS

According to Maxwell's laws, a time-varying magnetic field produces an electric field, which can be calculated by the integral equation

$$\oint E\,ds = \frac{d}{dt}\int^{A} B\,dA \tag{1}$$

which is simple to solve for a uniform magnetic field and a circular cross section perpendicular to the direction of the magnetic field

$$2\pi r[E(r)] = \pi r^2 \frac{dB}{dt} \tag{2}$$

$$E(r) = \frac{r}{2}\frac{dB}{dt}$$

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