AN ELECTRODE SYSTEM WITH ROUNDED EDGES 
FOR DIRECT VENTRICULAR DEFIBRILLATION*

G. KONING,‡ H. SCHNEIDER,‡ R. S. RENEMAN and A. J. HOELEN
Department of Cardiovascular Surgery, University Hospital, Utrecht, The Netherlands

Abstract—In this study it was assumed that the current density plays an important role in ventricular defibrillation. The best method for successful defibrillation is then with a homogeneous electrical field between the electrodes, so that the current density is the same in all parts of the ventricles. Electrodes have been compared with and without rounded edges and the same surface area in in vitro experiments, regarding their current density distribution and in in vivo experiments, regarding their total current strength, needed for successful defibrillation with a square current pulse. The electrodes with rounded edges needed 75 per cent of the current strength, required by the electrodes without rounded edges, resulting in a dissipated energy of 50–60 per cent. In addition, the local current density at the rims of the electrodes with rounded edges was lower than in the electrodes without rounded edges. It is therefore suggested that the electrodes with rounded edges may be less harmful to the myocardium and that the current density is an essential physical quantity involved in ventricular defibrillation.

INTRODUCTION
Ventricular fibrillation can be stopped by an electric shock. The physical entity involved in the mechanism of defibrillation is uncertain. Current strength, current density, charge, voltage or energy have all been used to explain defibrillation. SCHUDER et al. (1964) used the current strength as a parameter, while KILLPATRICK (1961) presented arguments that the current density plays an important role. Recent papers (TACKER et al., 1969; GEDDES et al., 1970) presented the energy, charge and current strength as a function of pulse duration, using capacitor discharges and half-sinusoidal pulses.

Our experiments are based on the presumption that the current density is the important parameter for effective defibrillation, this means that the current density through the entire myocardium has to be above a certain minimum value.

The effectiveness of a defibrillation pulse is related to the electrode size and contact with the myocardium (MACLEAN and VAN TYN, 1961; RIVKIN, 1963) and therefore the electrode system requires our attention. Most of the conventional electrode-systems for direct ventricular defibrillation are circular, a little concave, and have sharp rims and an insulated back-side. They are small in relation to the size of the heart (MACLEAN and VAN TYN, 1961). Therefore, they produce an inhomogeneous electrical field which means that the current density varies at different points in the heart. As a result, a higher current strength is necessary for effective defibrillation, than would be the case with a uniform current density. This gives rise to the use of a higher energy, which is harmful to the myocardium. High electric currents can provoke an A–V-block during several seconds (TACKER et al., 1968) and furthermore influence the contractile force of the myocardium in a negative way (TACKER et al., 1969). In addition, the high energy related to the high electric currents, is dissipated in the myocardium and gives an increase in temperature, which can produce cardiac burns (TEDESCHI and WHITE, 1954; MACLEAN and VAN TYN, 1961; RIVKIN, 1963). The high current density in the ventricles along the edges of electrodes with a sharp rim may cause local injuries. Therefore, we tried to develop an electrode system that enabled defibrillation to be performed with a lower total current strength, and thus energy.

* Received 15 August 1971.
† Present address: Laboratory of Medical Physics, Free University, Amsterdam, The Netherlands.
METHODS

A comparison was made between conventional electrodes and those to be described in this study; the conventional electrodes are indicated in Fig. 1a and are circular and slightly concave, with sharp rims. They were made of stainless steel and their backs were insulated with polyvinyl-chloride. Figure 1b shows the design of our electrodes. They were also made of stainless steel, with polyvinyl-chloride on their backs. They differ from the conventional electrodes only in that they have rounded rims. The surface area of both types of electrodes was exactly the same (12.5 cm²).

(a) In vitro measurements

The electrical fields of both types of electrode were compared in an electrolytic tank, filled with normal chlorided tap-water. The distance between the electrodes was 16 cm for both types. The size of the tank was: length 2 m, width 1.5 m and depth 1.5 m. The tank was thus large in comparison with the electrodes tested, preventing any disturbance of the field by the walls of the tank. An a.c. voltage at a frequency of 150 Hz and an amplitude of 24 V was applied to the electrodes in the tank. The equipotential lines were measured with a stainless steel probe of 0.5 mm dia., which was located 1 mm under the water surface. The signal of the probe was measured with a valve voltmeter. Due to the high input impedance of this meter and the small size of the probe no disturbance of the field was caused by the measuring system. An a.c. voltage was preferred to d.c. to avoid polarization of the electrodes. From the equipotential lines the equicurrent lines were constructed, by using the fact that current lines are perpendicular to potential lines.

(b) In-vivo measurements

Experiments were performed on 6 mongrel dogs of either sex, unknown age and ranging in body weight from 7 to 25 kg. The size of the heart was determined after the experiment by weighing, because the size affected the electrical field. Anaesthesia was induced with thiopentane sodium (30 mg/kg body weight) and, after intratracheal intubation, maintained with oxygen–nitrous oxide, halothane and intermittent injections of succinylcholine. All animals were ventilated with intermittent positive pressure. The chest was opened through the fifth right intercostal space. Total cardiopulmonary bypass was established by cannulation of both caval veins and one of the femoral arteries. The left ventricular cavity was drained by means of a cannula through the apex with a slight negative pressure suction.

The heart was brought to ventricular fibrillation by a 50 Hz sinewave-current and defibrillated with a square current pulse of 5 ms. duration (see Fig. 2); during this procedure the heart and electrodes were kept away from the chest wall. This pulse was delivered by a current-stabilized defibrillator (KONING, 1969). For each of the two types of electrodes the “threshold” for effective defibrillation was determined in the following way: defibrillation was tried with a pulse of fixed amplitude. If this trial was successful then the amplitude was decreased. If the defibrillation with this decreased amplitude was unsuccessful, then the current strength was increased, and so on. We tried to alternate successful and unsuccessful defibrillation. The amplitude of the defibrillation pulse between successful and unsuccessful defibrillation was called the “threshold”. The procedure of alternating successful and unsuccessful defibrillation to determine the “threshold” was chosen because