JACC Vol. 6, No. 3
September 1985:682–6

Defibrillator Electrode-Chest Wall Coupling Agents: Influence on Transthoracic Impedance and Shock Success

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The purpose of this study was to determine if the difference in transthoracic impedance produced by different coupling agents affects the success of shocks for defibrillation. Three different coupling agents, Harco pads (Hewlett-Packard), Littman pads (3M) and Redux paste (Hewlett-Packard), were assessed in 10 anesthetized dogs in which ventricular fibrillation was induced by electrical stimulation of the right ventricle. Defibrillation was attempted 15 seconds later, using 50, 100 and 150 joules (selected energy). Actual delivered energy, current, impedance and the percent of the shocks that achieved defibrillation were determined for the three coupling agents.

Redux paste gave significantly lower impedance and higher current than the two disposable preformed coupling pads tested. Despite this, there were no significant differences in shock success among the three coupling agents. Thus, in this experimental model, over a threefold energy range, disposable coupling pads were as effective as electrode paste for defibrillation despite the slightly higher impedance of the disposable pads.

(J Am Coll Cardiol 1985;6:682–6)

Defibrillation is accomplished by passing electrical current through the heart. Transthoracic impedance is a major determinant of the current reaching the myocardium (1,2), and it is therefore an important factor influencing the success of shocks for defibrillation. This impedance varies widely in the normal population (3) and is determined by several factors, some inherent to the subject, such as chest size (3), some inherent to the defibrillator, such as paddle electrode size (3,4) and some influenced by the operator, such as the selected energy of the shock and the pressure applied to the hand-held electrodes (3).

The defibrillator electrode-chest wall interface is a further determinant of transthoracic impedance. This interface consists of the coupling medium between the paddles and chest wall, usually electrode pastes or preformed conductive pads. Preformed conductive pads as an electrode-chest wall coupling agent have certain clinical advantages over pastes: they are less slippery (and may interfere less with closed chest cardiac massage) and may be safer because they minimize the chance of electrical arcing across the chest. However, previous studies performed in dogs with a nonfibrillating heart (4–6) or in in vitro preparations (7) showed that pastes produced a lower impedance than preformed pads, and because of this, Ewy and coworkers (5,8) recommended the use of electrode paste in preference to preformed coupling pads for defibrillation.

In a recent in vivo study of dogs in which ventricular fibrillation had been induced, Tacker and Paris (9) confirmed that impedance was higher with preformed pads than with paste. Surprisingly, however, they found that the percent success of defibrillation was somewhat greater with the pads than with the paste, although the difference did not achieve statistical significance. This result is the opposite of what would be expected based on the impedance findings.

To resolve the discrepancies of the previous studies, we undertook a comparative in vivo canine study of the effectiveness of electrode pastes versus preformed conductive pads as electrode-chest wall coupling agents for defibrillation over a wide range of energy and current.

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Methods

Experimental procedure. Experiments were performed on 10 mongrel dogs, 18 to 22 kg, anesthetized with pen-

0735-1097/85/$3.30

tobarbital, 15 mg/kg, fentanyl, 0.05 mg/kg and droperidol, 3 mg/kg (Innovar Vet., S.P.) and paralyzed with decamethonium (3 mg/kg). The animals were intubated and ventilated and blood gases and arterial pressure monitored.

Ventricular fibrillation was induced by stimulating the right ventricle for 5 seconds with high frequency (60 Hz) rectangular impulses (20 V, pulse width 8 ms) passed down a bipolar catheter from a Grass stimulator. Electrical stimulation was stopped after 5 seconds; ventricular fibrillation was allowed to persist for a total of 15 seconds before defibrillation was attempted.

Defibrillation procedure. One defibrillator (Hewlett-Packard, model 78660-A) equipped with 8 cm diameter electrode paddles was used throughout the study. After each shock the defibrillator gave an automated printout of actual delivered energy, current and impedance. Tacker and Paris (9) used only one energy level in each animal; to achieve a wider range of current flow and success rates, we delivered four shocks at each of three selected energy levels: 50, 100 and 150 joules, for each coupling medium in each dog. If defibrillation was not successful after four attempts, a suprathreshold 200 joule (or higher if necessary) shock was applied. The order in which the 50, 100 and 150 joule shocks were delivered was varied among dogs, but was constant for each paddle-chest coupling agent in a given dog.

Three different paddle-chest wall coupling agents were utilized: 1) Redux paste (Hewlett-Packard), 2) Littman Defib pads (3M), and 3) Harco pads (Hewlett-Packard). The defibrillator electrode paddles were placed against each dog's shaved chest over the palpable apex on the left side of the chest and at a similar level on the right. Constant, firm pressure was applied to the electrode paddles by a mechanical holding device so that pressure was not a variable. In five dogs the Harco pads and in five the Littman pads were used first. The Redux paste was always used last because it tended to impregnate the skin and could not be adequately removed; thus, were it to be used before either of the other two coupling agents it would affect their performance.

Defibrillation was deemed successful when ventricular fibrillation was terminated and a spontaneous rhythm restored. Success of defibrillation was expressed as a percent of the total number of shocks delivered at each energy level for each coupling agent. There were always four attempts to defibrillate the heart of each dog at each chosen energy level. However, if a heart failed to defibrillate on, for example, the third shock, up to three more shocks would be immediately given, and if the attempt still was not successful, then the suprathreshold shock was applied. Each dog, therefore, had a minimum of four and a maximum of seven shocks for each coupling agent at each energy level. Mean actual delivered energy, current and impedance were determined from the total number of shocks for each coupling agent and each energy level for each dog, and then the mean values for the individual dogs were averaged.

It is known that transthoracic impedance decreases with successive shocks (3,10). Because the Redux paste was always used last in this study, it was expected that this would probably result in a lower impedance for the paste as compared to the pads. To determine the magnitude of this effect, we reviewed data from a previous experiment performed on a fibrillating dog model in this laboratory (11) in which Redux paste was used for initial or midstudy shocks. From the previous study we selected 10 dogs whose data were comparable with those of the 10 dogs in the present

Table 1. Delivered Energy, Current, Impedance and Success of Shocks at Three Energy Levels (n = 10 dogs)

	Actual Delivered Energy (joules)	Current (amps)	Impedance (ohms)	Success (%)
	50 Joules Selected Energy			
Harco pads	50.5 ± 2.6	21.7 ± 3.2	55.6 ± 13.0	54 ± 42
Littman pads	51.5 ± 2.2	20.4 ± 2.9	62.1 ± 14.7	57 ± 35
Redux paste	48.1 ± 3.1*†	24.4 ± 3.3*†	44.3 ± 11.7*†	52 ± 43
	100 Joules Selected Energy			
Harco pads	99.6 ± 5.4	32.1 ± 4.2	51.3 ± 12.3	90 ± 18
Littman pads	101.0 ± 5.3	31.0 ± 4.6	55.5 ± 14.6	86 ± 17
Redux paste	94.8 ± 6.9*†	35.9 ± 5.0*†	41.5 ± 12.0*†	83 ± 31
	150 Joules Selected Energy			
Harco pads	145.3 ± 9.3	40.7 ± 5.8	48.0 ± 12.4	95 ± 11
Littman pads	148.2 ± 6.2	38.9 ± 4.5	51.9 ± 11.3	98 ± 6
Redux paste	138.9 ± 10.1*†	44.0 ± 5.8*†	39.3 ± 10.9*†	98 ± 6

*$p < 0.01$ for difference between Redux paste and Harco pads; †$p < 0.01$ for difference between Redux paste and Littman pads; values are mean ± standard deviation.

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study; that is, the energy levels were similar and Redux paste had been used initially (five dogs) or after the dog had already received a series of four to eight shocks (five dogs).

Statistical analysis. Data were analyzed using analysis of variance with a randomized block design. Variance was assessed between coupling media, between dogs and between selected energy levels. Significant differences were assessed using the Bonferroni procedure for multiple comparisons (12). All data are expressed as mean ± 1 standard deviation.

Results

Impedance and current (Table 1, Fig. 1). At each of the three energy levels tested, transthoracic impedance was significantly less with the Redux paste than with either of the two pads, while the current was correspondingly greater with Redux paste. There were no significant differences in transthoracic impedance or current between the two preformed coupling pads tested, but the impedance decreased significantly ($p < 0.01$) as energy increased.

Success of shocks (Table 1, Fig. 2). There were no significant differences in the success of shocks at each energy level between any of the three interfaces tested. As expected, increasing energy levels increased shock success.

Hemodynamics. Heart rate ranged from 146 ± 31 (Littman pads) to 163 ± 22 beats/min (Redux paste). Mean arterial pressure ranged from 89 ± 21 (Harco pads) to 93 ± 25 mm Hg (Redux paste). There were no significant differences between the values for heart rate, blood pressure and blood gases of the dogs while the different electrode-chest coupling agents were being tested.

Redux paste in previous studies (Table 2). The transthoracic impedance when Redux paste was used for initial or midstudy shocks was compared with that of a previous study (11), and was about 15% higher in the previous study than in the present one (p = NS).

Discussion

The principal finding in this study was that there were no differences in the success of shocks given with the three coupling agents, Harco pads, Littman pads or Redux paste. Redux paste produced a lower transthoracic impedance than either of the two disposable pads tested.

Influence of coupling agents on impedance. Previous workers (4–9) have shown that the paddle electrode-chest wall interface influences transthoracic impedance. Connell et al. (4) demonstrated a 30% reduction in impedance when Redux paste, rather than bare skin, was used as a coupling medium. Various conductive interfaces have been studied in the intact dog (5,6,9) and in an in vitro model (7) and pastes have generally been shown to produce the lowest impedance of those tested (8,9). Our study confirms these findings; Redux paste gave a lower impedance, by about 12 ohms, than the two preformed coupling pads.

Because Redux paste impregnated the skin and could not be easily removed, it was always tested last, after the two pads. Since transthoracic impedance decreases with successive shocks (3,10), this procedure could have contributed to the lower impedance found with the Redux paste. To examine this possibility, we compared the impedance levels achieved using Redux paste in this study with data from our previous study (11) in which this paste was used as a coupling material for initial or midstudy shocks. At similar energy levels, we found that the transthoracic impedance of Redux paste was about 15% higher in our previous study than in the present study. Thus, using Redux paste last in the present study probably contributed to the lower imped-

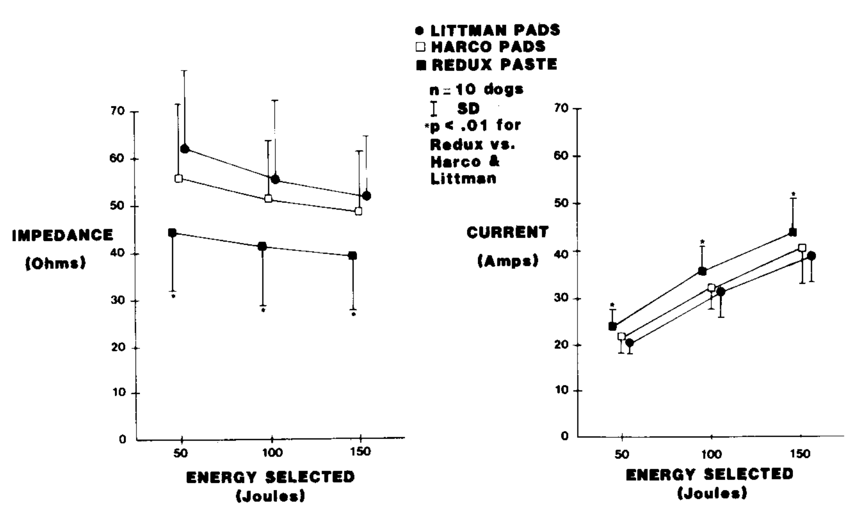

Figure 1. Impedance (**left**) and current (**right**) of three defibrillator electrode-chest wall coupling agents at three different energy levels. Impedance was significantly less with Redux paste, and current correspondingly greater, at each energy level.

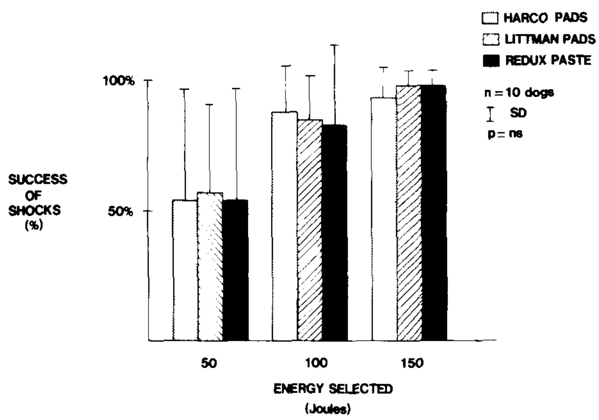

Figure 2. Percent success of shocks of three defibrillator electrode-chest wall coupling agents at three different energy levels. There were no significant differences in shock success among any of the three coupling agents at all energy levels.

ance we found with paste. However, despite the earlier use of Redux paste in our previous study, impedance was less than that obtained in the present study with the preformed pads, suggesting that the lower impedance with Redux paste is not an artifact of the present study's design but is inherent to this preparation.

Influence of impedance differences produced by different coupling agents on shock success. Impedance is known to be an important determinant of defibrillation. We recently showed (2) that low energy shocks have a poor success rate in patients with very high (>97 ohms) transthoracic impedance. Thus, it might initially appear surprising that the lower impedance associated with Redux paste in this study did not produce a greater shock success rate when compared with the rate obtained with other coupling agents. A similar result was found by Tacker and Paris (9). The explanation may be that the impedance differences among the coupling agents, although significant, were modest in absolute terms. The lower impedance produced by the Redux paste was small in comparison with the normal variability of transthoracic impedance. Impedance ranged

Table 2. Impedance When Redux Paste Was Used for Initial or Midstudy Shocks (11) Compared With Impedance in Present Study

Selected Energy (joules)	Impedance (ohms) Previous Study (11)* (n = 10 dogs)	Present Study* (n = 10 dogs)
50	51.1 ± 16.2	44.3 ± 11.7
100	45.9 ± 10.8	41.5 ± 12.0
150	46.1 ± 10.7	39.3 ± 10.9

*None of the previous study versus present study impedance differences are statistically significant.

from 24 to 87 ohms in the dogs in this study, and ranges from 15 to 143 ohms in humans (3). The reduction in impedance produced only a small increase in current, which at each energy level was only 3 to 5 amps greater with Redux paste. This small increase in current produced by the impedance differences among the coupling agents contrasts with the two- to threefold larger increase in current, approximately 10 amps, that occurred when the selected energy was increased from 50 to 100 joules or from 100 to 150 joules. The larger increase in current with increasing energy was associated with a marked improvement in the success of defibrillation. The current that traverses the heart and depolarizes an adequate mass of myocardium is the primary determinant of defibrillation (13,14). Thus, increasing the selected energy to substantially increase the current was a much more important factor in achieving defibrillation than were the modest impedance differences among the coupling agents.

It is possible that differences in shock success rates among the coupling agents tested might have become apparent had we used much lower energy levels or smaller increments between energy levels. The energy levels we tested were selected to be roughly equivalent to the energy ranges in clinical use on a joules per kilogram of body weight basis. Thus, the lowest energy we tested, 50 joules, or 2.5 joules/kg in our dogs, would be the equivalent of 175 joules in a 70 kg human. This is actually below the 200 to 300 joule initial energy range for defibrillation currently recommended by the American Heart Association (15) and commonly used in clinical practice.

Clinical implications. On the basis of in vitro studies and studies in dogs without fibrillation, it has been previously recommended that Redux paste is the most suitable coupling medium for clinical use because it gives the lowest impedance (5,8). However, all electrode paste or creams have some disadvantages: they must be well dispersed over the electrodes; they may then become further spread over the entire chest during resuscitation efforts, making the chest wall slippery and rendering external cardiac massage difficult and producing a low impedance, extracardiac pathway down which current can preferentially flow, making defibrillation attempts ineffective and potentially hazardous. Disposable conductive pads used as a coupling interface between electrode paddles and skin do not share these disadvantages and hence are attractive clinically. Our study shows that despite their modestly higher impedance, the success rates of the shocks given to defibrillate dogs through disposable pads are comparable with the success rates achieved with electrode paste. We conclude, therefore, that if these data from the dog can be transferred to the clinical situation, either the preformed disposable pads or electrode paste may be used effectively for defibrillation at currently recommended energy levels.

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We thank Diane Phillips for her secretarial assistance.

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