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Intracardiac voltage gradients during transthoracic defibrillation: Implications for post-shock myocardial injury

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"Shock energy provides an inaccurate measure of true shock intensity."

Objective

A defibrillation shock creates an electric field throughout the heart tissue, measurable as local voltage gradients. Voltage gradient is the actual therapeutic force acting directly on the heart to interrupt fibrillation. Within safety limits, the higher the voltage gradient, the more potent a shock's defibrillation action at the heart.

The objective of this animal study was to:

1. Measure the voltage gradients at the heart produced by various defibrillator shock doses
2. Assess the relationship between various measures of shock intensity and the resulting voltage gradients
3. Compare voltage gradients with those previously reported to cause cardiac injury

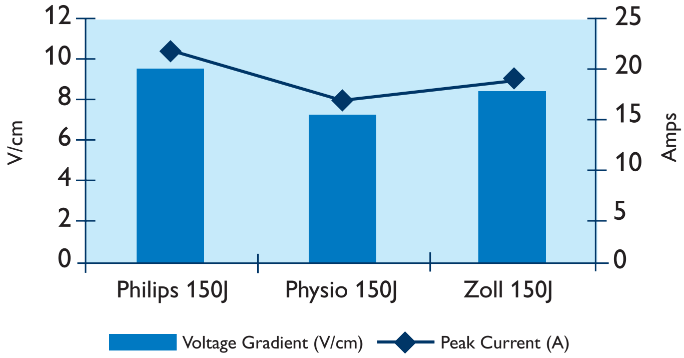
Methodology

Researchers inserted catheters into the arteries of 5 pigs, and routed them to locations in the heart. The catheters measured voltage gradients at various locations in the heart when defibrillation shocks were delivered. Each pig then received shocks from a Physio-Control monophasic defibrillator and 3 biphasic defibrillators: Philips, Physio-Control, and Zoll. For each device, up to three shock energies were administered, including each device's standard first shock energy, each device's highest shock energy, and 150 J (150J *is* Philips standard first shock therapy, so only two Philips shocks were delivered). Shocks were delivered at each of two impedances: that of the pigs studied, and a higher artificially produced impedance more typical of humans. Devices and shock sequences were randomized for the two impedances. Measurements included each shock's energy, peak current, and resulting average voltage gradient.

Results

- Myocardial voltage gradient, directly reflecting therapeutic potency, was strongly correlated with the indirect measure of peak current, but was *not* related to the indirect measure of defibrillator energy (joules).
- To elaborate (see graph below and on the next page):
  - Biphasics at the *same* energy often had *different* voltage gradients. For example, at any given energy, Philips voltage gradients were higher than those of Physio-Control's biphasic.
  - Philips 150J biphasic led all other 150J biphasics in both voltage gradient and peak current, indicating higher shock strength.

Measure of Shock Strength: 150J
(Simulated Human Impedance)



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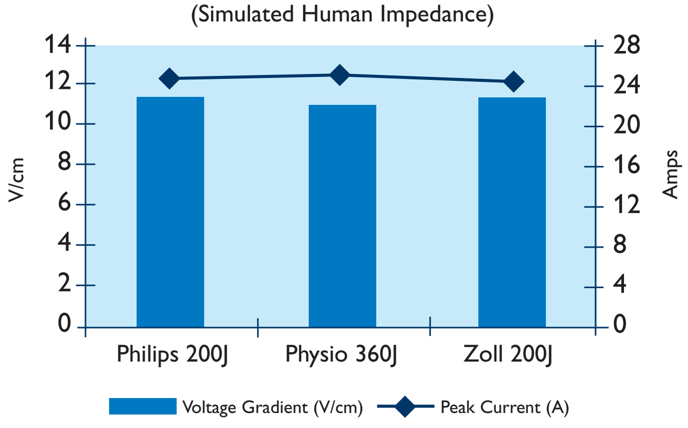
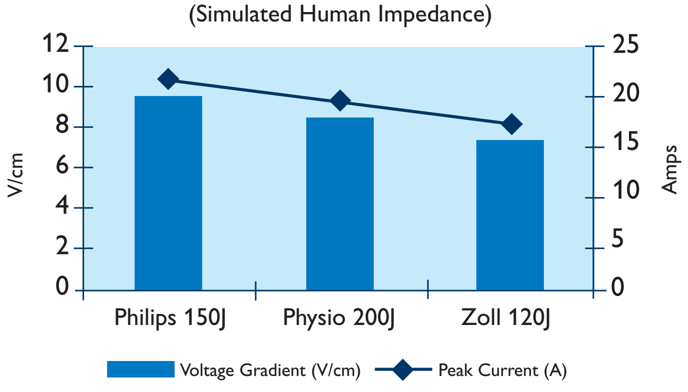
Results (continued)

- To further elaborate:
  - At a simulated human impedance, the Philips maximum energy 200J shock produced essentially the same voltage gradient and peak current as the Physio-Control biphasic maximum energy 360J shock did, indicating similar shock strength, despite the lower Philips energy.
  - At simulated human impedance, peak currents were similar for all biphasics at each device's maximum strength despite different energies (200J for Philips and Zoll, 360J for Physio-Control).
  - Philips standard first shock therapy led all other biphasics' first shock therapy in both voltage gradient and peak current, despite employing low energy.
- Voltage gradients of each biphasic shock were lower than those associated with myocardial injury.





Conclusions

Among different defibrillators, shock energy is an inaccurate measure of the true shock intensity. For each of 3 biphasic defibrillators, shocks at the maximum available dose at a typical human impedance expose the heart to essentially the same electric-field strength, despite widely different energy settings and delivered energy values. Peak current provides a better measure of true shock intensity.

Philips Commentary

It is not surprising that this study demonstrates that peak current is an accurate measure of shock strength, not energy. Basic physics (Ohm's law) would have predicted this. Philips has high peak current, similar to other much higher-energy biphasic therapies. On the other hand, as noted in the 2005 AHA Emergency Cardiac Care Guidelines: "Energy is a nonphysiologic descriptor of defibrillation despite its entrenchment in traditional jargon."[1] European Resuscitation Council guidelines make a similar statement. "Although energy levels are selected for defibrillation, it is the transmyocardial current flow that achieves defibrillation. Current correlates well with successful defibrillation and cardioversion. Future technology may enable defibrillators to discharge according to transthoracic current: a strategy that may lead to greater consistency in shock success."[2]

Regarding myocardial dysfunction side effects, note that this study does not actually measure dysfunction. It simply infers a lack of *peak current-related* dysfunction, based on the peak currents and voltage gradients reached by the biphasic therapies studied, which are all well within safety margins. But dysfunction can come from other sources. High energy is one such source. This study does not actually measure dysfunction associated with high energy, but other studies do,[3] and demonstrate this undesired side effect.

Philips combines high peak current for potency, with low energy to avoid unnecessary myocardial dysfunction.

References

[1] American Heart Association Guidelines 2005. Circulation 2005; 112.
[2] European Resuscitation Council Guidelines 2005. Resuscitation 2005;Vol 67 Supplement 1
[3] Tang et al. Journal of the American College of Cardiology 2004; Vol 43 No 7:1228-35.

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Printed in The Netherlands
4522 962 36181/861 * JUL 2008

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