Simulation and education

Will medical examination gloves protect rescuers from defibrillation voltages during hands-on defibrillation?

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A R T I C L E   I N F O

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A B S T R A C T

Background: Continuing compressions during a defibrillation shock has been proposed as a method of reducing pauses in cardiopulmonary resuscitation (CPR) but the safety of this procedure is unproven. The medical examination gloves worn by rescuers play an important role in protecting the rescuer yet the electrical characteristics of these gloves are unknown. This study examined the response of medical examination gloves to defibrillation voltages.

Methods: Part 1 of this study measured voltage–current curves for a small sample (8) of gloves. Part 2 tested more gloves (460) to determine the voltage required to produce a specific amount of current flow. Gloves were tested at two current levels: 0.1 mA and 10 mA. Testing included four glove materials (chloroprene, latex, nitrile, and vinyl) in a single layer and double-gloved.

Results: All gloves tested in part 1 allowed little current to flow (<1 mA) as the voltage was increased until breakdown occurred, at which point current flow increased precipitously. In part 2, 118 of 260 (45%) single gloves and 93 of 120 (77%) double gloves allowed at least 0.1 mA of current flow at voltages within the external defibrillation voltage range. Also, 6 of 80 (7.5%) single gloves and 5 of 80 (6.2%) double gloves allowed over 10 mA.

Conclusions: Few of the gloves tested limited the current to levels proven to be safe. A lack of sensation during hands-on defibrillation does not guarantee that a safety margin exists. As such, we encourage rescuers to minimize rather than eliminate the pause in compressions for defibrillation.

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1. Introduction

Pauses in chest compressions during CPR are known to be detrimental to survival. The 2005 American Heart Association Guidelines eliminated some reasons for pauses, but interruptions still occur to allow intubation, ventilations, AED analyses, charging, and defibrillation shocks. While shock delivery accounts for a relatively minor fraction of the total hands-off time in most cases, elimination of the shock pause is consistent with the overall goal of minimizing hands-off time. In addition, pausing CPR for shock delivery complicates the resuscitation protocol, requiring close coordination between multiple members of the resuscitation team to avoid inadvertent rescuer shocks while minimizing hands-off time.

Recently, Lloyd et al. suggested that it may be possible for rescuers to continue chest compressions during a defibrillation shock. They studied the safety of “hands-on defibrillation” by simulating chest compressions while delivering external cardioversion shocks to patients with atrial fibrillation. No harm came to the “rescuers,” and although the authors cautioned against extrapolation beyond the limits of their model, they concluded that, “Uninterrupted manual chest compressions during shock delivery are feasible.”

Although defibrillator shock intensity is commonly expressed in terms of joules, it is the voltage that determines the risk of an unintended operator shock. For common biphasic external defibrillators, the voltage applied to the patient for the first shock ranges from about 1300 to 1800 V. Maximum energy biphasic shocks can be as high as 2700 V. Due to the large magnitude of these voltages caution is wise. The best approach for providing optimal patient care while minimizing the rescuer hazards is unclear.

A number of factors contribute to the risk of hands-on defibrillation. Two key factors are, (1) the fraction of the shock voltage presented across the rescuer and (2) the voltage standoff capability of the gloves. Neither of these factors is known.

The fraction of the shock voltage presented across the rescuer is dependent on the electrical circuit formed by the patient and the rescuer. This is illustrated in Fig. 1.

The possible current paths through a rescuer have not been well studied but one model has been proposed that includes current flow
through the rescuer’s chest. In this model the gloves can serve as a barrier to current flow through the rescuer and may provide an important safety mechanism.

In general, medical examination gloves are designed as a barrier to bodily fluids, not electricity, and manufacturers typically do not provide electrical specifications for their gloves. One study using the AC (alternating current) voltage from an electrocautery device found latex and neoprene glove breakdown voltages as low as 2000 V, but it is unclear how these results relate to hands-on defibrillation. Little other information is available that would allow the safety of hands-on defibrillation to be assessed. A recent review paper by Petley et al. suggested, “Further work needs to be carried out to determine the necessary electrical and mechanical properties required of an insulator suitable to be used to protect rescuers.”

The purpose of this study was to compare the DC (direct current) electrical characteristics of common medical examination gloves with the output voltages of biphasic defibrillators.

2. Methods

2.1. Part 1

Part one of this study examined the shape of the voltage–current curve for several types of gloves by applying a range of DC voltages to each glove and recording the current at each level. The goal of this part of the study was to determine if the current flow in these gloves typically exhibits a “breakdown” characteristic and, if so, to determine the voltage level at which it occurs.

A dielectric analyzer (Vitrek 944i, San Diego, CA) was used to apply the voltage to the gloves and monitor current flow. The voltage across the glove was manually increased and allowed to dwell at each level long enough for the current to stabilize. Current values were recorded at 100 V, 200 V, 500 V, and 500 V increments thereafter until the current exceeded the device maximum (20 mA) or until a breakdown occurred. At breakdown the dielectric analyzer rapidly removes the voltage to prevent excessive current flow and, rather than reporting the actual current flow, simply reports that a breakdown was detected. All measurements in this part of the study were made by inserting a roughly palm-sized metal electrode into the glove, placing the unstretched glove on a metal sheet, and applying the voltage between the electrode and the sheet. Minimal compressive force (<0.5 pounds) was applied for each measurement.

Gloves made of four commonly used polymers were tested:

- Latex (Safe-Touch powder-free latex examination gloves, Dynarex Corporation, Orangeburg, NY; and Ambiex Powder free cleanroom latex gloves, Ambiex Corporation, Thailand)
- Nitrile (Estee Stretchy Nitrile power-free nitrile exam gloves, CardinalHealth, McGaw Park, IL; and Safe-Touch power-free nitrile examination gloves, Dynarex Corporation, Orangeburg, NY)
- Chloroprene (NeoPro powder-free chloroprene examination gloves, Microflex Corporation, Reno, NV)
- Vinyl (Safe-Touch powder-free vinyl examination gloves, Dynarex Corporation, Orangeburg, NY; and Disposable vinyl gloves powdered, Magid Corporation, China)

Part 1 of the study tested two gloves of each polymer.

2.2. Part 2

Part 2 measured the voltage necessary to produce a specific amount of current flow in each glove. This was done by programming the dielectric analyzer to increase the voltage until a pre-set current limit was reached. The voltage required to produce that current level was then recorded. If the desired current flow was not achieved before reaching the maximum output voltage of the dielectric analyzer (5000 V), then 5000 V was recorded.

The tests in Part 2 were performed using one of two current limits. The first current limit was 0.1 mA. This is the maximum direct current (DC) allowed to flow incidentally through an operator from a medical device with no faults as established by the widely recognized standards agency, the International Electrotechnical Commission (IEC). A current flow less than this amount is...
generally considered to be safe. For this study the voltage required to produce this amount of current flow is referred to as the “leakage voltage.”

The second current limit was set at 10 mA. This is more current than is allowed by any regulatory standards of which we are aware and is also above the threshold of perception (about 1 mA). This current limit was also chosen because Part 1 of our study showed that 10 mA is above the knee of the curve for all glove types. In other words, it represents a complete electrical breakdown of the glove material.

While Part 1 measurements were all made on single gloves, the measurements in Part 2 were made on both single and double gloves. The double-glove measurements were made by placing the electrode on top of the glove (rather than inside the glove) so that current flowed through two layers of material to reach the metal sheet.

The testing in Part 2 involved all four polymers listed in Part 1. Each polymer was tested at both current limits in single and double-layer configurations, giving a total of 16 polymer–current-layer combinations. At least 20 measurements were made of each combination, resulting in a total of 460 measurements in Part 2 of our study.

3. Results

3.1. Part 1

All gloves exhibited a highly nonlinear “hockey-stick” shaped voltage–current relationship that is characteristic of an electrical breakdown (Fig. 2). The current flow for every glove stayed below about 1 mA until breakdown, at which point current flow abruptly jumped up and the dielectric analyzer removed the voltage. The breakdown voltage varied greatly among gloves, ranging from 2500 V to 4000 V.

3.2. Part 2

Some single gloves (32/80 = 40% chloroprene, 2/60 = 3% latex, 42/60 = 70% nitrile, and 42/60 = 70% vinyl) of each polymer showed either a leakage voltage or a breakdown voltage (or both) within the output voltage range of biphasic defibrillators (Fig. 3). The leakage voltage of most double gloves (18/20 = 90% chloroprene, 35/40 = 87% nitrile, 40/40 = 100% vinyl gloves, and 0/20 = 0% latex) also fell within this range. The breakdown voltage for all (20 each) double latex, double nitrile, and double vinyl gloves tested increased to a level higher than the highest biphasic defibrillator output voltage.

4. Discussion

The main findings of this study are that current flow through medical examination gloves is highly non-linear with respect to voltage, and that the current flow is very inconsistent among glove types and between samples of a single glove type. This makes the risks of hands-on defibrillation difficult to predict (Fig. 4).

This study was the first to measure voltage–current curves for medical examination gloves. These data are relevant because they illustrate the difficulty of assessing the safety of hands-on defibrillation. During this procedure the rescuer may be relying partially or completely on the gloves to avoid an electrical shock. In our study the current flow for the gloves tested in Part 1 stayed low – below the threshold of perception – until an arc developed and the current precipitously increased. Importantly, this demonstrates that rescuers should not construe the absence of sensation as an indication of a safety margin. It is likely that hands-on defibrillation with medical examination gloves will produce no sensation at all unless the gloves completely break down, at which time the current will be limited by factors other than the gloves. In our study the current was limited by the dielectric analyzer but current flow through a rescuer could be far higher.

Part 2 of this study measured leakage and breakdown voltages. One strategy for ensuring the safety of hands-on defibrillation is to use only gloves that are guaranteed to have a leakage voltage greater than the defibrillator shock voltage. With biphasic defibrillators this appears to be possible with double latex gloves. None of the double latex gloves exceeded the leakage voltage threshold at less than 5000 V, giving these sample gloves at least a two-to-one voltage margin over most biphasic defibrillation voltages. All other polymers showed a distribution of leakage voltages that either straddles or is lower than some of biphasic shock voltages, even with gloves doubled up.

However, the risk to the operator from leakage current is probably small, even in the worst case, one in which a current path includes the heart. The 0.1 mA leakage current limit set by the IEC was selected to ensure that 1–3 s of current flow would induce
Fig. 3. Histograms of leakage (hatched bars) and breakdown (clear bars) voltages for single and double gloves. Median values are given for each group. For reference, biphasic defibrillation shock voltages are shown. Monophasic shock voltages are much higher, ranging up to 5000 V.

VF in less than 5% of the population. Defibrillation shocks are much shorter, typically less than 20 ms. In order for a defibrillation pulse to induce fibrillation the shock must be timed to hit the vulnerable period of the cardiac cycle. VF may be triggered in people with heart disease if they receive a well-timed low-energy internal defibrillation shock (<0.2 J) or pacing pulse (0.5 V); but for healthy adults it is estimated that, even if the defibrillation pulse is appropriately timed, as much as 500 mA of current flow is required to induce VF. Petley et al. propose a limit of 1 mA through a rescuer, and Hoke et al. assert that, “currents up to 200 mA should be regarded as safe.” If this is true, then any voltage less than the glove breakdown voltage would not present a hazard. By this standard, the double nitrile, double vinyl, and double latex gloves tested in our study appear safe.

Although the risk from leakage current is debatable, the potential harm from a glove breakdown is another matter. Hoke et al. report that healthy non-rescuers have suffered serious injuries from accidental or erroneous defibrillator shocks. All of these people apparently placed the defibrillator paddles directly on their chest, head, or other body part, delivered a shock, and suffered burns, arrhythmias, or death. This situation is somewhat different from a rescuer shock from hands-on defibrillation because during resuscitation the main current path is believed to be through the patient, with a smaller, secondary path through the rescuer. There are no data available that allow the amount of current on any of the possible secondary paths to be quantified.

Hoke et al. report that, although minor injuries are not rare, the medical literature contains no examples of a “life-threatening condition or long-term disability” suffered by a rescuer delivering an external defibrillation shock to a patient. This is a remarkable record considering that there are approximately 60,000 VF cardiac arrests in the United States annually. It should be pointed out, though, that these rescuers were trained to stand clear during a shock. It is not known how many of those rescuers may have been injured had they been trained to continue compressions during defibrillation. Even a relatively small glove failure rate could translate into a large number of rescuer shocks.

It is also possible that a rescuer could be harmed in other ways than immediate induction of VF. There are reports of arrhythmias, conduction disturbances, elevated cardiac enzymes, coronary
Interpretation of Study Results

![Diagram showing the relationship between voltage levels and safety implications.](image)

**Fig. 4.** The safety of hands-on defibrillation depends on the voltage applied to the gloves, the glove leakage voltage, and the glove breakdown voltage.

OCclusional thrombosis, and myocardial infarction due to coronary spasm as a result of an electrical shock from either an AC power line or a lightning strike. Unfortunately, the level and duration of current flow is not known in any of those cases so it is impossible to say whether an accidental defibrillation shock can cause any of those effects.

Besides shocks from AC power lines, lightning, and external defibrillators, there is one report in the literature of a nitrile-gloved rescuer suffering permanent nerve damage as a result of a shock from an implanted defibrillator. This report is of particular concern because internal defibrillator voltages are much lower than external defibrillator voltages. The defibrillator, a Medtronic-Concerto C174AWK, outputs a maximum peak voltage of 800 V lower than even the first shock voltage of most common external defibrillators. The risk of rescuer injury would be even more of a concern when treating patients with subcutaneous defibrillators which likely possess a higher output voltage and may utilize electrodes closer to the surface.

There is also a chance that gloves may contain a pinhole or small tear. Although gloves may be punctured by the wearer, some authors have suggested that as many as 15% of gloves may be manufactured with defects. We did not notice any defects in the hundreds of gloves that we tested, but our experiment was set up to examine the properties of glove materials, not to look for pinholes.

While it is clear that hazards exist for rescuers performing compressions during defibrillation, the potential patient benefit appears to be small. It should be possible for well trained rescuers to charge the defibrillator while performing chest compressions, take their hands off, shock, and resume compressions with a total interruption of perhaps four seconds. If a shock is delivered every 2 min CPR period, then these four second interruptions would only add 3.3% to the total hands-off time.

Our results indicate a need for further study of the other key factor not addressed in this study: the voltage to which the rescuer is exposed. Had we found that glove leakage and breakdown voltages were consistently higher than the shock voltages, then we could have concluded that hands-on defibrillation is safe. Because we instead found that many gloves allow current flow and some break down completely when faced with defibrillation voltages, the safety of this situation is much less clear. Without additional information about the voltages presented to rescuers in resuscitation scenarios, continuing compressions during defibrillation cannot be advised.

5. Limitations

This study was limited primarily because it characterized only one factor relating to the safety of hands-on defibrillation: the electrical characteristics of medical examination gloves. The other factor – the fraction of the shock voltage presented to the rescuer – is equally important. Currently, there are no data available on that factor.

In order for current to flow through a rescuer there must be a current path. This study is not predicated on a particular current path but merely postulates that one or more paths may exist. In the interests of safety, we believe this assumption is prudent unless it is proven otherwise.

For the sake of simplicity the gloves in our study were not compressed as they would be during chest compressions nor were they stretched as they would be when worn by a person. These factors would likely reduce the leakage and breakdown voltages for the gloves, increasing the risk to the wearer.

We applied voltages to these gloves relatively slowly compared to the rise time of a defibrillation shock. It is not known whether the rate of voltage application influences the leakage or breakdown voltages.

6. Conclusions

Few of the gloves tested limited the current to levels proven to be safe. A lack of sensation during hands-on defibrillation does not guarantee that a safety margin exists. As such, we encourage rescuers to minimize rather than eliminate the pause in compressions for defibrillation.

Conflict of interest statement

The authors are both employees of Physio-Control, Inc., a manufacturer of external defibrillators.

References


