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Experimental paper

Ex vivo evaluation of personal protective equipment in hands-on defibrillation

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Abstract

Background: Defibrillation guidelines recommend avoiding patient contact during shock delivery. However, hands-on defibrillation (compressions during shock) and manual pressure augmentation (MPA – pushing on the defibrillator pads during shock) may lead to improved clinical outcomes. There are limited data addressing the protection provided by personal protective equipment (PPE) during hands-on defibrillation and MPA. This study investigated the hand-to-hand and hand-to-knee leakage current experienced by a simulated kneeling provider wearing different PPE.

Methods: A defibrillator was used in experiments on a pork shoulder, investigating three different hands-on positions: closed fist on defibrillator pads; open palm on pads with inadvertent finger contact (overhang); and open palm on the chest. Evaluated PPE included single and double gloves (nitrile and latex) and rescuer cargo trousers in wet and dry conditions (N = 126 experiments).

Results: Mean hand-to-hand leakage currents in MPA without PPE was 0.41 mA (0.2–0.74 mA) and with PPE was 0.2 mA (0.08–0.58 mA). For experiments involving finger or palm contact on the chest, wearing any PPE resulted in a >99% reduction in mean leakage currents from an average 354.58 mA (258.96–446.22 mA) to an average 0.48 mA (0.16–1.56 mA). Rescuer trousers were insulative in dry conditions even without gloves (0.2–1.2 mA).

Conclusion: This study demonstrated that the tested clinical examination gloves markedly reduced leakage current to the rescuer and that the lowest levels of leakage current occurred during MPA attributed to the electrical insulation of the pads.

Keywords: Manual Pressure Augmentation, Cardiac arrest, Nitrile Glove, Latex Glove, Leakage, Current

Introduction

High-quality cardiopulmonary resuscitation (CPR) and early defibrillation are critical in ensuring optimal outcomes in cardiac arrest.[1] International resuscitation guidelines emphasize minimizing interruptions to chest compressions during CPR.[2] Meanwhile, defibrillation guidelines specify that direct contact between CPR providers and the patient should be avoided.[3] As a result, chest compressions are stopped to provide defibrillation, resulting in increased 'hands-off' time during CPR. Studies have shown that a shorter duration of hands-off time is a predictor for return of spontaneous circulation and patient survival.[4–6] The role of 'hands-on' defibrillation, where the rescuer maintains direct contact with the victim, providing ongoing chest compressions as active defibrillation occurs, is garnering increasing discussion.[7]

In a recent systematic review, authors found that the safety of hands-on defibrillation depended on the personal protective equipment (PPE) used.[8] The review yielded conflicting results on the degree of safety provided to the rescuer by wearing clinical examination gloves, with the authors highlighting the electrical and mechanical breakdown of gloves as a vital factor in protective reliability.

Meanwhile, manual pressure augmentation (MPA) is a technique where compression is applied to the defibrillator pads during active defibrillation. Typically performed with closed fists while wearing clinical examination gloves, the goal of the MPA is to achieve lower transthoracic impedance and improve the contact at the electrode–skin interface, thereby increasing current delivery to the heart.[9] Only

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a single study examining elective cardioversion for atrial fibrillation in obese patients has investigated the safety profile of MPA, concluding that gloves provided adequate protection.[9]

Previous studies investigating the electrical protection of PPE have not specifically focused on hand-to-hand leakage current (current that "leaks" through the PPE into the rescuer), which may transpire during MPA, and have not modelled hand-to-knee leakage current as may occur to a rescuer providing hands-on defibrillation over a patient or have not modeled rescuer resistance in their electric pathway.[10–12] Hand-to-foot or hand-to-knee leakage current is potentially more concerning to rescuers, owing to the potential for increased current travelling through the heart.[13] Due to the potential hazards associated with hands-on defibrillation, it is essential to thoroughly investigate the efficacy of different PPE at reducing rescuer shocks in hands-on defibrillation and MPA.

The aim of this study was to quantify the hand-to-hand and hand-to-knee leakage current delivered to a simulated rescuer in a range of simulated clinical defibrillation scenarios. The study investigates the electrical protection offered by several commonly used PPE materials.

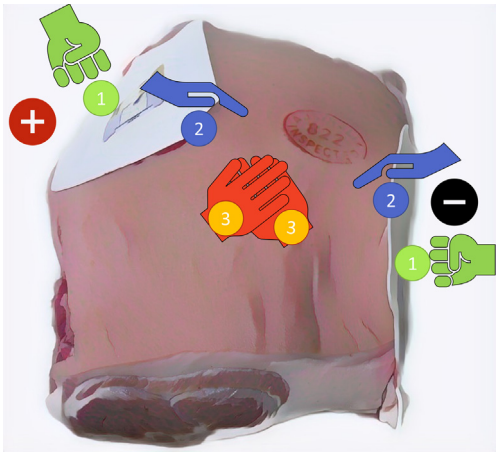

Fig. 1 – Illustration of pork shoulder used to simulate an adult patient in cardiac arrest. Three hands-on positions were tested in this study. 1 – Pushing on the pads, closed fists; 2 – Pushing on the pads with open palms and fingers overhanging the pad; 3 – Pushing directly on the skin between the pads, open palms.

Methods

Experimental setup

A full occupational health and safety risk assessment was undertaken at the Authors' institution to ensure researcher safety. Experiments were conducted on a 7.5 kg rack of pork shoulder, simulating the volume of an adult chest in the vector between the defibrillator pads. A pork shoulder was chosen as it could accurately replicate clinical resistance while facilitating tissue compression during manual pressure augmentation. The pork shoulder was bought from a local butcher and came from a pig slaughtered that day. Experiments were conducted at room temperature (23 °C). The defibrillator was a Zoll X-Series for Emergency Medical Services with Stat Padz defibrillator pads (Zoll Medical Corporation, MA, USA) which delivers a rectilinear biphasic waveform with impedance compensation based on transthoracic resistance. Defibrillator pads were positioned on the anterior and lateral part of the pork shoulder, with distance adjusted to provide an electrical resistance of between 70 and 80 Ω as measured by the defibrillator, representative of typical adult transthoracic resistances.[14,15]

Leakage current was measured with the hands placed at three positions (Fig. 1). The first position was on the pads using closed fists to apply pressure to each pad, simulating MPA performed for elective cardioversion, with the electrode located on the defibrillator pad's foam backing. The second position was on the skin, adjacent to the pads, using an open hand MPA technique with the palm on the pad and the fingers hanging over the pad, simulating inadvertent finger misplacement during MPA. In that position, the electrode was located on the skin at the edge of the pad. The final position was between the pads, pushing with a palm directly onto the skin, simulating typical hands-on defibrillation compressions; the electrode was located directly on the skin. All instances of pressure application were conducted by a single investigator (MS), while wearing 0.6 mm thick insulated polyvinyl chloride gloves (KV660, Showa Group, GA, USA). Pushing was achieved by applying a force of 93.5 ± 1.2 N per hand (equivalent to approximately 10 kg of downward force).[12]

Experiments were conducted using two circuits, one measuring hand-to-hand leakage current and one measuring hand-to-knee leakage current (Fig. 2). The sensing array was a "sandwich", including pork skin or pad, the test PPE, a sensing electrode, and the presser hand (Fig. 3). The sensing array contained a 5 W (5% tolerance) resistor of 1000 Ω or 500 Ω, depending on the experiment, simulating conservative values of the body resistance of the hands-on provider.[13] Current was calculated by measuring the voltage drop across the 5 W resistor using a digital oscilloscope (SDS 1304CFL, Siglent Technologies, OH, USE), with all readings taken with respect to true ground (earth).

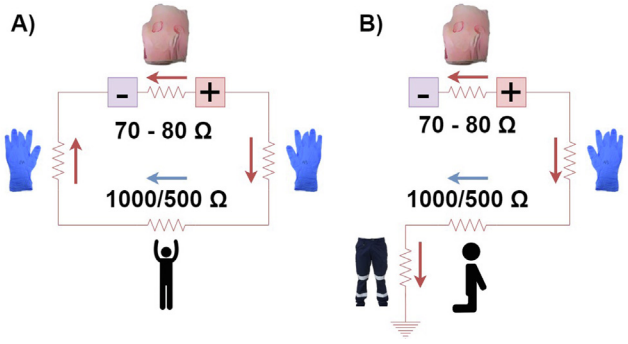

Fig. 2 – Circuit diagrams showing provider resistance, personal protective equipment, and pork shoulder between pads. The blue arrow is the point of current measurement. (A) Simulating hand-to-hand leakage, current travels from the positive pad to the negative pad through gloves on each hand. (B) Simulating hand to knee leakage, current travels through a single glove and rescuer trousers to earth.

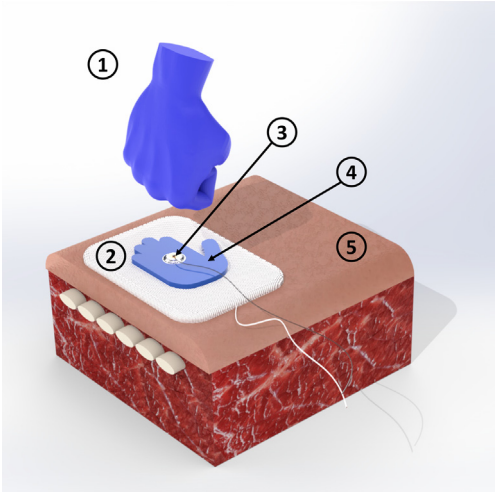

Fig. 3 – Render of sensing array with (1) gloved hand for pushing, (2) defibrillator pad, (3) sensor electrode, (4) personal protective equipment being tested, and (5) pork shoulder.

Experimental protocol

Fourteen configurations of PPE (or no PPE) were used in these experiments; the materials chosen for the PPE were based on common PPE used at the authors' institution (Table 1). Experiments with each configuration were performed three times with hands placed at each test position (Fig. 1), resulting in 14 configurations at three hand positions with three repeats each ($N = 126$ experiments). In addition, baseline experiments without pushing were conducted for 1000 Ω and 500 Ω. The defibrillator was set to deliver a 200 J biphasic shock in all experiments.

PPE included clinical examination gloves and rescuer trousers. Gloves were used in experiments detecting hand-to-hand leakage and hand-to-knee leakage. Two brands of nitrile gloves (N1 and N2 respectively, Paladin, Mun Global, NSW, AU; and Medico Gloves, Shijiazhuang Hongray Group, Hebei Province, China), one brand of latex glove (L1 – Flexi, MediFlex Industries, NSW, AU), and emergency services trousers used by Ambulance Victoria paramedics (Cargo Pant Cotton/Nylon, Australian Defence Apparel, VIC, AU). Electrodes were placed on the inside of the gloves in experiments, and the same pair of gloves was used throughout all experiments to identify any dielectric breakdown (reductions material resistance).

Trousers were used in experiments detecting hand-to-knee leakage current under dry and wet conditions. One electrode was placed inside the trouser leg, with another electrode parallel outside the trouser leg. Next, 40 ± 3 kg of downward force was placed on top of the electrode simulating an adult kneeling. Wet conditions were simulated by saturating the trousers with a solution of sodium chloride and tap water mixed to 2.5 g/L to replicate the conductivity of human sweat.[16] Hand-to-knee leakage was measured with no gloves, one N1 glove, and two N1 gloves; chosen as it is the most used brand at the authors' institutions. Test media material thickness was calculated as the average of five measurements at random points in the material by a dial with an accuracy of ±0.005 mm (RS

Table 1 – List of all personal protective equipment evaluated in these experiments. All experiments were conducted in three positions: on the defibrillator pads, on the pads with inadvertent finger contact, and directly on the chest. N1 – Paladin nitrile glove; N2 – Medico Gloves nitrile glove; L1 – Flexi latex glove.

#	Personal Protective Equipment	Nominal Provider Resistance (Ω)	Thickness (mm)	Scenario
Baseline Measurements – No Pushing				
1	None	1000	–	Baseline leakage with normal provider skin resistance
2	None	500	–	Baseline leakage with lowered provider resistance (gold ring, jewelry, sweaty hands, broken skin)
Hand-To-Hand Leakage – Pushing				
3	None	1000	–	Pushing with no gloves
4	None	500	–	Hands-on with lowered skin resistance and no gloves (e.g., wearing gold ring/jewelry, or having sweaty hands or broken skin)
5	Single N1	1000	0.05	Hands-on with a single layer of high-quality nitrile gloves commonly used by our paramedics and clinicians
6	Single Layer N2	1000	0.04	Hands-on with a single layer of thinner examination gloves
7	Single Layer L1	1000	0.06	Hands-on with a single layer of latex gloves used in our laboratories
8	Double Layer N1	1000	0.10	Hands-on while wearing two high-quality gloves used by our paramedics and clinicians
9	Double N2	1000	0.10	Hands-on while wearing two thinner examination gloves
10	Double Layer L1	1000	0.12	Hands-on while wearing two latex gloves used in our laboratories
Hand-to-Knee Leakage – Pushing				
11	Dry Trousers, No Glove	1000	0.24	Hands-on defibrillation kneeling over the patient, no gloves in a dry environment
12	Wet Trousers, No Glove	1000	0.24	Hands-on defibrillation over the patient, no gloves in a wet environment or with heavy sweat
13	Wet Trousers, Single N1 glove	1000	0.24 + 0.05*	Hands-on defibrillation over the patient, a single layer of high-quality nitrile gloves, in a wet environment or with heavy sweat
14	Wet Trousers Double N1 Gloves	1000	0.24 + 0.10*	Hands-on defibrillation over the patient, two layers of high-quality nitrile gloves, in a wet environment or with heavy sweat

* Thickness of rescuer trousers and gloves.

Table 2 – Average [range] of leakage current detected during experiments when pushing on the pads, with on the pads with finger overhang, and on the directly on the chest for different personal protective equipment (PPE). Experimental configurations correspond to those in Table 1.

Experiment Configuration	Short Description	Average Leakage Current (mA)		
		Pads	Finger Overhang	Chest
1	No PPE, No push 1000 Ω	0.30 [0.20–0.48]	89.35 [3.67–258.97]	290.84 [201.20–462.15]
2	No PPE, No push 500 Ω	0.44 [0.32–0.64]	129.29 [6.07–375.25]	670.66 [646.71–686.62]
3	No PPE, Pushing 1000 Ω	0.41 [0.24–0.74]	173.50 [6.55–258.96]	364.01 [199.60–446.22]
4	No PPE, Pushing 500 Ω	0.51 [0.32–0.68]	255.75 [0.78–391.22]	441.98 [0.60–694.61]
5	Single N1 Glove	0.13 [0.08–0.24]	0.39 [0.16–0.60]	1.20 [0.80–1.59]
6	Single N2 Glove	0.19 [0.08–0.34]	0.61 [0.24–1.28]	0.33 [0.20–0.60]
7	Single Latex Glove	0.41 [0.24–0.58]	0.54 [0.15–1.28]	0.54 [0.20–1.00]
8	Double N1 Gloves	0.15 [0.12–0.16]	0.16 [0.16–0.16]	0.60 [0.40–0.82]
9	Double N2 Gloves	0.17 [0.08–0.26]	0.16 [0.16–0.16]	0.47 [0.40–0.62]
10	Double Latex Gloves	0.19 [0.08–0.32]	0.38 [0.16–0.80]	0.60 [0.20–1.20]
11	Dry Trouser, No Glove	0.21 [0.20–0.22]	7.70 [0.40–22.31]	9.23 [1.00–25.50]
12	Wet Trouser, No Glove	0.53 [0.24–0.74]	15.22 [8.21–23.11]	18.33 [4.78–25.50]
13	Wet Trouser, Single N1	0.34 [0.14–0.48]	3.56 [2.15–6.38]	15.34 [10.16–20.72]
14	Wet Trouser, Double N1	0.21 [0.16–0.24]	4.08 [2.59–5.58]	5.28 [5.18–5.38]

Pro, RS Components, Corby, UK). Direct current PPE resistances (material resistance under constant current) were measured by a handheld multimeter (72–2590, Tenma Corporation, Kita-Ku, JP).

The defibrillator measured the transthoracic resistance between the pads and the energy delivered during the shock. Scenarios where no pushing occurred were used for baseline transthoracic impedance, and changes in transthoracic impedance were recorded at each hand position and aggregated to test for reductions in impedance caused by pushing on pads. Transthoracic impedance data were found to be not normally distributed by Kolmogorov-Smirnoff and Lilliefors tests and analyzed accordingly by Wilcoxon Rank-Sum test ($\alpha = 0.01$).

Recordings were taken via the oscilloscope during each shock to determine the voltage drop (difference in voltage before and after resistor) across the simulated provider representing the leakage current. Leakage currents to the simulated rescuer were calculated using Ohm's law (Voltage = Current·Resistance) with the absolute ($|x|$) maximum and minimum voltages measured across the resistor. The leakage current of each shock was the maximum absolute current detected. It is important to note that no safety standards exist for hands-on defibrillation; however, using existing international electrical standards (IEEE 60479-2), leakage current was classified into four categories (zones).[17] This standard was chosen as it applies to electrical pulse durations $\leq$10 milliseconds, in keeping with the defibrillator model used in this study and others.[18,19] The four categories were: Zone 1 (<2 mA) – slight sensation possible; Zone 2 (2–200 mA) – involuntary muscular contractions likely, usually no harmful electrical physiological effects; Zone 3 (200–500 mA) – strong involuntary muscular contractions, non-fibrillating disturbances to heart function, usually no organic damage; Zone 4 (>500 mA) – possible cardiac or respiratory arrest, and burns or cellular damage.[17,20] More information about these Zones is available in Supplemental Fig. 1.

Results

Measured provider resistances were 501 Ω and 1004 Ω, with hands-on leakage current calculated accordingly (Table 2, Table 1 – supplemental online materials). Resistances of all gloves were measured as >200 MΩ (multimeter limit), while trouser resistances were 62 MΩ (53–71 MΩ) when dry and 17 KΩ (14–18 KΩ) when wet. All current values stated herein are absolute values. For context, Fig. 4 shows results from this study against the established physiological effects thresholds from the international electrical standards.[20] When the defibrillator was off, background electrical current (electronic noise) on the oscilloscope was between 0.08 and 0.42 mA, mean 0.20 mA.

Position 1 – Pressing on the defibrillator pads, closed fist (MPA)

Baseline leakage current through the pads ranged between 0.2 and 0.48 mA (1000 Ω) and between 0.32 and 0.64 mA (500 Ω). Baseline transthoracic resistance ranged from 78 to 84 Ω (mean 80 Ω).

Of the 42 shocks delivered with MPA, all detected leakage currents were below 1 mA (0.08 to 0.74 mA), even in cases with no gloves and wet trousers. These currents all fell within Zone 1 (<2 mA) of the electrical standards (slight sensation possible) and demonstrated that the defibrillator pads are highly insulative.

Compared to the leakage current in performing MPA without gloves, wearing nitrile gloves resulted in a mean reduction in leakage current of 62% (0.41–0.16 mA). There were minimal differences in leakage current between the brands of nitrile gloves worn or by wearing a second layer of gloves. With latex gloves, there was no difference in leakage current with one glove layer and no gloves; however, two layers of latex gloves resulted in a mean 54% reduction in leakage current (0.41 vs 0.41 and 0.19 mA, respectively). Performing MPA reduced transthoracic from a mean of 80 Ω to a mean of 62 Ω, an average 22% reduction ($P < 0.001$).

Position 2 – Pressing on the pads, open palm with inadvertent finger contact (MPA)

Without applying pressure, the baseline leakage current ranged from 3.67 to 4.18 mA (1000 Ω) and 6.07 to 6.55 mA (500 Ω) with transthoracic resistances ranging between 75 and 77 Ω (mean 76 Ω). Of the 42 shocks delivered in position 2, the recorded leakage currents ranged from 0.16 to 391.22 mA. Leakage currents occurring in Zone 2 or higher were observed when not wearing gloves with finger overhang on the chest. However, adding a single or double pair of gloves

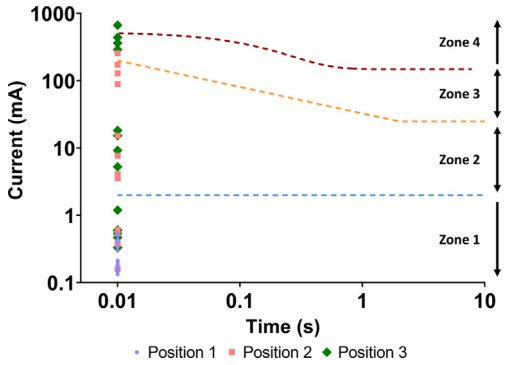

Fig. 4 – Effect of current on the human body changes with exposure time. Values from this study are compared against established thresholds from international electrical standard IEC 60479-1 and 60479-2. Data are the leakage currents recorded in this study at position 1 (pushing on pads), position 2 (pushing on pads with finger overhang), and position 3 (pushing directly on the chest). Note: All values above Zone 2 occurred with no personal protective equipment.

reduced all leakage current to Zone 1 levels. All leakage currents in the wet trousers scenario were within Zone 2, demonstrating reduced electrical protection with wet trousers and skin contact. A single N1 glove reduced hand-to-knee current intensity by an average of 80%, from 20.18 to 4.16 mA. Adding a second N1 glove did not result in lower leakage currents, with mean measured currents of 4.84 mA.

Impedance when pushing on the pads with overhanging fingers was reduced from the baseline of 76 Ω to an average of 61 Ω (average 20% reduction) ($P < 0.001$).

Position 3 – Pushing on the chest, open palm (hands-on defibrillation)

Baseline current when not pushing, ranged from 201 to 209 mA (1000 Ω) and 446 to 462 mA (500 Ω). Baseline transthoracic resistances were measured between 77 and 85 Ω (mean 79 Ω).

All leakage currents detected through gloves were observed in Zone 1. Meanwhile, ten leakage currents were observed within Zone 2, nine during the wet pants scenario (even with gloves), and one with hands-on the chest and reduced provider resistance. Six shocks had leakage currents within Zone 3 (200–500 mA), all of which occurred with normal provider resistance but no gloves. Finally, the leakage currents for five shocks fell within Zone 4, all of which occurred with no gloves and reduced skin resistance. For the wet trousers scenario, adding a single N1 glove reduced hand-to-knee leakage current by an average of 53%, resulting in low-level Zone 2 shocks, mean 11.89 mA. Doubling gloves reduced the current by a further 13%, resulting in average Zone 2 leakage currents of 8.57 mA.

Applying pressure on the chest reduced transthoracic resistance from 79 Ω to an average of 74 Ω (6%, $P = 0.002$).

The investigator applying external pressure while wearing the polyvinyl gloves experienced no electrical stimulus in all 108 experiments where pressure was applied. In over 72 shocks with gloves (N1 gloves being exposed to 36 shocks, and N2 and L1 gloves exposed to 18 shocks each), there was no evidence of dielectric breakdown (electrical damage) of any glove material throughout the experimental protocol.

Discussion

This study investigated the electrical protection offered by different rescuer PPE by evaluating the hand-to-hand and hand-to-knee leakage current through simulated hands-on CPR and MPA. There were 24 shocks delivered with the simulated provider in direct contact with the pig skin (either in position 2 or 3), and no provider PPE worn. These shocks resulted in leakage currents above Zone 1 (>2 mA). Seven of those currents fell within Zone 2 (likely resulting in involuntary muscle contraction, but usually no physiological harm), while 12 were in Zone 3 (resulting in strong involuntary muscle contraction, but usually no organic damage), and five were in Zone four (possibly resulting in cardiac or respiratory arrest, and serious harm to the provider). Notably, all these in Zone 4 were with simulated low skin resistance conditions (provider broken skin or wearing jewelry). Of the 36 shocks in dry conditions with skin contact and PPE, all leakage currents fell within Zone 1 of the international electrical standards. Of note, the average current threshold for human perception is 1 mA, with all but four Zone 1 shocks falling below 1 mA.[13] Modest further reductions in leakage current were seen by adding a second pair of gloves for hand-to-hand leakage current.

Human hand-to-foot resistance is lower than hand-to-hand resistance, and hand-to-foot shocks may direct more current through the heart, making them potentially more hazardous.[13] By subtracting the known resistance of the lower leg, this study measured hand-to-*knee* leakage current that could be experienced by a rescuer giving hands-on defibrillation over a patient on the ground. The experiments found that the protection offered by the emergency services trousers greatly decreased when the trousers were saturated with a saline solution simulating sweat, with resistance reducing from 62 MΩ to 17 KΩ. With no gloves and dry trousers, all shocks were categorized as Zone 1. However, with wet trousers, all shocks were categorized as Zone 2; even with gloves suggesting that in wet conditions, hands-on defibrillation carries a greater likelihood of perceptible hand-to-knee shock unless pushing directly on the pads.

In the context of hands-on defibrillation, the risk to rescuer must be weighed carefully against the benefit to the patient. Some studies have demonstrated a favorable safety profile afforded by wearing clinical examination gloves during hands-on defibrillation.[11,12,21] Lloyd and colleagues studied the leakage current through rescuers wearing clinical examination gloves with hands-on defibrillation and found leakage current to be below safety standards, with no shocks perceived by the rescuer. Similarly, other studies have reported no perceivable shocks to rescuers in animal and cadaver models.[11,21] Conversely, several studies have concluded that examination gloves do not provide adequate safety to rescuers.[22–24] Those studies have primarily focused on the dielectric breakdown of the gloves (gloves failing completely) rather than the insulation provided by an intact glove. Of note, two studies did not use a defibrillator but instead used a continuous, direct current, which is not representative of the electrical waveform or duration of current exposure occurring in defibrillation.[22,23] The study that used a defibrillator created a model within a saline bath but did not simulate any provider resistance, potentially overestimating the incidence of dielectric breakdown in the clinical setting.[24] Putting previous studies into proper context

requires more fundamental research into the defibrillator leakage currents and their associated hazards.

The effects of current on the human body change with frequency (waveform shape), exposure time (shock duration), body mass, and current pathway.[13,25,26] A previous study found that at commercial voltages, the threshold of current required to induce fibrillation in 8–16 kg dogs was 1000 mA for an 8.3 ms shock, but only 50 mA for a 5-second shock, a twentyfold difference based on the exposure time alone.[26] By comparison, the shock duration of a defibrillator is between 3 and 10 ms per phase,[18] potentially raising the human perception and fibrillation thresholds. This study classified shocks into safety zones outlined in the International Electrotechnical Commission standards.[17,20] However, it is essential to consider that these guidelines were based on data on the effects of alternating and pulsed currents (electric fences or tasers) on humans. Defibrillator waveforms have a unique shape and short duration, and consequently, electrical safety standards applied to medical devices and consumer goods may be overly conservative in the context of hands-on defibrillation.

Future research into hands-on defibrillation must be undertaken within the appropriate electrical contexts to ensure potential advancements in clinical practice are not unduly hindered by safety standards developed for commercial applications, which are immensely different in an electrical sense. These standards must be balanced to ensure that the risk to providers can be weighed appropriately against the benefits to patients.

Limitations

This benchtop study used an *ex vivo model* in a laboratory setting and serves as a controlled investigation into the leakage current occurring during MPA and hands-on defibrillation. This model cannot replicate all of the complexities, confounders, and wide variety of inter-patient and inter-environment factors present in clinical practice.

This study used a single 1000 Ω resistor to represent both hand-to-hand and hand-to-knee resistance. The value of 1000 Ω was considered a conservative value representing the lower 50th percentile of hand-to-foot resistance and the lowest 5th percentile of hand-to-hand resistances reported in the literature.[13] In reality, skin resistance can vary widely between 100 and 10,000 Ω depending on conditions and contact surface area.[27] In this study, only a single defibrillator model was evaluated. Skin resistance will vary based on the amplitude and shape of each defibrillator's specific output waveform.[27] Provider trousers were saturated to create "wet conditions" that represent more severe form of trouser wetness. A continuum of wetness or "sweaty" conditions is likely to be found in clinical practice, which was not replicated in this study. Finally, this study only evaluated one brand of defibrillator pads, which was found to have adequate insulation to prevent human perceptible current leakage. Other pads may not provide the same level of electrical insulation.

Conclusion

This *ex vivo* study demonstrated low levels of defibrillator leakage current when using any of the evaluated gloves in all hand-to-hand and dry hand-to-knee scenarios. Additionally, the findings of this study showed no leakage current in the human perceptible range when performing MPA. Data from this study adds to a growing body of evidence illustrating the safety profile and electrical protection offered by clinical PPE when performing hands-on defibrillation and MPA. Further research into the clinical efficacy and hazards to the provider during hands-on defibrillation and MPA is required, balancing the benefits to patient outcomes with provider safety.

Conflict of Interest Statement

All authors are involved in state-wide clinical trials related to manual pressure augmentation in ventricular fibrillation. Authors declare no financial conflicts of interest.

CRediT authorship contribution statement

Andrew F. Stephens: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Michael Šeman:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Ziad Nehme:** Conceptualization, Writing – review & editing, Resources, Project administration, Funding acquisition. **Aleksandr Voskoboinik:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Karen Smith:** Conceptualization, Writing – review & editing, Supervision, Project administration, Resources. **Shaun D Gregory:** Resources, Writing – review & editing, Supervision, Funding acquisition. **Dion Stub:** Conceptualization, Methodology, Resources, Supervision, Project administration, Funding acquisition, Writing – review & editing.

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Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.resplu.2022.100284.

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