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Major Article

Efficacy of placing tape over glove-protective clothing interface to prevent fluid leakage

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Background: Personal protective equipment (PPE) is crucial for healthcare personnel to protect against infections from exposure to body fluids containing bloodborne pathogens such as Ebola, HIV, Hepatitis B, and Hepatitis C. Despite advancements in PPE materials, interface regions, particularly the junction between gloves and protective clothing, remain vulnerable to fluid leakage. Although taping these interfaces is a common practice, its efficacy has not been thoroughly evaluated. This study examined the barrier performance of various tape models applied at the glove–protective clothing interface using a quantitative fluid leakage test.

Methods: Five tape models; Gorilla Crystal Clear, 3M Contractor Grade Multi-Use Duct tape, Kappler Chemtape, 3M Durapore Surgical tape, and 3M Nexcare tape were evaluated under controlled conditions using a robotic arm that simulated healthcare personnel movements. A 5-second soak exposure followed by motion sequences was conducted, and fluid penetration was quantified by measuring absorption by the inner cotton sleeve. One-way analysis of variance and post-hoc comparisons determined differences among tape models.

Results: Gorilla Crystal Clear Tape significantly reduced fluid leakage compared to all other models. 3M Durapore showed the highest leakage, while 3M Nexcare performed moderately.

Conclusions: Taping significantly decreases fluid leakage at the glove–protective clothing interface, though performance depends on tape type. Some tapes may damage garments during removal, underscoring the need to balance barrier efficacy with ease of doffing in PPE use.

BACKGROUND

Personal protective equipment (PPE), including coveralls, gowns, and gloves, is designed to provide essential barrier protection to individuals exposed to hazardous environments or biological contaminants. These contaminants can include bodily fluids such as blood, saliva, and perspiration.[1–5] The effectiveness of protective clothing is determined by several factors, including the barrier properties of the fabrics, construction techniques, and overall design of the protective clothing.[6] Critical to the protective efficacy of PPE is the interface between gloves and protective clothing, which is considered one of the most vulnerable areas of the overall ensemble due to being in the critical zone where they may be subjected to direct contact with biological contaminants.[7,8] The interface between gloves and protective clothing is particularly challenging due to

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issues such as glove roll-down and channel formation.[9] Glove roll-down occurs when the glove slides down, creating gaps, while channel formation results from the glove being worn over a baggy sleeve, leading to creases that can trap and channel fluids.[10] These issues can compromise the barrier integrity and pose significant risks in environments where exposure to biological contaminants is a concern. To address these challenges, healthcare personnel (HCP) may choose to employ tape to secure gloves to protective clothing, aiming to close gaps and enhance barrier protection. However, the use of tape presents both advantages and potential drawbacks. Proper taping can indeed prevent fluid ingress by sealing small gaps between PPE components.[11–15] Nevertheless, adhesives used in tapes can be susceptible to breakdown when exposed to liquids, particularly over extended periods.[16,17] Additionally, the process of taping can complicate the doffing process, potentially increasing the risk of contamination due to difficulties in removing the tape without damaging the protective clothing.[18] Strong adhesives can bond aggressively to protective clothing surfaces, leading to tears or rips during removal.[19] It is also important to consider that contact between the tape and the wearer's skin may lead to micro-abrasions or discomfort upon removal.[20] Although the Centers for Disease Control and Prevention does not explicitly endorse or discourage the use of tape in its Viral Hemorrhagic Fever guidance due to the potential risk of contamination and complications during the doffing process, it advises that facilities carefully evaluate its use and the necessary training requirements.[19] Various tape models are available on the market, each with distinct properties. Water-resistant materials are preferred, as textile layers can absorb fluids through capillary action, undermining the effectiveness of the barrier.[11] The adhesive components are ideally resistant to both water and chemicals to maintain their grip and prevent dissolution. Additionally, a flexible tape design can facilitate freehand movements without compromising the protective function.

This study aims to evaluate the barrier efficacy of different tape models applied at the glove-protective clothing interface. By assessing the performance of various tapes in preventing fluid leakage, we seek to provide insights into the optimal solutions for enhancing PPE effectiveness and addressing the specific challenges of the glove-protective clothing interface.

METHODS

A single coverall model and 5 distinct tape models with varying properties were selected for this study. All relevant information regarding the coverall and tapes was obtained from the manufacturers' product data sheet and is described in the text below, while Table 1 summarizes the tape models and their advertised key features. In this manuscript, "protective clothing" refers to barrier garments such as coverall. The term "garment" is used when describing the specific test article used in this study. The chosen coverall was the DuPont Tyvek 800J garment (model number TJ198TWHLG0025PI), composed of flash-spun high-density polyethylene nonwoven material, referred to as 1C. This model was selected for its superior fluid resistance and common use in several applications, such as chemical handling and pharmaceutical manufacturing, to minimize fabric failures and better isolate interface-related failures. The 1C coverall had an average thickness of 0.196 mm (σ = 0.017), an average basis weight of 62.362 g/m² (σ = 2.598), and an average circular bending stiffness of 0.5192 lbf (σ = 0.099). Five tape models were selected based on market research and recommendations from our partners, who were consulted on the study design. The 3M Contractor Grade Multi-Use Duct Tape (model number 2979) was constructed with a waterproof polyethylene film over cloth scrim backing and a rubber adhesive. The Gorilla Crystal Clear Tape was advertised as heavy-duty, UV and temperature resistant, and suitable for underwater applications. The Kappler Chemtape was marketed as chemical-resistant and specifically designed for protective clothing applications. The 3M Durapore Surgical Tape was known for its strong adhesion, with good initial and long-term skin adherence. The 3M Nexcare Absolute Waterproof Tape was described as waterproof, flexible, and breathable. These tape models were denoted as 1TP, 2TP, 3TP, 4TP, and 5TP, respectively, for the purposes of this study, as shown in Table 1.

Additionally, a single examination glove model was used consistently across all testing scenarios. The gloves selected were Fisherbrand extended cuff nitrile examination gloves (Fisher Scientific catalog number 19-041-170B), labeled as 1GLV, manufactured from non-latex, powder-free nitrile material. The manufacturer specified that these nonsterile gloves feature a beaded cuff and a textured finish for superior wet or dry grip, were tested for use with chemotherapy drug exposure, and comply with ASTM F1671, ASTM F739, and ASTM D3578 standards and were FDA 510(k)-cleared for medical use. The 1GLV gloves measured 12 in. in length with thicknesses of 6 mil (palm), 7 mil (finger), and 4.5 mil (cuff). This glove model was selected for its great fluid resistance and common use in the market.

This study was designed to simulate fluid exposure directly at the glove-protective clothing interface. The surface tension of the challenge fluid is a critical factor, as fluids with higher surface tension tend to penetrate less than those with lower surface tension.[9,15,21,22] The challenge fluid was prepared using deionized water and a surfactant, as recommended in ASTM F903,[23] consisting of a 0.03% weight percent solution of Surfynol 104H (Air Products, Vandalia, IL). This preparation maintained the surface tension at approximately 42 ± 2 dyn/cm and was used consistently across all experiments. A surface tension of 42 ± 2 dyn/cm was chosen for 2 primary reasons: 1) the surface tension of various human body fluids ranges between 27 and 75 dyn/cm, with an average of 40 dyn/cm at 20 °C to 25 °C, and 2) both ASTM F1670[24] and ISO 16603[25] specify the use of synthetic blood with a surface tension of 42 ± 2 dyn/cm to simulate body fluids.

To test leakage at the interface, a testing methodology developed by NIOSH was used, employing a robotic arm to simulate HCP movements.[9,15,21] The robotic arm can replicate nearly all human arm movements, with the specific movements chosen based on current literature and consensus among researchers, HCPs, and subject matter experts in the field.[9,15,21,22,26–29] The testing setup included an exposure system capable of simulating both spray and soak exposures. Spray exposure was achieved using 4 corner nozzles aimed directly at the interface area, while soak exposure involved a

Table 1
Overview of tape models and key features

Tape model	Brand	Product name	Advertised key features	Width (inch)
1TP	3M	Contractor Grade Multi-Use Duct Tape (2979)	Waterproof polyethylene film, cloth scrim backing, rubber adhesive	1.89
2TP	Gorilla	Crystal Clear Gorilla Tape	Heavy duty, UV and temperature resistant, suitable for underwater use	1.5
3TP	Kappler	Chemtape	Chemical resistant, designed for protective clothing applications	1.89
4TP	3M	Durapore Surgical Tape	Strong adhesion, good initial and long-term skin adhesion	1
5TP	3M	Nexcare Absolute Waterproof Tape	Waterproof, flexible, breathable	1.5

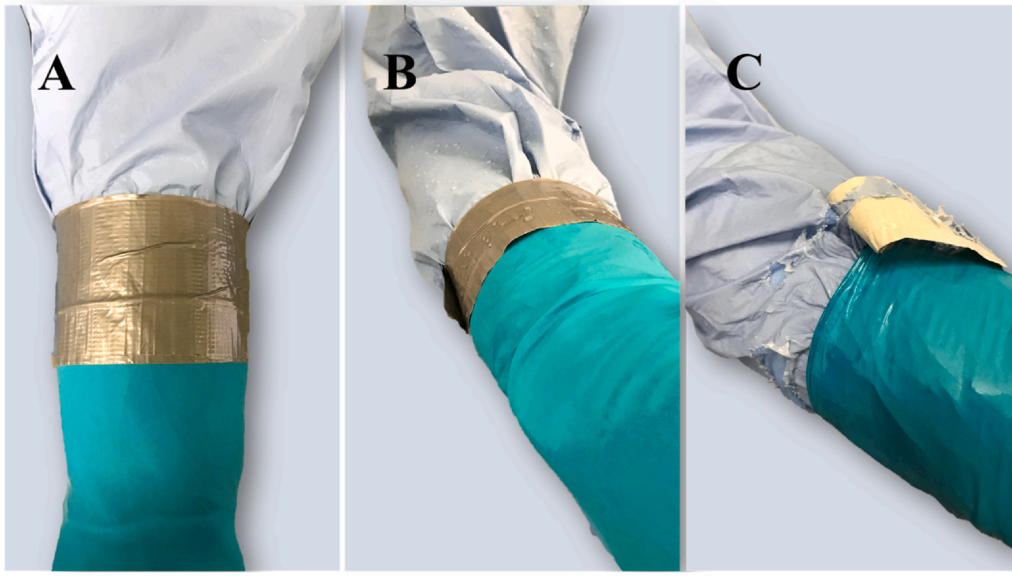

Fig. 1. **(A)** Top view after applying 2 rounds of tape, demonstrating the initial sealing method used to secure the interface. **(B)** Post-simulation showing tape separation due to compromised adhesion from fluid exposure. **(C)** Tape removal process, illustrating garment tearing caused by strong adhesion, highlighting risks during doffing.

container filled with challenge fluid on a motorized elevator, which dipped the arm into the fluid for a specified duration according to the selected testing protocol.

In this study, the testing procedure began by donning the robotic arm with an inner cotton sleeve (93/7% Cotton/Spandex, Medline, NONSLEEVE), which was used to collect any penetrated fluid, followed by the proper application of the selected coverall and glove.[15] For each trial, a fresh coverall was used so that the sleeve material was not reused between tests. Two full rounds of tape were carefully applied around the interface area (see Figure 1). The testing commenced with a 1-time 5-second soaking exposure, in which the arm was dipped into the challenge fluid container.[9] Subsequently, the robotic arm performed a series of pre-programmed movements over a 15-minute test duration. Upon completion of the movement protocol, the tape, glove, and coverall were carefully removed, and observations were recorded. Tearing was assessed qualitatively during tape removal by visually observing whether any portion of the underlying clothing material was visibly torn, ripped, or delaminated (eg, fiber breakage, layer separation). Fluid leakage was evaluated by measuring the amount of fluid absorbed by the inner cotton sleeve. This was done by weighing the sleeve in both its dry and wet states and calculating the difference. The scale used for these measurements was a Symmetry by Cole-Parmer model # S-PT 413E with 0.001-g sensitivity. Fabric stiffness was measured using the SASD-672 pneumatic fabric stiffness tester by J.A. King (Whitsett, NC), following ASTM D1388. This test method measures the force required to push a flat, folded swatch of fabric through a circular opening using a plunger.

Each tape model was tested using the same glove and coverall model. For each tape model, the test was repeated 10 times, resulting in a total of 50 data points. A 15-minute test duration was selected because isolation procedures are generally brief, typically lasting less than 15 minutes.[30] A 5-second soaking was chosen to simulate a worst-case scenario, as taping over the interface is recommended when large amounts of liquid exposure are anticipated. Testing under these conditions was considered beneficial for identifying even small amounts of fluid penetration, which might not be detectable with shorter or spray-type exposures. Analysis of variance was used to examine fluid exposure at the interface for each of the 5 tape models individually. Post-hoc pairwise comparisons using the least significant difference adjustment identified specific differences among tape models where applicable. Additionally, to evaluate the baseline effectiveness of taping, we incorporated data from our previous study[10] in which single- and double-glove penetration resistance was tested using the same garment and tape models. These conditions were included to isolate and compare the impact of taping alone on fluid leakage at the glove-protective clothing interface.

RESULTS

This study evaluated the effectiveness of 5 different tape models in preventing fluid leakage at the glove-protective clothing interface. The findings demonstrate that taping significantly reduces fluid penetration, with notable differences in performance among tape types (Tables 2 and 3). Specifically, the Gorilla Crystal Clear Tape (2TP) provided the most effective barrier, while the 3M Durapore Surgical Tape (4TP) showed the highest leakage. Descriptive statistics, including mean fluid leakage, standard deviation, and 95% confidence intervals, are presented in Table 2, and bivariate analyses are summarized in Table 3.

To isolate the specific effect of taping on fluid leakage, additional data were used from our earlier study where single- and double-glove conditions compared.[10] Previously, we reported mean fluid leakage values of 0.875 g for the single-glove condition and 0.757 g for the double-glove condition.[10] In comparison, the taped interface evaluated in the current study resulted in a mean leakage of 0.132 g,

Table 2
Fluid leakage descriptive statistics

Tape model	Mean (g)	Std. deviation	Std. error of mean	95% Confidence interval
1TP	0.296	0.104	0.033	0.225-0.367
2TP	0.101	0.049	0.016	0.030-0.172
3TP	0.322	0.168	0.053	0.251-0.393
4TP	0.341	0.122	0.039	0.270-0.412
5TP	0.229	0.076	0.024	0.158-0.300

Table 3
Post-hoc pairwise *P* values (least significant difference test) by tape model

	1TP	2TP	3TP	4TP	5TP
1TP	–				
2TP	**< 0.001**	–			
3TP	> 0.05	**< 0.001**	–		
4TP	> 0.05	**< 0.001**	> 0.05	–	
5TP	> 0.05	**0.01**	> 0.05	**0.03**	–

Bold values indicate statistically significant differences ($p < 0.05$).

representing an 85% and 83% reduction in leakage relative to the single and double glove conditions, respectively (Figure 2).

One-way analysis of variance results revealed a statistically significant difference in mean fluid leakage across the tape models ($F = 7.66$, df = 4, $P < .001$); meaning that the use of each tape model will provide significantly different interface protection. Post-hoc least significant difference comparisons identified tape model 2TP as the most effective, with a mean fluid leakage of 0.101 g. The performance of 2TP was significantly better than tape models 1TP ($M = 0.296$ g, $P < .001$), 3TP ($M = 0.322$ g, $P < .001$), 4TP ($M = 0.341$ g, $P < .001$), and 5TP ($M = 0.229$ g, $P = .01$).

Tape model 4TP exhibited the highest mean fluid leakage ($M = 0.341$ g), significantly greater than 2TP ($P < .001$). Tape model 5TP demonstrated moderate performance with significantly lower fluid leakage compared to 4TP ($P = .03$). No statistically significant differences were observed between the remaining tape models (1TP, 3TP, and 5TP), indicating comparable performance.

In addition to fluid leakage data, tape removal during the doffing process resulted in varying degrees of garment tearing across tape models. Specifically, 100% of trials using tape models 1TP and 3TP resulted in visible tearing of the garment's outer coating. Tearing occurred in approximately 50% of trials with models 2TP and 4TP, while model 5TP exhibited tearing in about 30% of cases.

DISCUSSION

The findings of this study demonstrate that taping over the glove-protective clothing interface improves fluid resistance. Compared to our previously reported single- and double-glove configurations without taping,[10] the taped interface resulted in substantially lower fluid leakage, highlighting its potential to enhance PPE performance in high-exposure settings. Among the 5 tape models tested in this study, the choice of tape significantly influenced fluid containment, with tape model 2TP outperforming the others. The superior performance of 2TP can likely be attributed to its heavy-duty construction and suitability for underwater applications, which enhance its sealing properties. In contrast, 4TP, despite being marketed for strong adhesion, exhibited the highest fluid leakage. Its reduced effectiveness may be associated with limitations in flexibility and waterproofing, which prevented it from conforming adequately to the interface surface. Flexible tapes such as 5TP demonstrated intermediate performance, suggesting that adaptability to surface contours plays a key role in achieving an effective seal. These findings emphasize the importance of both adhesive strength and flexibility in selecting tape materials for fluid containment applications.

An important consideration revealed by our findings is the trade-off between adhesive strength and ease of removal. While stronger adhesion, as seen with tapes like 2TP, contributes to superior sealing performance and reduced fluid leakage, it also increases the risk of garment tearing and complicates the doffing process. This highlights the importance of balancing strong adhesion for fluid containment with ease of removal, as tapes may improve sealing but also raise the risk of exposure during removal. Selecting tape materials with adequate sealing capability while minimizing damage during removal is therefore crucial. The risk of garment tearing during tape removal was observed across most tape models, posing a concern for potential exposure to contaminated fluids during the doffing process. The results of garment tearing, which was observed on the thin surface coating during the doffing process, varied significantly across tape models. Specifically, the use of 1TP and 3TP resulted in tearing in all instances during doffing. In contrast, 2TP and 4TP led to tearing in approximately 50% of cases. Tape model 5TP exhibited the least amount of tearing during doffing, suggesting that these models are less likely to cause damage to the protective clothing during removal. The extent of garment tearing likely depends on the material properties of the protective clothing as well. The tearing observed in the current study highlights the importance of further investigation into tape compatibility with different protective clothing materials. While the selected coverall demonstrated surface tearing, it should be noted that other materials commonly used in gown and coverall construction are often less durable. The tearing effect observed here may therefore be even more pronounced with thinner or less tear-resistant fabrics, such as those found in certain gown types. Exploratory testing on various coverall types indicated some variation in tearing outcomes between models, supporting the importance of further testing to optimize tape use for each specific material.

Taping improves barrier performance of the glove-protective clothing interface through 3 main mechanisms. First, taping prevents glove roll-down and sleeve roll-up, thereby reducing the formation of gaps between the sleeve and glove cuff. This physical stabilization is crucial in maintaining a continuous barrier against fluid ingress. Second, the pressure exerted by the tape compresses the sleeve fabric,

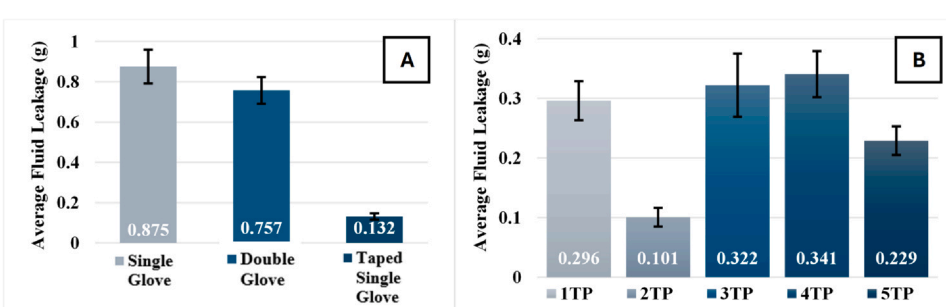

Fig. 2. Average fluid leakage across glove configurations **(A)** and tape models **(B)**. Panel A compares average fluid leakage (g) among 3 glove configurations: single glove, double glove, and taped single glove. Panel B compares average leakage across 5 tape models applied at the glove–coverall interface. Bars represent the average fluid leakage (g) measured across repeated trials, with error bars indicating standard deviation. Tape model abbreviations: 1TP = 3M Contractor Grade Multi-Use Duct Tape (2979); 2TP = Gorilla Crystal Clear Tape; 3TP = Kappler Chemtape; 4TP = 3M Durapore Surgical Tape; 5TP = 3M Nexcare Absolute Waterproof Tape. All tape types were applied using 2 full wraps around the glove-coverall interface.

reducing any creases that might serve as channels for fluid passage. This compression results in a narrower, more secure interface, further reducing the risk of fluid penetration. Finally, the adhesive properties of the tape create a direct seal over the openings, adding an additional layer of protection against fluid leakage.

While this study provides valuable insights into the effectiveness of taping for fluid containment, it is important to acknowledge certain limitations. First, the experimental setup, which utilized a robotic arm to simulate movements, may not fully replicate the range of dynamic tasks performed in real-world healthcare settings. Second, the study evaluated a specific set of tape and protective clothing models and glove configurations, which, while diverse, may not encompass all available options. Future studies could include a broader range of tape models used in the field, such as vinyl tapes. Third, the testing conditions (including a single exposure type and limited duration) may not reflect prolonged use or the variety of fluid exposure scenarios commonly encountered in clinical practice. Additionally, the testing conditions, including the single exposure type and duration, may not fully reflect prolonged use or varying fluid exposure scenarios commonly encountered in clinical practice. Finally, the gloves and coveralls used in this study did not include manufacturer instructions regarding the use of tape on their surfaces, as well as some of the tape models tested are also not specifically designed for healthcare applications, which could influence their suitability for clinical environments. The robotic arm model also cannot replicate human movement or doffing-related contamination risks, underscoring the need for human-subject or clinical simulation studies. Future studies could investigate the testing of different tape, glove, and protective clothing combinations, arm movements, and exposure durations, as well as examine the stretching and tearing properties of tapes.

CONCLUSIONS

This study evaluated the efficacy of different tape models in preventing fluid penetration at the glove-protective clothing interface, with tape model 2TP providing the best performance. The choice of tape model significantly impacts the effectiveness of sealing, as evidenced by the varying levels of fluid leakage. Flexible tapes generally conformed better to the interface area, forming a tighter seal, whereas more rigid tapes did not adapt as well to the surface contours, leading to increased fluid leakage. This difference underscores the importance of tape material properties, particularly flexibility and adhesive strength, in achieving effective sealing at the PPE interface. Glove material may also impact seal durability by influencing how pressure is distributed at the interface.

Despite the clear benefits of taping, tape removal can tear protective clothing, posing contamination risks during doffing. Taping also adds time to donning and doffing, increasing the chance of user error. Contact between tape and skin can cause abrasions, and rigid tapes may reduce comfort by limiting wrist movement, airflow, and thermal comfort. While taping reduces fluid penetration, its use in high-risk settings may benefit from careful evaluation of application ease, removal challenges, and garment integrity before integrating taping over the interface.

Future research could focus on optimizing both tape and coverall materials to achieve effective sealing while allowing easy removal, with the aim of reducing garment tearing. Exploring alternative adhesive technologies or designs that maintain seal integrity during doffing is key to improving safety in environments with hazardous fluid exposure. Additionally, developing training protocols to ensure proper tape application and removal could further enhance safety.

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