Effective personal protective clothing for health care workers attending patients with severe acute respiratory syndrome

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Background: Optimal usability is crucial in providing protection for health care workers who are exposed to severe acute respiratory syndrome day and night while taking care of patients with the virus. No research study has yet tested the usability of personal protective clothing (PPC).

Method: The study was carried out in 3 stages. PPC available in Hong Kong were sorted by their physical properties in the first stage. The second stage was a single-blinded study examining the different usability aspects of the PPC. The third stage was a simulated viral load test.

Results: Four types were identified: good water repellency and water resistance, poor air permeability (Type A PPC); good water repellency and air permeability, poor water resistance (Type B PPC); poor water repellency, poor water resistance, and fair air permeability (Type C PPC); and good water repellency, poor air permeability, and fair water resistance (Type D PPC). Type D PPC had a significantly higher number of contamination sites on the subjects' dorsum and palm. Type C PPC had the highest contamination over the trunk. Findings in the viral load test showed that there was a significant difference in the contamination of the face ($t = 4.69$, $df = 38$, $P < .00$) between 1 and 2 strokes.

Conclusion: Type A PPC is effective in providing a desirable protective function against droplet splash, if a disposable PPC is required. Type C PPC, the surgical gown, is also appropriate, as the cost is low, air permeability is fair, and the level of possible hand contamination is lowest among the 4 groups in the current study. (Am J Infect Control 2004;32:90-6.)

The severe acute respiratory syndrome (SARS) epidemic continues to affect the world. SARS has been described as a highly contagious disease, and health care workers are the most vulnerable group. So far in Hong Kong, more than 1700 cases of SARS have been reported, with more than 22% of the total affected being health care workers.[1] To prevent cross-infection, 1 of the most effective strategies is the use of personal protective clothing (PPC).[2–4] PPC in this study refers specifically to gown. In Hong Kong, various PPC types are available (eg, Barrierman, Airmate, Tyvek, surgical gowns), but despite their use, health care workers have still been affected. It is interesting to note that hospitals using traditional PPC such as surgical and plastic aprons have a lower incidence of staff-contracted SARS.[5]

Whether the available types of PPC provide full protection against the virus has not yet been determined. However, important in ensuring high PPC performance is the PPC's usability. PPC usability is defined as the level of comfort, ease of use, time taken to put on/take off, and risk of contamination. Optimal usability is crucial in providing protection for health care workers who are exposed to the virus day and night while taking care of SARS patients. No research study has yet tested PPC usability. To this end, a team of academic and clinical investigators designed a study to examine the usability of each PPC type available in Hong Kong.

It would be both dangerous and unethical to conduct PPC tests by exposing participants (health care workers) to SARS patients. Therefore, this study was conducted in the laboratories of the School of Nursing at the Hong Kong Polytechnic University, and a fluorescence stain was used, instead of the live virus, to simulate viral attachment.

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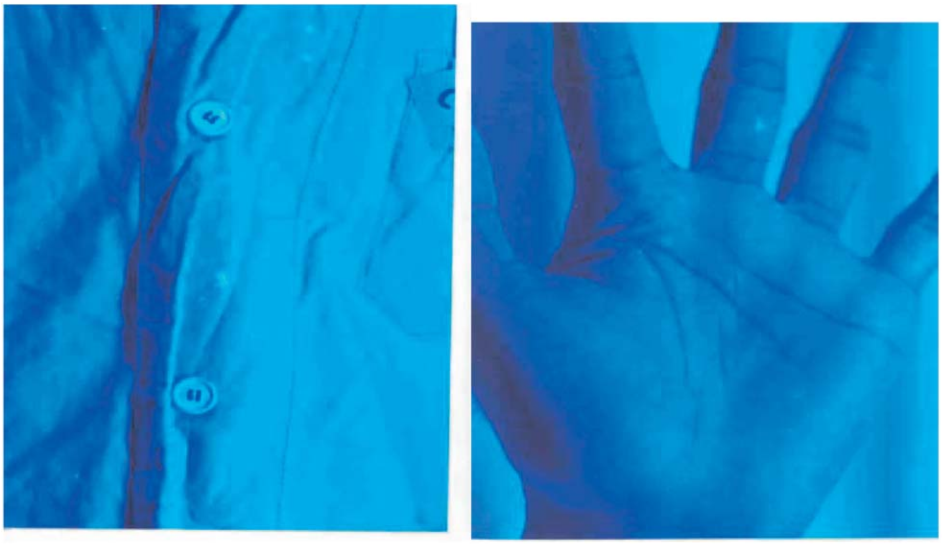

Fig 1. Stained area on trunk and fingers.

The purpose of the study was to evaluate the usability of the PPC types. The objectives were to (1) examine the physical properties of the PPC; (2) assess the usability of the PPC; and (3) evaluate the effect of increased viral load.

DESIGN AND METHOD

The study comprised 3 stages. The first stage investigated the physical properties of the PPC. The second stage was a single-blinded study: subjects were allocated a PPC using a random table. The third stage was a simulated viral load test.

Details of the procedures in stage 2 were as follows. Explanation of the study's purpose was given and written consent was sought before study implementation. The researcher demonstrated the method for putting on and taking off a gown. For Type D PPC, subjects were asked to read the user instructions that came with the PPC. Subjects were asked to put on the allocated PPC, and the researcher recorded the time required for put-on. Subjects were then asked to go to laboratory 2 next door and stand in front of a perplex box that exposed the trunk while blocking the remaining parts of the body. The researcher sprayed the exposed part with either fluorescein or water with an atomizer (subjects were blindfolded during this process). Subjects then returned to the first laboratory and took off the PPC, while the researcher recorded the time required for take-off. Subjects were next asked to go to laboratory 3 for a UV scan and to have the stains photographed. Subjects were then asked to remove the stains, if any, by washing with alcohol; afterward, the researcher scanned subjects with UV light to ensure the stains had been removed. Subjects were then asked to repeat the above procedure twice. Upon completion of all 3 trials, subjects were asked to fill out the usability questionnaire.

Instruments

In addition to demographic data and the usability questionnaire, instruments used include PPC and fluorescence stain. For the stain, 0.2 mg of fluorescein (25% diluted in 100 mL of water) was used. Assuming the density of the solution is 1, the weight of the splash in 1 stroke was 1.92 g (which is 1.92 mL by volume) as determined by an electronic analytical balance. The precision of the balance is 0.001 g.

Data analysis

Descriptive statistics were computed to provide an overview of the sample and the distribution of scores, including clarity of instructions, degree of comfort, and ease of use. The stained area was measured by counting the number of spots and patches over different areas of the body (Fig 1). Analysis of variance tests were used to examine differences in the stained area by type of PPC, and *t* tests were conducted to determine the difference in contamination after an increase in viral load.

Ethical considerations

Subjects were informed of the purpose and procedures of the study. Written consent was obtained beforehand. Confidentiality and anonymity were assured, and participation was voluntary: subjects could withdraw at any time.

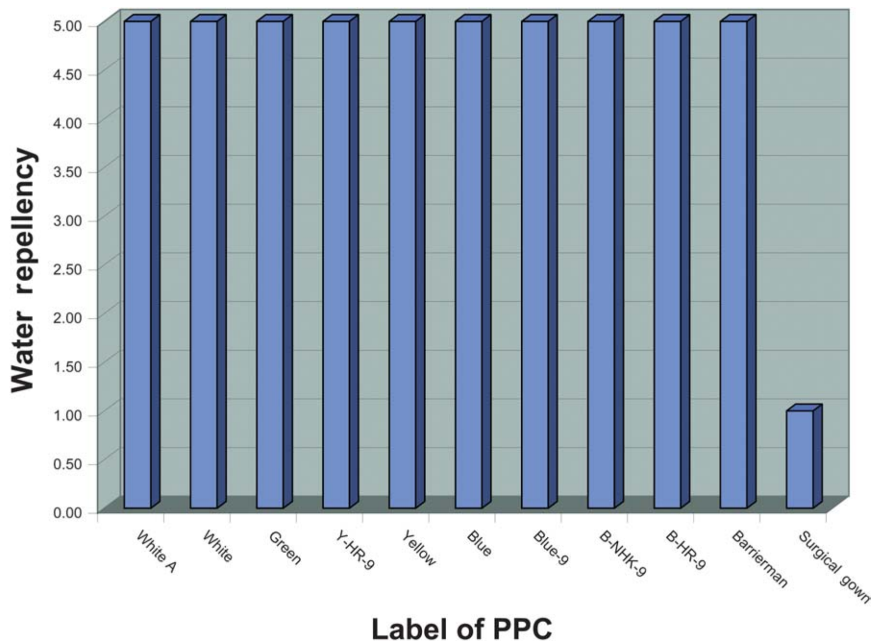

Fig 2. Results of water repellency—spray test. *PPC*, Personal protective clothing.

RESULTS

One hundred voluntary subjects participated in the study. The majority (82%) were female, and all were nursing students in a school of nursing. The mean age was 21.03 years (SD = 1.23). Fifty-six (56%) were studying for a higher diploma in nursing and 44 (44%) were working toward a bachelor's degree in nursing. Forty of them (40%) had completed year 1, 42 (42%) had completed year 2, 16 (16%) had completed year 3, and 2 (2%) had completed year 4. None had experience in nursing SARS patients. They had previously been taught the method of putting on and taking off a gown as part of their training. Furthermore, all had some clinical experience.

Stage 1: Physical properties of the PPC

PPC allocated in the study was that currently in use by health care workers while caring for SARS patients in hospitals in Hong Kong. All PPC bore labels identical to those given out by the hospitals and were tested for physical properties related to protection and comfort. For protection, materials used in making PPC should be resistant to absorption and diffusion of liquids, thus preventing the penetration of droplets contaminated with viruses (characterized as water repellency). For comfort, the ideal PPC would be made of highly permeable clothing materials that allow excess body heat to be dispersed by means of air and moisture transfer (characterized as water vapor permeability, thermal resistance, and air permeability). In this paper, we focus on the protective performance and usability of PPC by carrying out a series of tests to characterize their physical properties, including water repellency and wettability, liquid penetration, and air permeability.

Water repellency and wettability. A spray test was completed according to the American Association of Textile Chemists and Colorists standard 22.[6] The test is used to show water repellency versus wettability of porous textile materials. In Fig 2, index on the y-axis indicates no sticking or wetting of upper surface (excellent water repellency), whereas a 0 means complete wetting of upper and lower surfaces (ie, poor water repellency). As shown in Fig 2, the traditional surgical gown has very good wettability, whereas other PPC gowns have excellent water repellency. These results show that the traditional surgical gown is wettable and absorbs liquid contaminated with viruses, whereas other PPC gowns can resist the absorption of liquid contaminated with viruses. On the other hand, the surgical gown may be better able to prevent subsequent cross-infections from hand touch and bumping off liquid splashed onto its surface, as it has a greater ability to absorb and hold the liquid in its structure.

Liquid penetration test. The liquid penetration test was performed according to the Association of Textile Chemists and Colorists standard 127.[7] Fig 3 shows the hydrostatic pressure of liquid water required to penetrate a fabric and form water drops on its opposite surface. A larger value means higher resistance to liquid water penetration. The 2 white gowns have the highest resistance to liquid water penetration, followed by the Barrierman. The other PPC gowns had much lower resistances to liquid water penetration, and the surgical gown is completely unable to resist liquid water penetration. These results indicate that the white gowns and the Barrierman have a much higher ability, during a splash, to prevent the penetration of liquid contaminated with viruses than do other PPC gowns, particularly the traditional surgical gown.

Air permeability. The air permeability test was completed in accordance with the standard American Society for Testing and Materials D 737-96.[8] In Fig 4, the y-axis indicates the airflow rate on the fabric surface at a pressure of 100 Pa. Higher values mean better breathability. As Fig 4 shows, the white PPC gown and the Barrierman have very poor air permeability, whereas the other nonwoven PPC gowns have very good air permeability. Performance of the traditional surgical gown fell between the 2 groups. Results indicate that the white PPC gown and the Barrierman cannot allow easy transfer of excess heat away from the body by movement of air and moisture and so are more likely to cause thermal discomfort and heat stress to the wearer. On the other hand, the white PPC gown and the Barrierman have higher resistance to the penetration of contaminated droplets and airborne particles in air streams.

On the basis of the test results, the team grouped the PPC into 4 types for subsequent comparison—namely, Types A, B, C, and D (Table 1). It was noted that the Barrierman was typed on its own because its design was vastly different from those of the rest (ie, the zipper is in the front).

Stage 2: Usability of the PPC

Subjects were asked to rate PPC for usability on a 5-point scale, where 1 was strongly disagree and 5 was strongly agree (results shown in Table 2). There were significant differences in usability among the groups ($P < .00$). Type B PPC had the highest mean usability score, whereas Type D PPC had the lowest.

Time required to put on and take off. Analysis of variance tests were computed among the 3 trials for each type of PPC to examine the differences in time required to put on the PPC (put-on time) and take off the PPC (take-off time). Results showed no significant difference among the 3 trials. Therefore, mean put-on time and mean take-off time were used for comparison among the groups (Table 3).

One-way analysis of variance with post hoc test was computed to examine the differences in put-on time among the groups. Results show significant differences. Type D PPC took a significantly longer time for put-on (mean difference $_{D\text{-}A}$ = 33.83, $P < .00$; mean difference $_{D\text{-}B}$ = 27.13, $P < .00$; mean difference $_{D\text{-}C}$ = 17.11, $P < .00$). Similarly, Type D PPC also took a longer time for take-off (mean difference $_{D\text{-}A}$ = 17.56, $P < .00$; mean difference $_{D\text{-}B}$ = 16.36, $P < .00$; mean difference $_{D\text{-}C}$ = 16.51, $P < .00$).

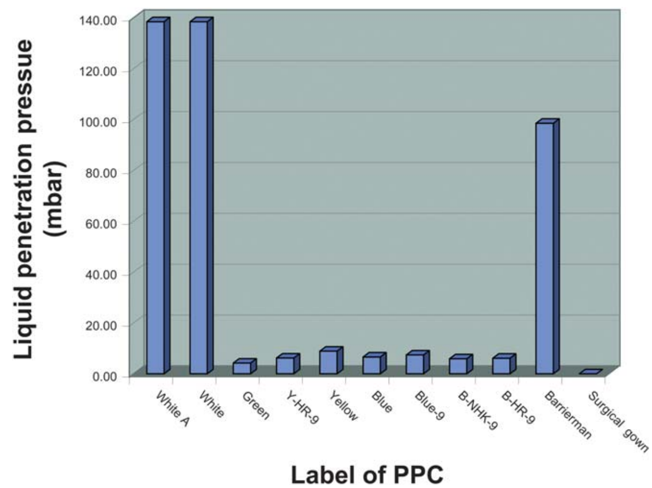

Fig 3. Results of water resistance—hydrostatic pressure test. *PPC*, Personal protective clothing.

Extent of contamination. Several *t* tests were performed to examine differences in contamination at different regions between the first and third trials for each type. When results showed no significant differences, mean values for contamination of the region were computed for subsequent comparison. Table 4 summarizes mean contamination by region for each type.

Fig 5 illustrates the confidence intervals around the mean and reveals a significant contamination of the palm for Type D PPC.

There was a significant difference in the number of contamination sites on the dorsum (F = 6.96, df = 3, $P < .00$) and the palm (F = 5.36, df = 3, $P < .00$) among the groups. For the dorsum, Type D PPC had a significantly higher number of contamination sites (mean difference $_{D\text{-}A}$ = 4.10, $P < .00$; mean difference $_{D\text{-}B}$ = 3.14, P = .01; mean difference $_{D\text{-}C}$ = 4.62, $P < .00$). For the palm, Type D PPC had a significantly higher contamination than Types C and A (mean difference $_{D\text{-}A}$ = 12.76, $P < .00$; mean difference $_{D\text{-}C}$ = 14.60, $P < .00$).

Stage 3: Viral load

On the basis of the aforementioned results, Type A PPC was further tested for increased viral load. Type C PPC was not considered for the viral load test because of its water repellency, air permeability, and water resistance properties and its high contamination over the trunk. Though it had a middle-range usability score, Type A PPC had the shortest take-off time and comparatively minimal contamination overall (Tables 3 and 4). Twenty-two subjects participated in the viral

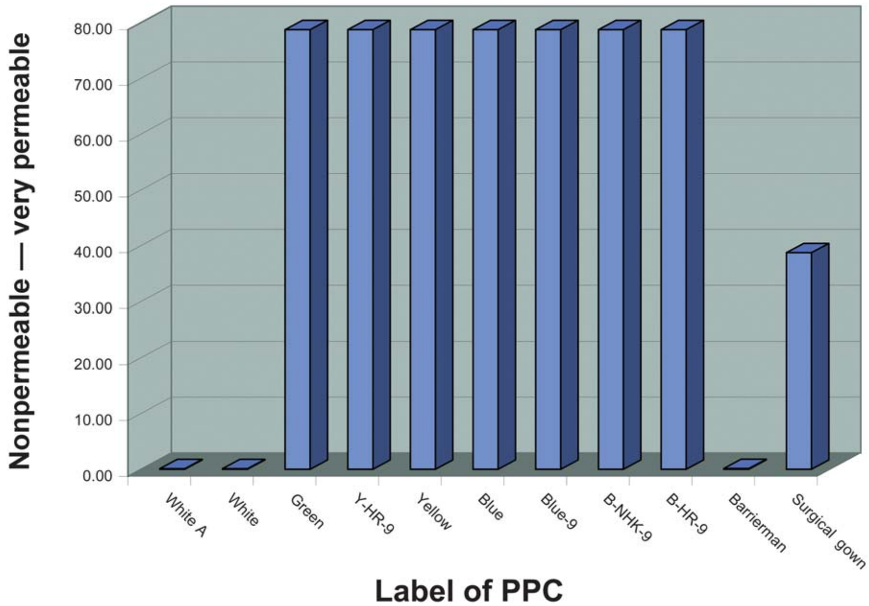

Fig 4. A comparison of the mean contamination (95% CI) at different sites for the 4 PPC. *PPC*, Personal protective clothing.

Table 1. Types of PPC for comparison

Label of the PPC	Water repellency	Air permeability (mL/s cm^2) at 100 Pa	Water penetration resistance	Type
White A	Good	Poor	Good	A
White	Good	Poor	Good	A
Green	Good	Good	Poor	B
Y-HR-9	Good	Good	Poor	B
Yellow	Good	Good	Poor	B
Blue	Good	Good	Poor	B
Blue-9	Good	Good	Poor	B
Blue-NHR-9	Good	Good	Poor	B
BLUE-HR-9	Good	Good	Poor	B
Surgical gown	Poor	Fair	Poor	C
Barrierman	Good	Poor	Fair	D

PPC, Personal protective clothing.

Table 2. Distribution of usability scores (N = 100)

Items in usability questionnaire	Type A PPC (n = 25)	Type B PPC (n = 25)	Type C PPC (n = 25)	Type D PPC (n = 25)
Relevancy of the instruction to use	4.12 (1.20)	4.20 (1.04)	3.76 (1.27)	3.60 (1.35)
Clarity of the instructions for use	3.44 (1.33)	3.56 (1.19)	3.56 (1.42)	3.08 (1.08)
Difficulty in comprehending the instructions for use	2.52 (0.96)	2.96 (0.77)	2.88 (1.09)	3.00 (1.15)
Comfortable to wear	3.80 (1.38)	4.32 (1.11)	4.00 (1.12)	3.64 (1.11)
Easy to put on the PPC	3.68 (1.28)	4.44 (0.96)	3.56 (1.39)	3.08 (1.26)
Easy to take off the PPC	3.28 (1.43)	4.32 (1.11)	3.88 (1.17)	3.28 (1.37)
Satisfaction	3.12 (1.33)	4.28 (1.21)	3.68 (1.35)	3.48 (1.12)
Mean usability score	3.56 (0.76)	4.02 (0.62)	3.65 (0.80)	3.31 (0.58)

PPC, Personal protective clothing.
Values enclosed in parentheses represent mean (standard deviation).

load test. In this stage, each subject was asked to put on a Type A PPC, then received 2 splashes (ie, 2 strokes) of 3.68 mL of diluted stain, sprayed from the nozzle at the trunk from a distance of 18 inches. Subjects took off the PPC, and fluorescent stains were counted. The mean number of spots of contamination over the face, neck, trunk, dorsum, and palm were 0.6 (SD = 1.12), 0.47 (SD = 1.81), 0.4 (SD = 1.12), 0.4 (SD = 0.74), 0.6 (SD = 1.24), respectively. An independent t test was done to examine the difference between 1 stroke and 2 strokes. Results showed a significant difference on face contamination (t = 4.69, df = 38, $P < .00$). There was less contamination with 2 strokes. However, it was noted that mean contamination of the trunk increased from 0.02 to 0.4, though there was no significant statistical difference.

DISCUSSION

The proportion of subjects by gender in this sample reasonably reflects the gender distribution of nursing students in the school. In terms of usability, mean scores of Type A PPC for most items ranked either second or third among the 4 types. Whether or not poor air permeability contributed to this has yet to be determined. Type A PPC took the shortest time for take-off, which may imply ease of use. Type B PPC took longer as compared with Type A. The research team suggests that the light weight and thinness of the materials contribute to this. Because of these physical properties, Type B PPC can be easily lifted in the air, and extra care may be required to avoid contamination. Obviously, Type D PPC took the longest time for take-off, perhaps because its 1-piece construction (ie, from hood to body to trousers) forces users to take off the hood, then unzip the zipper in the front, then remove the trousers. This is a complicated procedure as compared with a conventional gown (ie, tie at the back, without hood and trousers).

Contamination did not differ significantly for the face and neck. However, the trunk was more heavily contaminated in Type C PPC. This may be because of the fabrics used (ie, poor water repellency and poor water resistance). Type B PPC offers poor resistance; thus, with a splash of solution, the fluid actually goes from the outer layer of the fabric to the inner layer. As a result, stains were found on the trunk. However, the research team does not exclude the possibility of contamination, though minimal, during take-off. Both the dorsum and the palm were heavily contaminated as compared with the other regions. This can be explained by the fact that participants used their hands to take off the PPC. However, the significantly high contamination in Types B and D PPC may reflect the design and materials used. Undoubtedly, the results of this study also provide good evidence for the need to thoroughly wash hands, especially the palms, to prevent the spread of infection.[9–12]

The higher viral load did not demonstrate significantly different results in all aspects. This may be because of the feeling of weight over the front of the gown (the weight increased from 1.92 g [with 1 stroke] to 3.68 g [with 2 strokes]). Therefore, participants degowned with extra care. However, it is important to highlight that contamination of the trunk increases. Whether or not this is because of the high volume of splash with 2 strokes has yet to be determined.

Several factors must be considered in deciding which PPC provides best personal protection in terms of contamination. All PPC is similar with respect to face and neck contamination, except for Type D (for which there was no contamination at the neck). For the dorsum and palm contamination, Types B and D PPC were worse than Types A and C. Thus, either Type A or Type C would be preferable. However, when we examined contamination over the trunk, results

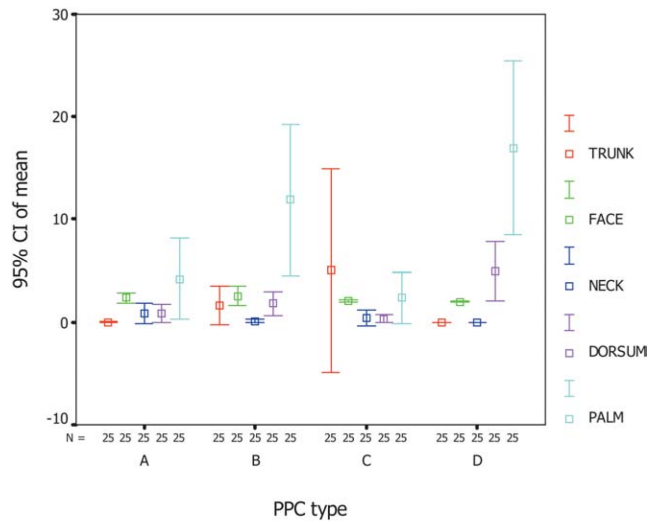

Fig 5. Results of air permeability test. *PPC*, Personal protective clothing.

Table 3. A comparison of put-on and take-off times

Type	Put-on time (seconds)	Take-off time (seconds)
A	48.84 (10.84)	20.05 (5.67)
B	55.53 (14.05)	21.25 (10.64)
C	65.56 (13.03)	21.21 (6.92)
D	82.67 (22.09)	37.61 (13.50)

Values enclosed in parentheses represent mean (standard deviation).

Table 4. The mean contamination by region by type

	Mean contamination				
Type	Face	Neck	Trunk	Dorsum	Palm
A	2.36 (1.19)	0.82 (2.43)	0.02 (0.01)	0.86 (2.11)	4.20 (9.54)
B	2.56 (2.25)	0.12 (0.36)	1.62 (4.47)	1.82 (2.86)	11.92 (17.83)
C	2.08 (0.31)	0.40 (1.80)	5.04 (23.95)	0.34 (0.89)	2.36 (5.93)
D	2.00 (0.14)	0.00 (0.00)	0.00 (0.00)	4.96 (6.94)	16.96 (20.49)

Values enclosed in parentheses represent mean (standard deviation).

showed that Type C PPC was much worse than Type A (Table 4). Data on air permeability (Table 1) suggest that Type A may be best if the PPC is to be disposable and is used for high-risk procedures. On the other hand, Type C may be the better choice for its cost-effectiveness (it can be disinfected and washed), but it is not recommended for procedures at high risk for splash.

A limitation addressed in this study is the size of the particles yielded by the atomizer used, since this could not be determined by the current atomizer. It is suggested that an atomizer with the highest precision be used to provide measurements on force applied per stroke, nozzle size, and pressure within the atomizer.

CONCLUSION

Considering the nature of the fabrics, usability, and possible contamination resulting from an increased viral load, it is suggested that, if a disposable PPC is required, Type A PPC is effective in providing a desirable protective function against droplet splash (though air permeability is poor). However, it must be noted that in real work, droplets are not generally as heavy as those produced in the simulation; thus, Type C PPC, surgical gowns, should still be considered. The cost is low, air permeability is fair, and the level of hand contamination is lowest among the 4 groups in the current study. If heavy splashes or droplets are expected, an additional apron may be worn to protect the trunk.

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