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Durability of fluoropolymer and antibacterial finishes on woven surgical gown fabrics

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Abstract

Commercially available polyester, polyester-cotton and cotton plain woven fabrics of 150 g/m^2 weight and cotton woven fabric samples of 200 g/m^2 weight with plain, twill and satin weave were studied for their suitability as surgical gowns. Water repellent and anti bacterial finishes were applied in single bath using pad-dry-cure method with four concentration levels of these finishes. Liquid barrier properties of samples were analyzed by water impact penetration and hydrostatic pressure test. Parallel streak method was used to measure the antibacterial activity on the fabric samples with *Staphylococcus aureus*. The fabric samples were also analyzed for air permeability and stiffness. Optimum concentration level of fluoropolymer and antibacterial finishes for achieving desired liquid barrier and antibacterial properties were determined for each fabric samples. Fabric samples were subjected to repeated laundering cycles to evaluate the durability of finishes.
It was observed that polyester fabric samples and 200 g/m^2 cotton twill woven fabrics show highest level of liquid barrier protection of Level 2 according to Association for the Advancement of Medical Instrumentation (AAMI) standards, with 4% and 7% fluoropolymers. The fabrics maintain their barrier protection upto 20 laundering cycles, whereas 100% cotton fabric samples show minimal liquid barrier protection and do not provide Level 2 protection even at 4% and 7% fluoropolymer.

Keywords: Air permeability; Antibacterial; Fluoropolymer; Hydrostatic; *Staphylococcus aureus*; Water repellency

Introduction

Surgical gowns address a dual function of preventing transfer of microorganism and body fluids from operating staff to the patient and also from patient to operating staff (CDC 1998; Huang & Leonas 2000; Laufman et al. 1979; Slater 1998). Several organizations like Centers for Disease Control and Prevention (CDC), Association of Peri-operative Registered Nurses (AORN), Occupational Safety and Health Administration (OSHA), The Operating Room Nurses Association of Canada (ORNAC), and the Association for the Advancement of Medical Instrumentation (AAMI) have made recommendations on how to protect surgical staff as well as patients from exposure to blood borne pathogens and bacteria (AAMI 2003; Slater 1998). AAMI standard, PB70:2003 provides four classification levels for barrier performance of surgical gowns (Table 1). Using these classification levels, manufacturers are able to label their products according to the level of protection provided and healthcare workers are able to identify the level of protection that the product provides, so they may choose the appropriate barrier needed for their procedure. A wide range of

Table 1 AAMI classification levels

AAMI classification levels			
Level	**Test**	**Result**	**Test**
1	AATCC 42	≤ 4.5 g	Impact penetration test
2	AATCC 42	≤ 1 g	Impact penetration test
	AATCC127	≥ 20 cm	Hydrostatic pressure test
3	AATCC 42	≤ 1 g	Impact penetration test
	AATCC127	≥ 50 cm	Hydrostatic pressure test
4	ASTM F1670	Pass	Synthetic blood test
	ASTMF1671	Pass	Bacteriophage test

disposable (single-use), reusables and reinforced surgical gowns are available (Behera and Arora 2009; Garibaldi et al. 1986; Lankester et al. 2002; Laufman et al. 1975; Leonas and Jinkins 1997; Leonas 1998; Olderman 1984; Pamuk et al. 2009; Parthasarathi and Thilagavathi 2011; Rutala and Weber 2001; Smith and Nichols 1991; Virk et al. 2004). Disposable surgical gowns offer several advantages over reusables, but they are expensive and pose a risk of contamination outside of the hospital setting. Reusable gowns are generally made from woven fabrics and often contain cotton, polyester or a blend of these two fibres. The reusable surgical gowns are laundered and sterilized after every use in order to remove stains and kill bacteria. The greater advantage with reusable surgical gowns include less solid waste from limited disposal and more comfort to the wearer because of their better water vapour transmission. However they lose durability and barrier protection after repeated washing (Laufman et al. 1975). Several researchers reported that water repellency and antibacterial resistance can be improved by applying water repellent and antibacterial finishes to the fabric (Brock et al. 1994; Garibaldi et al. 1986; Gupta 1998; Laufman et al. 1975; Leonas and Miller 1990; Leonas 1997; Leonas, 1998; Leonas and Jinkins, 1997; Olderman 1984; Smith and Nichols 1991; Midha et al. 2012). Fluorocarbon-based finishes are most commonly used in protective apparels for reducing the surface energy of the fabric sufficiently to repel both water and oil-based liquids.

In this paper, different concentration levels of fluoropolymer and antibacterial finishes were applied on woven fabrics of different weave and fibre content. Their performance with respect to barrier resistance, air permeability and stiffness has been studied. The fabrics were subjected to repeated laundering cycles for evaluating the durability of water repellent and antibacterial finishes.

Methods

Plain, twill, satin woven fabrics with different weaves and area density were used in the study. Fabrics A-C are plain weave structures of 150 g/m^2 made from different fibre materials but almost same mean flow pore diameter. Sample D-F are 200 g/m^2 cotton fabrics with different weave structures (Table 2) and hence different pore diameter.

A fluoropolymer 'Clarient Nuva SRCN liq' was used to impart the liquid repellent properties. 'Zydex Zycrobial' non-leaching type antibacterial finish, a quaternary ammonium salts based compound was used to impart antibacterial properties on surgical gowns.

Water repellent and antibacterial finishes were applied on the fabric samples in a single bath after checking their compatibility. Three concentration levels of

Table 2 Characteristics of fabric samples

Sample	Fibre composition	Fabric weight (g/m^2)	Weave	Warp density (ends/cm)	Weft density (picks/cm)	Warp linear density (Tex)	Weft linear density (Tex)	Fabric thickness (mm)	Mean flow pore diameter (microns)
A	100% PET	150	Plain	356	538	8	12	0.232	46.09
B	65/35 PC*	150	Plain	249	173	24	24	0.300	42.87
C	100% cotton	150	Plain	325	157	20	20	0.304	47.72
D	100% cotton	200	Plain	290	173	30	20	0.582	30.27
E	100% cotton	200	2/1Twill	320	203	20	30	0.531	26.84
F	100% cotton	200	5 Ends	457	234	17	20	0.500	62.97

*Note: PC- Polyester cotton blend.

fluoropolymer finish (i.e. 1%, 4% and 7% on weight of fibre) were co-applied with 1%, 1.5% and 3% (on weight of fibre) of antibacterial finish. The pad dry cure process was used for the application of finishes. The fabric samples were immersed in the stock solution prepared according to the required concentration levels, followed by padding through squeezed rollers to get 70% wet pick-up. After padding, the fabrics were dried at 90°C and then cured at 140-150°C for two minutes. The treated and untreated fabric samples were tested for water repellence, antibacterial activity, air permeability and stiffness.

Impact penetration test was performed according to the AATCC 42, wherein 500 ml of distilled water was poured on standard blotter paper of 152 × 230 mm inserted beneath the 178 × 330 mm test specimen on an inclined surface. The amount of water passing through the fabric is given by the change in weight of the blotting paper, which is used as an indication of water repellence of fabric. Five readings were taken and the average calculated. Hydrostatic pressure test was performed according to AATCC-127 to measure the force required by water to penetrate through a textile material under a water pressure constantly increasing at 10 ± 0.5 cm per minute, until three leakage points appear on its surface. Five readings were taken and the average calculated.

Parallel streak method was used to determine the antibacterial property of the fabric samples according to AATCC 147. *Staphylococcus aureus*, a pathogenic gram positive bacterium was used in the study, since it is most commonly present in human body fluids. In this test, five streaks of *S. aureus* were inoculated onto nutrient agar plate approximately 60 mm in length, spaced 10 mm apart covering the central area of Petri dish without refilling the loop. The fabric specimen of 40 mm diameter was placed in intimate contact with the agar previously streaked with the inoculums of *S.aureus.* The plate was incubated at a temperature of 37°C for 24 hours. After incubation, a clear area of interrupted growth underneath and along the sides of the test material indicates antibacterial activity of the specimen. Five readings were taken for each sample.

Air permeability of fabric samples was measured by Textest air permeability tester according to ASTM standard D737. The air permeability was measured as volume of airflow in cubic centimetres passed per second through 1 cm^2 of the fabric at a pressure of 98 N/m^2. The 20 × 20 cm^2 specimen was clamped on the holder in such a way that a 5 cm^2 area, exposed to test is sufficiently away from the edges in order to avoid the edge leakage. Ten readings were taken and the average calculated. The stiffness of the fabric samples was measured on Shirley stiffness tester using circular bend test method according to ASTM D4032. The maximum force required by a plunger (25.4 cm diameter) to force a flat, folded fabric swatch through an orifice (of 38.1 mm in a platform of

102 mm × 102 mm × 6 mm) for a stroke length of 57 mm is an indication of the fabric stiffness. Ten readings were taken and the average calculated.

Fabric thickness was measured by Shredor thickness gauge according to ASTM standard D5736 and weight of fabric was determined according to ASTM standard test method D3776 using an electronic balance. Ten readings were taken and the average calculated. Mean flow pore diameter was measured according to ASTM standards D6767 on 'PMI Capillary flow porometer (CFP- 1100 AN)' using a sample size of 2.5 mm diameter. Five readings were taken and the average calculated.

The treated fabric samples were subjected to 1, 5, 10, 15 and 20 laundering cycles to check the durability of finishes with laundering cycles. Laundering was performed according to AATCC Test Method 124–2007. Wash settings were hot wash (62 ± 3°C), large load (18 ± 1 gallons of water), warm rinse (41 ± 3°C) and regular spin. The fabric samples were washed with $1\frac{1}{2}$ cups of detergent 'Tide' for 10 min. The samples were subsequently air-dried at room temperature and heat-pressed. Heat pressing helps in partially restoring the liquid repellence lost during laundering. Statistical significance tests were performed to check the effect of fabric material, fabric weave, level of antibacterial and fluoropolymer finishes on the fabric barrier properties.

Results and discussions

The fabric samples were tested for water repellence, antibacterial acitivity, air permeability and stiffness force before and after applying different concentration levels of fluoropolymer and antibacterial finishes.

Water repellence

Table 3 shows the liquid barrier and antibacterial characteristics of untreated fabric samples. It is observed that among 150 g/m^2 plain fabrics (i.e. sample A, B and C), the weight of water penetrating through the fabric during impact penetration is highest for 100% cotton fabric and least for 100% polyester fabrics. Similarly, the hydrostatic pressure head value is least for 100% cotton and highest for 100% polyester fabric. The results are statistically significant at 95% confidence level. The polyester fabric shows highest water repellence, whereas 100% cotton fabric shows least water repellence due to lower surface tension of polyester fibres as compared to cotton fibres. Cotton fibres immediately absorb water and therefore the fabrics offer least water repllence. According AAMI barrier performance classification, all the fabrics except 100% cotton fabric of 150 g/m^2 (i.e. fabric C) can be used for level 1 protection only. 100% cotton 150 g/m^2 fabric is not suitable for even level 1 protection for surgical gowns.

Table 3 Properties of untreated fabric samples

Sample	Impact penetration (g)	Hydrostatic pressure (cm)	Antibacterial activity	Air permeability (cm^3/cm^2/sec)	Stiffness force (N)
A	1.53	6.5	Fail	6.62	1.05
B	1.72	5.3	Fail	6.17	1.02
C	4.97	4.5	Fail	5.86	1.10
D	0.97	6.0	Fail	4.67	2.43
E	0.73	9.0	Fail	2.98	2.90
F	1.17	4.3	Fail	13.29	2.10

Table 4 Liquid barrier properties of treated fabric samples

Experimental conditions			Impact penetration (g)						Hydrostatic pressure (cm)					
	Antibacterial finish (%)	Water repellent finish (%)	A	B	C	D	E	F	A	B	C	D	E	F
1.	0	1	0.91	1.32	3.51	0.56	0.42	0.86	14.5	14.0	7.9	17.0	18.5	15.5
2.	0	4	0.70	0.68	2.54	0.45	0.31	0.54	22.5	20.6	13.6	25.3	28.5	20.5
3.	0	7	0.49	0.64*	1.30	0.35	0.24	0.43	25.7	22.9	16.1	27.0	32.7	22.3
4.	1	1	0.96	1.29	3.27	0.53	0.41	0.81	15.2	13.9	9.3	18.2	19.0	16.5
5.	1	4	0.72	0.61	2.52	0.41	0.27	0.55	23.2	21.4	14.7	25.8	29.5	21.0
6.	1	7	0.46	0.53	1.30	0.29	0.24	0.38	26.6	23.5	16.8	27.8	32.3	22.9
7.	1.5	1	0.96	1.06	3.12	0.47	0.37	0.84	15.5	15.3	9.5	17.9	19.0	16.5
8.	1.5	4	0.64	0.59	2.30	0.39	0.28	0.51	24.4	22.3	15.1	25.9	29.5	21.4
9.	1.5	7	0.41	0.56	1.19	0.28	0.25	0.36	28.0	23.9	17.1	27.8	34.7	23.1
10.	3	1	0.89	0.90	3.16	0.43	0.36	0.76	16.1	15.9	10.3	18.7	19.5	17.3
11.	3	4	0.57	0.54	2.01	0.36	0.24	0.39	26.6	23.0	15.7	26.0	29.0	22.0
12.	3	7	0.42	0.53*	1.03	0.23	0.21	0.30	29.7	24.2	17.5	29.0	36.0	24.0
13.	1	0	1.56#	1.69#	4.57	0.89	0.59*	1.03	6.8#	6.1	5.5*#	5.8#	9.2#	4.9
14.	1.5	0	1.49#	1.62*	4.49	0.82*	0.58*	0.96	6.9*#	7.1	5.4*#	6.7*#	9.0*#	4.8*
15.	3	0	1.43*	1.54	4.23	0.79*	0.54*	0.91	7.7*	7.2*	6.3*	8.0*	11.1	5.7
16.	0	0	1.53	1.72	4.97	0.97	0.73	1.17	6.5	5.3	4.5	6.0	9.0	4.3

Note: '*' means results are statistically insignificant at 95% confidence level with respect to finish level & '#' means results are with respect to untreated fabric.

Table 4 shows the results for samples treated with fluoropolymer (1%, 4% and 7%) and antibacterial finish (1%, 1.5% and 3%). It is observed that, impact penetration decreases and hydrostatic pressure increases with increase in concentration level of fluoropolymer at all levels of antibacterial finish.

Application of fluoropolymer finish reduces the surface energy of the fabric and does not permit the water or other fluids to adsorb and spread on the fabric surface. The difference in water repellence is significant at 1% and 4% concentration level of fluoropolymer, but when the concentration level increases to 7%, the difference is insignificant, which may be due to the fact that the fluoropolymer has already linked with functional groups of the polymer. 100% polyester and polyester cotton fabrics treated with 4% and 7% fluorpolymer reach hydrostatic pressure level of more than 20 cm and therefore can be used for level 2 protection as per AAMI barrier classification, whereas 100% cotton fabric can provide only level 1 protection even on application of 7% fluoropolymer finish.

Among plain, twill and satin cotton fabric samples of 200 g/m^2 (i.e. sample D, E and F), twill fabrics offer highest water repellence with least impact penetration and highest hydrostatic pressure, whereas satin woven structure offers the least water repellence. The trend is same even after the application of fluoropolymer and antibacterial finish. The results are statistically significant at 95% confidence level. Longer float in the satin weave inspite of finer yarns and higher yarn density, leads to larger pore size (62.97 μm) and long capillary formation that enhance the movement of the liquid through the fabric (Tables 2 and 3). Plain and twill fabric have smaller pore sizes of the order of 26–30 μm. The plain weave with its simple and regular interlacing pattern is susceptible to capillary forces that enhance the movement of the liquid through the fabric. Whereas in twill fabrics, the orientation of the yarns or fiber to

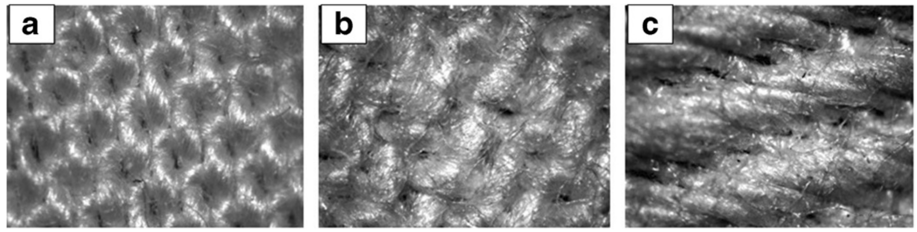

Figure 1 Microscope images of 100% cotton woven fabric samples of 200 g/m^2: (a) plain, (b) twill and (c) satin.

one another is disrupted; capillaries are shorter, which reduce the liquid flow. Figure 1 shows the microscopic images of these fabrics.

All the fabrics provide level 2 protection as per AAMI barrier classification after application of 4% and 7% fluoropolymer finish. The highest level of hydrostatic pressure achieved is 36 cm by the twill woven fabric after application of 7% fluoropolymer finish.

200 g/m^2 plain woven cotton fabric shows higher hydrostatic pressure than 150 g/m^2 weight of fabric at all concentration levels of fluoropolymer. Thicker yarns in the heavier fabric are responsible for smaller pores and hence better water repellence as compared to lighter fabrics (Table 2). Table 5 shows the effect of laundering on hydrostatic pressure for fabric samples which passed AAMI barrier protection level two. It is observed that 100% polyester plain woven fabric of 150 g/m^2 weight treated with 7% fluoropolymer maintains its liquid barrier properties for AAMI level-2 protection up to 20 washing cycles. 150 g/m^2

Table 5 Effect of laundering on hydrostatic pressure of fabric samples

Sample	Experimental conditions		Hydrostatic pressure(cm)						
	Antimicrobial finish (%)	Water repellent finish (%)	0 wash	1 wash	2 wash	5 wash	10 wash	15 wash	20 wash
A	1.5	4	24.4	22.3	22.1	21.0	20.2	18.3	16.3
	1.5	7	28.0	26.1	25.7	23.5	21.3	19.6	19.7
	3	4	26.6	23.9	23.6	22.0	20.3	20.0	19.5
	3	7	29.7	25.8	24.2	23.7	23.0	21.1	20.3
B	1.5	4	22.3	21.0	21.2	20.3	18.8	17.2	14.3
	1.5	7	23.9	21.3	21.0	20.6	18.5	15.6	13.1
	3	4	23.0	21.4	19.6	19.2	17.6	15.1	13.5
	3	7	24.2	22.3	19.7	19.1	17.9	16.3	14.2
D	1.5	4	25.9	23.8	23.5	23.0	21.5	19.8	17.2
	1.5	7	26.9	24.1	23.7	23.1	22.3	21.3	20.2
	3	4	26.0	23.7	23.0	22.6	21.9	19.5	18.1
	3	7	29.0	26.0	25.4	22.3	21.6	19.6	18.6
E	1.5	4	29.5	27.6	27.0	26.3	23.9	21.5	20.4
	1.5	7	34.7	31.2	29.3	28.4	25.9	23.4	22.7
	3	4	29.0	27.3	26.0	24.7	22.7	21.0	19.3
	3	7	36.0	32.0	31.2	28.6	26.1	23.7	22.2
F	1.5	4	21.4	20.9	20.1	18.8	16.5	15.1	13.9
	1.5	7	23.1	21.0	21.0	19.3	17.4	15.3	14.7
	3	4	22.0	20.2	20.0	19.4	16.9	14.6	13.4
	3	7	24.0	21.6	21.4	20.1	17.8	16.7	14.1

polyester-cotton plain woven fabrics treated with 4% and 7% fluoropolymer loose their liquid barrier properties and could not maintain AAMI level-2 protection even upto 10 washing cycles. 200 g/m^2 cotton plain fabrics treated with 7% fluoropolymer maintain their liquid barrier properties for AAMI level-2 protection upto 15 washing cycles. 200 g/m^2 cotton twill fabrics treated with 4% and 7% fluoropolymer maintain their liquid barrier properties for AAMI level-2 protection even after 20 washing cycles. 200 g/m^2 cotton satin fabrics treated with 4% and 7% fluoropolymer loose their liquid barrier properties for level-2 protection after 5 washing cycles.

Antibacterial activity

Table 3 shows the results of antibacterial activity on untreated fabrics, whereas Table 6 shows the results of antibacterial activity on the fabric samples treated with different levels of fluoropolymer and antibacterial finishes.

It is observed that fabric samples with 1.5% and 3% antibacterial finish pass the antibacterial activity test. Figure 2 (a-b) shows the antibacterial activity test on polyester-cotton fabrics without antibacterial finish and with 1% antibacterial finish respectively. It is observed that the bacterial growth is not inhibited by both the samples. Untreated fabrics show the growth of bacteria in the streaks of the inoculums, spread beyond the parallel streaks and even beneath the fabric sample, whereas 1% antibacterial finish on the fabric shows spreading of bacteria in the parallel streaks only.

Figure 2 (c-d) shows the bacterial inhibition under the fabric samples for 1.5% and 3% concentration for plain cotton fabric samples. The antibacterial finished fabric inhibits bacterial growth beneath the fabric. 1.5% or greater concentration levels of the antibacterial finish on all the fabrics is sufficient to inhibit the growth of *S. aureus*. Further, it is observed that the effectiveness of the antibacterial finish is not influenced by the level of fluoropolymer finish. The type of fabric had also no influence on the effectiveness of the antibacterial finish necessary to achieve the antibacterial activity. Further it is observed that all the fabrics used in study treated with 1.5 and 3% concentration level of antibacterial finishes maintain their effectiveness even after 20 washing cycles.

Air permeability

Among 150 g/m^2 fabrics of different materials (i.e. sample A, B and C) air permeability is highest for 100% polyester filament fabric because of smooth and hairiness free yarns (Table 3). Hairy yarns in 100% cotton and cotton blends offers more resistance to air flow and therefore lead to lower air permeability. Among plain, twill and satin fabrics of 200 g/m^2 weight (i.e. sample D, E and F), satin woven fabric offers highest air permeability, whereas twill fabric shows the least. This is due to the longer floats and larger pore sizes (Table 2) in satin structure. Twill fabric with compact structure offer the lowest air permeability. Further, air permeability decreases as the fabric weight increases due to compact structure with smaller pores and higher thickness.

It was observed that the air permeability decreases on the application of antibacterial and fluoropoylmer finish for all samples (Table 7). The results are statistically significant at 95% confidence level. The application of chemical finishes over the fabric surface results in blocking of some pores, which may be responsible for the reduction of air permeability.

Table 6 Fabric thickness and antibacterial activity of finished fabric samples

	Experimental conditions		Fabric thickness (mm)						Antibacterial activity					
	Antibacterial finish (%)	Water repellent finish (%)	A	B	C	D	E	F	A	B	C	D	E	F
1.	0	1	0.236	0.309*	0.309	0.600	0.540*	0.504#	-	-	-	-	-	-
2.	0	4	0.237*	0.312*	0.312	0.601*	0.541*	0.507*	-	-	-	-	-	-
3.	0	7	0.241	0.316*	0.317	0.603*	0.543	0.514	-	-	-	-	-	-
4	1	1	0.234#	0.308	0.313	0.599	0.539	0.509	-	-	-	-	-	-
5.	1	4	0.237#	0.315	0.315*	0.603*	0.547*	0.517	-	-	-	-	-	-
6.	1	7	0.241	0.322	0.319#	0.608*	0.548	0.518	-	-	-	-	-	-
7.	1.5	1	0.232	0.310	0.310	0.620	0.541	0.514	Pass	Pass	Pass	Pass	Pass	Pass
8.	1.5	4	0.234	0.317*	0.311*	0.619*	0.546*	0.520	Pass	Pass	Pass	Pass	Pass	Pass
9.	1.5	7	0.241	0.319	0.321	0.623	0.550	0.524*	Pass	Pass	Pass	Pass	Pass	Pass
10.	3	1	0.232#	0.312	0.310	0.610	0.540	0.510	Pass	Pass	Pass	Pass	Pass	Pass
11.	3	4	0.241	0.319	0.316	0.620	0.554	0.520	Pass	Pass	Pass	Pass	Pass	Pass
12.	3	7	0.249	0.322*	0.321#	0.623	0.561*	0.526*	Pass	Pass	Pass	Pass	Pass	Pass
13.	1	0	0.232#	0.304	0.306#	0.588	0.530#	0.510	-	-	-	-	-	-
14.	1.5	0	0.232*#	0.305	0.310	0.590	0.533*	0.514	Pass	Pass	Pass	Pass	Pass	Pass
15	3	0	0.236	0.309	0.312	0.610	0.541	0.520	Pass	Pass	Pass	Pass	Pass	Pass
16.	0	0	0.232	0.304	0.303	0.582	0.531	0.500	-	-	-	-	-	-

Note: (–) Sign means the fabric samples fails the test.

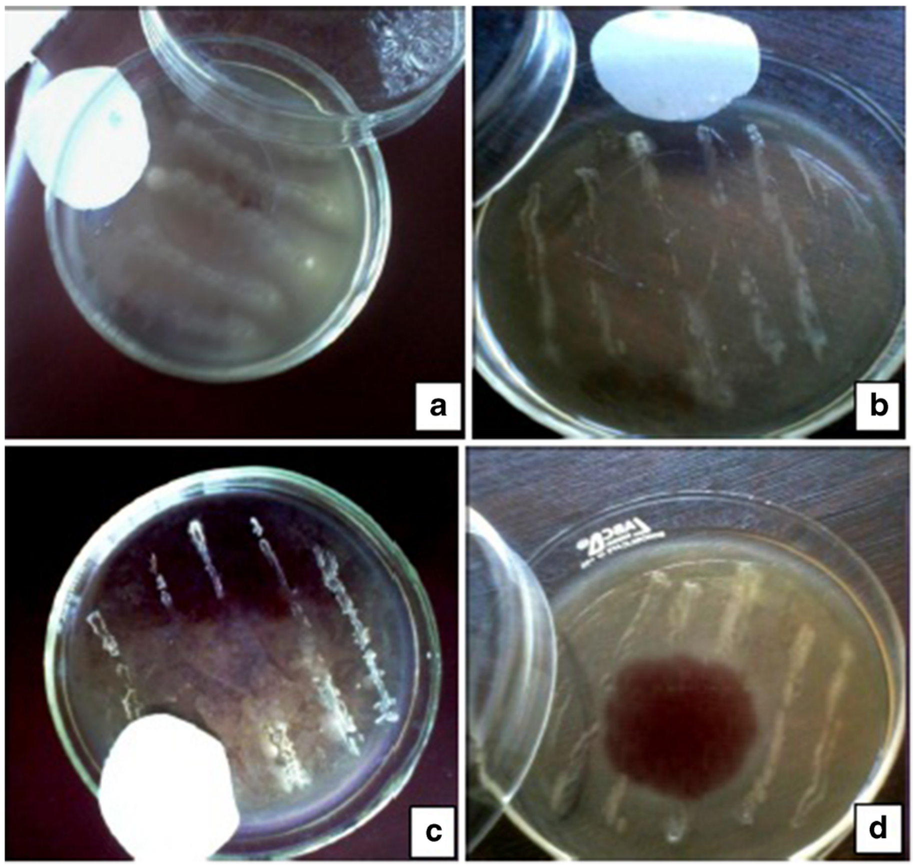

Figure 2 Growth of bacteria in parallel streaks: (a) untreated polyester cotton 150 g/m^2 fabric; (b) 150 g/m^2 polyester-cotton blend fabric treated with 1% antibacterial finish; (c) 200 g/m^2 cotton fabric treated with 1.5% antibacterial finish; (d) 200 g/m^2 cotton fabric treated with 3% antibacterial finish.

Fabric stiffness force

150 g/m^2 plain fabrics (i.e. sample A, B and C) do not show any significant difference in their fabric stiffness. Among plain, twill and satin fabrics of 200 g/m^2 weight (i.e. sample D, E and F), it is observed that satin fabric with longer floats and few interlacement points offer lower stiffness than plain and twill fabrics. More regular pattern in plain weave and diagonal line pattern in twill weave make the fabric stiffer. Heavier fabric with coarser yarns offers higher stiffness as compared to lighter fabrics. Further, the stiffness force increases with increasing concentration level of antibacterial and fluoropolymer finishes for all fabric samples which may be due to increase in fabric thickness. Results are statistically significant at 95% confidence level. The fabric samples shows highest stiffness at concentration level of 3% antibacterial finish and 7% of fluoropolymer finish.

Out of 100% polyester, polyester-cotton and 100% cotton plain woven fabric samples of weight 150 g/m^2, 100% polyester fabric shows least stiffness and highest air permeability value.Twill fabrics are less comfortable as compared to plain and satin fabrics, because of their higher stiffness and lower air permeability values. Satin fabric offers the highest air permeability and lowest stiffness force but shows least barrier protection.

Table 7 Air permeability and stiffness properties of treated fabric samples

	Experimental conditions		Air permeability ($cm^3/cm^2/sec$)						Stiffness force (N)					
	Antibacterial finish (%)	Water repellent finish (%)	A	B	C	D	E	F	A	B	C	D	E	F
1	0	1	6.51	6.06	5.62	4.55	2.95#	12.43	1.03#	1.07	1.13#	2.43#	3.10	2.20
2	0	4	6.09	5.87	5.18	4.38	2.84	12.13	1.10#	1.20	1.20	2.50	3.40	2.33
3	0	7	5.83	5.69	5.15	4.27	2.69	11.25	1.15*	1.28	1.40	3.10	3.90	2.63
4	1	1	6.21	5.93	5.39	4.54	2.84	12.15	1.15	1.20	1.27	2.70	3.40	2.44
5	1	4	5.94	5.89	5.32*	4.40	2.81	12.10*	1.18*	1.22	1.40	2.87	3.50*#	2.50
6	1	7	5.56	5.64	5.15	4.21	2.81	11.69	1.20*	1.30	1.43*	3.60	3.90	2.70
7	1.5	1	6.25	5.87	5.34	4.44	2.87	12.31	1.28	1.32	1.30	2.90	3.50#	2.67
8	1.5	4	5.93	5.77	5.32	4.25	2.80	11.68	1.38	1.40	1.40	3.60	4.10	2.83
9	1.5	7	5.85	5.58	5.23	4.15	2.61	11.55	1.50	1.47	1.73	3.72	4.60	3.20
10	3	1	6.13	5.74	5.31	4.33	2.89	11.62	1.30	1.30	1.53	3.60	4.00	2.90
11	3	4	5.83	5.66	5.29*	4.21	2.78	11.45	1.48	1.53	1.67	3.60*	4.40	3.00*
12	3	7	5.82*	5.61	5.18	4.13	2.55	11.36	1.80	2.00	2.06	3.93	4.80	3.50
13	1	0	6.53	6.09	5.74	4.59	2.89	12.55	1.03#	1.02#	1.10#	2.63	3.40	2.20
14	1.5	0	6.47	5.90	5.62	4.54	2.83	12.43	1.13	1.10	1.20	3.10	3.70	2.48
15	3	0	6.39	5.85*	5.31	4.47	2.69	11.23	1.23	1.20	1.30	3.30	4.20	2.53*
16	0	0	6.62	6.17	5.86	4.67	2.98	13.29	1.05	1.02	1.10	2.43	2.90	2.10

Note: '*' means results are statistically insignificant at 95% confidence level with respect to finish level & '#' means results are statistically insignificant at 95% confidence level with respect to untreated fabrics.

Conclusion

Plain, twill and satin woven fabrics of cotton, polyester and polyester-cotton of 150 g/m^2 and 200 g/m^2 have been used to study their suitability for surgical gowns before and after application of flouropolymer and antibacterial finishes. Different concentration levels of fluoropolymer and antibacterial finishes were used to find the level of finishes required for different AAMI protection levels along with their durability using standard laundering cycles. It is observed that all the fabrics except 150 g/m^2 cotton fabric, can be used for AAMI protection level 1 only without any finish. The water repellence of fabrics increases on application of fluoropolymer finish. 4% fluoropolymer finish on these fabrics can be used to make them suitable for AAMI protection level 2. Increasing fluropolymer concentration level further increases the hydrostatic pressure but does not make them suitable for protection level 3 and therefore are not recommended for critical areas of the surgical gown. Twill woven fabrics of 200 g/m^2 show highest hydrostatic pressure, but higher stiffness and low air permeability make them quite uncomfortable for longer duration usage. Satin fabrics are more comfortable offering higher air permeability and lower stiffness, but show lowest hydrostatic pressure values and therefore offer minimal water repellence. Repeated laundering cycles lead to reduction in the barrier resistance of fabrics. It is observed that 150 g/m^2 polyester and twill woven 200 g/m^2 cotton fabrics with 4% fluoropolymer finish maintain their AAMI protection level 2 upto 20 washing cycles. Satin woven fabrics treated with 4% fluoropolymer finish can maintain AAMI protection level 2 upto 5 washing cycles only. 1.5% antibacterial finish is sufficient to inhibit the growth of *S. aureus* bacteria for all fabric samples and this antibacterial activity is maintained upto 20 washing cycles for all fabrics.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
VKM and RV contributed to the conception and design of the study, and analysis of data. VM contributed to procurement of bacteria and antibacterial testing of the fabrics. All authors prepared and approved the final manuscript.

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