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The evaluation of fabrics in relation to their use as protective garments in nursing and surgery. III. Wet penetration and contact transfer of particles through clothing

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SUMMARY

A method is described for comparing the resistance to penetration by aqueous fluids, under rubbing contact, of a representative series of fabrics. Untreated woven fabrics are rapidly penetrated, but some non-woven synthetic materials resist penetration for much longer and tightly woven proofed cotton fabrics for prolonged periods, even after repeated washing and sterilizing. If a wetting agent is added to water, penetration occurs more quickly, but fabrics containing natural cotton are penetrated more slowly by serum.

The same fabrics were examined by a test designed to simulate transfer of dry particulate material, e.g. skin scales, through them during nursing contact. The proportionate differences observed were much greater than for air dispersal during exercise and closely resembled those obtained by a laboratory rubbing test. In particular, one of the non-woven fabrics showed much greater relative penetration when examined by these methods than the relative dispersal of skin scales through it during exercise.

INTRODUCTION

In previous papers (Lidwell & Mackintosh, 1978; Lidwell, Mackintosh & Towers, 1978) we have described the behaviour of various fabrics, which have been or might be used in protective garments for operating room staff or nurses, when subjected to a variety of tests. Trousers were made from these fabrics and worn by a group of volunteers. The dispersion of airborne skin organisms during standardized exercise was then estimated and the effectiveness of each fabric in reducing this compared with the earlier test results (Lidwell *et al.* 1978). This procedure simulates one aspect of the function of protective garments for operating room use. Penetration of bacteria during contact between medical personnel and patients is also of potential significance as a means for transferring infection and is

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Table 1. *Fabrics tested*

Name	Code	Description	Weight (g/m^2)
White sheeting	WS		150
Nylon taffeta	NT	34 × 52 threads/cm	66
Balloon cotton	B	Ex-surgical gown	163
Utopia plus	U	65% dacron, 35% cotton	200
Featherproof cotton	F	Herringbone weave	230
Johnson & Johnson '450'	J2	60% terylene, 40% cellulose non-woven	65
Johnson & Johnson Dexter	J1	88% cellulose, 12% nylon non-woven	80
Tyvek 1443	T	100% polyolefin, spunbonded	43
'Ceramic' terylene 8085	C	100% terylene	110
Ventile 'L34'	V	Proofed cotton	155
Quarpel-proofed Pima cotton	P	100% cotton	195

probably the most important one in relation to nursing activities. Penetration of this kind may be relevant in either direction through the fabric. Bacteria may pass from infected patients, from their skin, infected wounds or secretions, or from contaminated fomites, through the nurses' protective clothing and contaminate their skin or underwear. They may also pass from the nurses' skin or underwear through protective garments to the patient. These organisms may be either those carried as part of the nurses own bacterial flora or organisms which have been acquired previously when nursing another patient.

Experiments by Dr Hambraeus and her colleagues in a burns unit at Uppsala University Hospital (Hambraeus, 1973*a*, *b*; Hambraeus & Ransjö, 1977) have shown that the protective garments worn and studied there had only a limited effect in reducing the transfer of microorganisms from patient to patient, and that contact was the most likely route of transfer. They also suggested (Ransjö & Hambraeus, 1979) that contact involving wet secretions might be of major significance under these circumstances.

We have therefore devised a method for testing fabrics for resistance to penetration by water under conditions of rubbing contact and a procedure for simulating contact transfer of dry particulate material through fabrics worn as protective garments. These tests have then been used on the fabrics assessed in our previous papers. For convenience, a description of these fabrics is given in Table 1.

MATERIALS AND METHODS

Resistance to penetration by fluids

The machine used for assessing penetration by dry particles (Lidwell & Mackintosh, 1978) was modified as follows. Two 8·5 cm disks of cellulose sponge (Spontex) were placed in the Petri dish, forming a layer about 11 mm thick. These were wetted with 20 ml of fluid, tap water or other aqueous liquid. Over the Petri dish was placed an 11 cm square of the fabric to be tested and on top of this a similar sized, weighed, piece of clean dry white cotton sheeting (approximately 150 g/m^2). These were held in place by the lid of a plastic Petri dish in which an 8 cm diameter

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hole had been cut. The assembly was then placed on the rotating table and held in position by three light spring clips. (The upper fabric holder of the original apparatus was not used and the pawl for lifting the rubber arm removed.) The machine was then set in motion so that the glass spreader was rubbed to and fro over the upper surface of the cotton sheeting under a pressure of 44 g. At suitable intervals the machine was stopped, the fabric assembly removed and the cotton sheeting weighed to estimate the mass of water which had passed through the test fabric. The fabric assembly was then returned to the machine for a further period of rubbing.

As it seemed likely that the wetting characteristics of the fluid might significantly influence the rate of liquid penetration, tests were done with tap water, with an 0·5% aqueous solution of 'Teepol' (British Drug Houses) and with serum (fetal or new-born calf). Fabrics intended for repeated use, i.e. the cotton materials, were also tested after laundering, at 60 °C in an automatic washing machine (programme 2) using a household detergent. The laundering process was repeated up to 11 times for the proofed materials, Ventile and Quarpel-proofed Pima. The fabrics were tested unironed after washing, after ironing with a steam iron and after subsequent autoclaving at 20 lb (140 kN/m^2) for 20 min.

More than 150 runs were carried out. Not every combination of treatment and test fluid was examined.

Penetration of dry particles in simulated nursing contact

Test particles

It was decided to use fluorescent particles since these could be readily observed under ultraviolet illumination. The material used was activated cadmium sulphide (supplied by Derby Co., Code 163G). This was a granular material with a median particle size of 10 μm (geometric S.D. = 1·9).

Source

About 50 g of the powder was enclosed in a pouch of loosely woven cotton fabric approximately 9 × 9 cm, closed by a zip fastener along one of the vertical edges and divided by horizontal stitching into five pockets. This structure kept the powder evenly distributed and allowed it to leak out at a reasonably steady rate in use. The pouch was stuck by double-sided adhesive tape on to a 12·5 cm square of polythene sheet stuck in its turn to a backing square of rigid cardboard. In use, this assembly was attached to a heavy-gauge polythene apron and a panel of the fabric under test taped over the pouch with autoclave tape (Fig. 1). The apron and pouch surround could be cleaned between experiments so that dispersal was restricted to the area of the pouch itself. The cardboard backing ensured that the pouch was always proud of the general body contour and was brought into effective contact with the 'target'.

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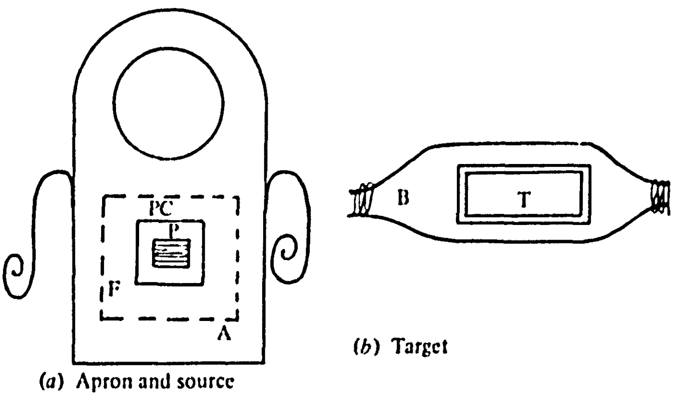

Fig. 1. Diagram of the test assembly. A: apron of heavy-gauge polythene; F: fabric under test; PC: polythene sheet on cardboard backing; P: pouch containing fluorescent powder; B: bolster, a roll of foam rubber inside a polythene tube; T: the target fabric of cotton-polyester sheeting.

Target

The target, designed to simulate a clothed body, was formed as a roll of foam rubber in the form of a bolster 75 cm long × 40 cm diameter, encased in polythene tubing. On to this, forming the target area itself, was taped a piece of cotton-polyester sheeting 25 × 18 cm. Purple or brown fabric was used as this formed a good background against which to view any fluorescent particles reaching it and was free of any inherent fluorescence under the ultraviolet illumination used.

Procedure

The experimenter, wearing the apron with the pouch attached, stood and rubbed the target area against the fabric under test over the source area. He did this, moving the target vertically ten times and then horizontally ten times and carried out this sequence five times in all.

The bolster was then laid down carefully with the target area upwards and left while the experimenter removed the apron, with the source, and washed his hands. He then removed the target fabric and placed it on a metal frame. This allowed air to be sucked through the fabric.

If the amount transferred was small, both faces of the fabric were examined in turn under ultra-violet illumination by means of low-power *magnification* either with a plate microscope or a hand lens. If large amounts were involved, the fabric was sampled by suction using an open faced 2·5 cm diameter Millipore plastic filter holder with a Whatman No. 41 filter paper (this passed a large airflow while still retaining the particles). Up to five or six filter papers might be used when the number of particles was large in order to avoid overcrowding the surface. Counting on the papers was done using ultraviolet illumination under a suitable microscope power. After suction sampling, the fabric surfaces were examined in the same way as for small transfers. The plastic surface of the bolster under the fabric was

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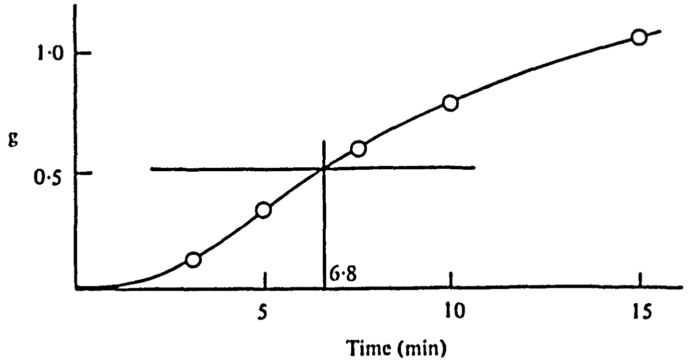

Fig. 2. Rate of penetration of water through a piece of Ventile L34 fabric after a single laundering (washed and ironed).

sampled with a moistened 15 cm Whatman No. 1 filter paper. Counting of the particles removed in this way was easier if the paper was wrapped over a straight edge so that all the particles were collected on to a line and if sufficient filter papers were used to avoid overcrowding.

RESULTS

I. *Penetration by fluid*

The rate of penetration followed an approximately sigmoid form (Fig. 2) with a more rapid phase following an initial lag, which slowed down as the cotton sheeting became saturated. From the form of these curves, the time to reach penetration of 0·5 g was chosen as likely to provide the most consistent statistic. These times are given in Table 2. Materials with considerable resistance to wet penetration, such as the proofed cottons, Pima and Ventile, and the synthetic Tyvek, showed large variations in successive tests, especially when tested against plain water. Penetration of these materials is often a function of local weaknesses in their structure which are irregularly distributed over the fabric. Penetration times of less than 15 s could not be estimated with any great accuracy and approached the limiting rate for water uptake by the accepting cotton sheeting. The variability between successive samples of material made it difficult to determine whether the interruptions in the rubbing to carry out weighing had any influence on the rate of water penetration. No evidence was found, however, that this was of importance.

The experiments were not generally extended beyond a time corresponding to the penetration of 0·5 g in 1 h. This could be assumed if there was no visible penetration after 30–45 min. If there was some penetration by that time the test was continued up to 60 min, and sometimes longer. The median ratio of observed penetration times for duplicate runs was about 1·2 for the tests with tap water and 1·5 for those with Teepol solution or serum. These values correspond to a geometric standard deviation of 1·15 for the experiments with tap water, and of 1·33 for those with teepol solution or with serum. The 95 % confidence limits for

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Table 2(*a*). *Time for penetration of* 0·5 *g of fluid* (*minutes*)

Fabric	Treatment	Tap water	Test fluid 0·5% Teepol	Serum
White sheeting	Unwashed	0·15	0·09	0·15
Nylon taffeta	Unwashed	0·17	0·09, 0·10	0·15
Utopia plus	Unwashed	0·9	0·25	1·5, 1·3
	Washed once	0·28	—	—
	and ironed	0·46	0·15	1·0, 1·0
Balloon cotton	From hospital	0·18, 0·17	0·21	—
	Rewashed and ironed	0·22	0·14	0·7, 0·4
Featherproof cotton	Unwashed	0·9, 0·7	1·4, 1·6	5·2
	Washed once	0·4	0·3	—
	and ironed	1·2	0·5	5·5
'Ceramic' terylene	Unwashed	0·7, 0·8	0·9	0·5, 0·5
	Washed once and ironed	0·7	1·5	0·8, 0·5
Johnson & Johnson '450'	As supplied	32, 11, 19	1·4, 1·3	6·1, 6·2
Johnson & Johnson Dexter	As supplied	NP*, NP	2·5, 2·8	NP
Tyvek	As supplied	24, NP*, 10	3·8, 2·1	5·1, 7·4

Table 2(*b*). *Time for penetration of* 0·5 *g of fluid* (*minutes*) *through proofed cotton fabrics*

Fabric	Ventile L34			Quarpel-proofed Pima		
Treatment	Tap water	0·5% Teepol	Serum	Tap water	0·5% Teepol	Serum
As supplied, unwashed	NP	6, 15, 4·5, 16	NP	NP	NP	NP
Once washed	2·4, 2·6	1·1, 2·3	15, 8	45	9, 25, 5	NP
and ironed	7	1·1	55	—	NP	—
and autoclaved	11	2·1	30	—	—	—
Twice washed	1·9	0·8	6	22	6, 3·4, 3·4	—
and ironed	5	0·5	10	—	45	NP
and autoclaved	5	1·6	—	NP	NP	—
Three times						
washed and	1·1	0·7	—	7	3	NP*
ironed and	3	1·3	16	55	17	NP
autoclaved	8	1·9	7	—	NP	—
5/6 times						
washed and	2·5, 3·5	0·7, 1·3	—	NP	57, 45	—
ironed and						
autoclaved	—	—	10	—	—	—
10/12 times						
washed and	2·0	1·5, 1·3	8, 6, 11	NP	30	NP*
ironed and						
autoclaved	2·5	1·1, 1·1	4·5, 7	—	NP*	—

NP, Penetration time greater than 60 min, no trace detectable after 30–45 min.

NP*, Penetration time greater than 60 min, a trace of penetration observed within 30–45 min.

The surface tensions of the fluids as estimated by capillary tube rise at room temperature were 66 dynes/cm (mN/m) for the tap water. 50 for serum and 22 for the 0·5% aqueous teepol solution.

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the means of duplicate observations are then $\bar{x}/1{\cdot}2$ and $\bar{x}\times 1{\cdot}2$ for the water results, and $\bar{x}/1{\cdot}5$ and $\bar{x}\times 1{\cdot}5$ for the Teepol or serum results, where $\bar{x}$ is the mean value. (The geometric standard deviation is the ratio of the eighty-fourth percentile to the mean or median or the ratio of the mean or median to the sixteenth percentile where the distribution of values approximates to the log normal form.)

Laundering increased the rate of penetration of plain water. Ironing, after washing, partly restored resistance, especially with the proofed Ventile and Pima. Autoclaving these two after ironing produced a further improvement. These effects were most marked with the Quarpel-proofed Pima fabric and are presumably due to reforming of the proofing by the action of heat, and perhaps pressure.

Penetration by the Teepol solution was more rapid than by plain water and sometimes, e.g. with the synthetic fabrics, JJ 450, JJ Dexter and Tyvek, much more rapid. There was little or no increase in the penetration time of Ventile fabric after ironing and the benefit of autoclaving was not observed beyond a few washings. Ironing and, to a greater degree, ironing followed by autoclaving, considerably increased the resistance to penetration of the Quarpel-proofed Pima.

The results with serum showed an unexpected effect. With the wholly synthetic fabrics the penetration times lay between those for plain water and those for the Teepol solution, and closer to the first. This corresponds with the relative values of surface tension of the three fluids. For all the fabrics containing cotton, however, except the test sheeting when penetration was, in every situation, extremely rapid, the rate of penetration by the serum was slower than that found for plain water. The effect was large. The penetration times were increased between two and more than ten times. It would seem likely that this is a consequence of adsorption and clotting of the serum on the cotton fibres.

Considering the results with plain water, the fabrics tested fall into three groups. The first comprises Balloon cotton, nylon taffeta and Utopia. These all allow the passage of 0·5 g of water in less than 30 s of test rubbing. The second group, Featherproof cotton and 'Ceramic' terylene requires around 45 s for the passage of this amount of water, which is about four times longer than the time for Balloon cotton. The other fabrics all have penetration times longer than 1 min and in many cases longer than 1 h. Even though the resistance of the Ventile fabric to the passage of water is much reduced by laundering, the penetration time for 0·5 g remains above 1 min after more than ten launderings and even then exceeds 2 min if ironed and autoclaved.

There have been several published comparative tests of the resistance to water penetration of fabrics in hospital use. Brigden (1964) states that Ventile fabrics retain their water-repellent characteristics up to some 30 launderings but he gives no indication of the test method or standard. Eudy *et al.* (1975) and Laufman *et al.* (1979) put aqueous bacterial suspensions into 'hammocks' of the fabrics, tensed with a 2 kg weight, and tested the undersurface of the fabrics at intervals by contact with a nutrient surface. Penetration through plain cotton was immediate but Quarpel-proofed Pima showed penetration only after 30 min following 75 laundering and sterilizing cycles. Although the material is under strain this is a static test.

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Table 3. *Numbers of particles penetrating Balloon cotton*

Surface sampled	Surface of bolster: Polythene sheet	Surface of bolster: Aluminized Melinex
Front face of target fabric	5000	2900
Rear face of target fabric	51000	21600
Surface bolster	112000	2800
Total particles penetrating	168000	27300

Table 4. *Numbers of particles penetrating test materials*

Test fabric	Total penetration	Relative penetration†	
		Microspheres	Talc
Nylon taffeta	200000	45000	140000
Balloon cotton	170000	160000	315000
Johnson & Johnson 450	138000	190000	30000
Utopia plus	91000*	270000	470000
Featherproof cotton	2400	450	3300
Johnson & Johnson Dexter	155	450	20
'Ceramic' terylene	28	20	7
Pima cotton	17	40	70
Ventile L34	12	20	30
Tyvek	8	50	50
PVC sheet	5	<10	—

* The results with this fabric were more variable than with the others.

† For a description of the fabrics and the other tests see Lidwell & Mackintosh (1978). The figures given here are taken from Table 3 in that publication after multiplying by 100 to give numerically comparable values.

Ransjö & Hambraeus (1979) placed their test fabric over a nutrient agar surface in a petri dish. The fabric was then covered with a contaminated piece of cotton fabric and a 2 cm diameter hemispherical teflon probe was rubbed over the cotton fabric. The agar surface was replaced at intervals and incubated. (The tests were also carried out with a dry filter as the collecting surface in place of the blood agar.) In these experiments Balloon cotton showed rapid penetration, Tyvek only a short resistance time while the proofed Ventiles still exhibited reduced penetration up to 2 h or more. This is a dynamic test but the wet surface is not very 'wet'. There is no *a priori* way of determining which form of test will correspond most closely to clinical experience and this is likely to differ according to the circumstances. Nursing procedures are not the same as those for surgery and wet procedures will have different requirements from those in which the surfaces involved are dry.

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II. *Penetration by dry particles*

Preliminary experiments showed that with easily penetrable fabrics the greatest amount of the transmitted material was found on the polythene surface under the target fabric. This appeared to be probably due to electrostatic attraction and some tests were also done with an aluminized plastic film (Melinex) over the bolster beneath the fabric with its metallized surface next to the fabric to eliminate static effects. The results of these tests are shown in Table 3 and confirm that electrostatic attraction was the most probable cause of accumulation of particles on the polythene surface. This effect, which results in the surface beneath the fabric acting as a large capacity sink for particles passing through both the test and target fabrics, is an advantage since it reduces or eliminates saturation effects.

The main series of experiments was conducted using the polythene bolster surface, four or five replicate tests being made on each fabric. The results are given in Table 4, where these are compared with the results of the rub-through tests in the earlier paper (Lidwell & Mackintosh, 1978). Control samplings of the various surfaces in the absence of the source gave on average less than one particle per surface and a mean aggregate of 2·6. Comparison with the results using a PVC, supposedly impermeable, barrier material showed that transfer of particles to the target other than through the fabrics under test was negligible. The observed value of 5 with the PVC did not differ significantly from that of 2·6 for background contamination. Considerable care was necessary to achieve these low figures since the possible leakage into the environment from the source was very high. It is immediately apparent by inspection of Table 4 that the results of these tests are closely correlated with those obtained in the previous rub-through tests.

DISCUSSION

These experiments illustrate further that fabrics behave quite differently under different conditions so that a test suitable for selecting an effective fabric for one purpose may give altogether false guidance if applied to another set of conditions. This is clearly shown in Table 5 where some of the results from this and the preceding papers are brought together. Thus, the very low penetration of the open-weave nylon taffeta by skin particles on exercise is not maintained either for dry rubbing contact or for fluid penetration. The close-woven 'Ceramic' terylene has a low penetration by dry contact, although, relative to the other fabrics, by no means as low as it showed against skin particles, but is readily penetrated by all fluids. The two Johnson & Johnson disposable fabrics which are among the less-penetrated fabrics with respect to the skin particles generated by exercise are also both fairly effective against fluid penetration. However, while the Dexter fabric is also resistant to penetration by dry particle on rubbing contact, the 450 material offers little barrier to this challenge.

These examples are not intended to suggest that there was little correlation between the results obtained from the various tests. As Table 4 shows, for example, the results obtained in a test of simulated nursing contact under dry conditions

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Table 5. *Comparative performance of materials in various tests*

Material	(1) Largest pore	(2) Airborne dispersal	(3) Dry contact	(4) Penetration by fluids (*a*) Tap water	(*b*) Serum	(c) 0·5 % Teepol
White sheeting	—	—	—	130	130	220
Nylon taffeta	89	2·7	118	120	130	200
Balloon cotton	*100*	*100*	*100*	*100*	38	118
Utopia plus	160	180	54	40	19	105
Featherproof	45	71	1·4	25	3·7	27
JJ '450'	65	30	81	1·1	3·3	15
JJ Dexter	29	30	0·09	< 0·3	< 0·3	7·5
Tyvek	26	8	< 0·01	0·8	3·3	7·1
'Ceramic' terylene	13	2·4	0·02	28	36	17
Ventile L34	17	18	< 0·01	< 0·3	< 0·3	2·2
1–3 washes	—	—	—	10/4·3/2·7	2·2/1·0/ 0·7	18/22/10
5–11 washes	—	—	—	—/7/8·0	—/25/4·4	—/17/18
Pima Quarpel	39	27	0·01	< 0·3	< 0·3	< 0·3
1–3 washes	—	—	—	1·1/0·4/ < 0·3	< 0·3/0·3/ (< 0·3)	3·4/0·4/ < 0·3
5–11 washes	—	—	—	—/ < 0·3/ (< 0·3)	—/ < 0·3/ (< 0·3)	—/0·5/ < 0·3

Values in column (1) from Lidwell & Mackintosh (1978), in column (2) from Lidwell, Mackintosh & Towers (1978). These values as well as those in column (3) are expressed relative to Balloon cotton as 100. The values in columns 4, (*a*), (*b*) and (*c*), have been derived from those in Tables 2(*a*) and 2(*b*). The penetrations are given as 100 times the penetration time for Balloon cotton divided by that for the fabric and test concerned, i.e. smaller values represent a better performance as for the other test values. Geometric means have been taken where there are multiple readings. The value < 0·3 corresponds to no penetration in 1 h. Values in parentheses are deduced from other results in the same row. The three values, separated by solidi, for the washed Ventile and Pima fabrics correspond to the penetration after washing, after subsequent ironing and after autoclaving.

are closely similar to those obtained previously by mechanical rubbing of dry powders over the fabrics. Generally, however, even among this small number of fabrics there was one or more which behaved differently relative to the other fabrics in any chosen bench test when the results from this test were compared with those from other bench tests or from simulated transfer experiments. Among the reusable woven fabrics, the Quarpel-proofed Pima cotton retains its resistance to fluid penetration after repeated washing, particularly when autoclaved after ironing (Eudy *et al.* 1975).

It must be emphasized that the object of the present series of studies is to devise and assess test procedures applied to a representative range of fabric types. They are not intended to determine the 'best' fabric, which can be ascertained only by experience in use, although valid clinical judgement is, in practice, very difficult. They may, however, give useful guidance as to what fabrics are worth evaluation and, if the tests are applied to other fabrics, some idea of the similarities and differences among them.

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