Strike-through of Moist Contamination by Woven and Nonwoven Surgical Materials

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A test is described which correlates the stress of stretching surgical gown and drape material with moist bacterial strike-through. By application of this test to a number of woven and nonwoven surgical gown and drape materials, it was found that not all of these materials, either woven or nonwoven, are impermeable to moist contamination for equal periods of time. Nonwoven disposable materials now in use range from those which remain impermeable to moist bacterial permeation through all tests while some remain impermeable for limited periods of time, and others almost immediately permeable to moist bacterial penetration. The same situation holds for woven materials. Under conditions of our test, Quarpel treated Pima tight-woven cotton cloth was impermeable to moist bacterial strike-through, through up to 75 washing and sterilizing cyclings, while ordinary linen and untreated Pima cloth permitted bacterial permeation almost immediately. These results have significance in lengthy wet surgical operations.

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A NUMBER OF PROPRIETARY TESTS have been developed for the evaluation of permeability of nonwoven materials used in operating room apparel. However, quantitative information on a comparison of various nonwoven and woven materials is meager. Most tests deal with the effects of pressure without friction on either dry penetration or moist strike-through, using the amount of pressure and time as variants, with the test material being sandwiched between a weight and a bacterial spread.[1] In the tests employing pressure, a weight or a column of contaminated liquid is usually placed on a disc of the material, compressing the material against another surface.[2,3,4] In other tests, a suction device such as an air sampler is used to draw contaminated air through the fabric.[5]

Most if not all the tests now in use are open to the criticism that they do not mimic the stresses encountered during lengthy surgical operations. Under these circumstances, stresses are often caused by unopposed pressure such as that exerted by an elbow against a sleeve, or by stretch or friction, often in the presence of moisture. After measuring some of the stresses of use, we devised a test with an unopposed weight supported by the test material in the presence of a standardized moist contaminant. We subjected many of the presently marketed nonwoven and woven materials to this test, and compared the results with those of a commonly-used test for transmission of moist contamination. Moreover, since we could find no data which correlated bursting or stretch tests of surgical gown and drape materials with changes in bacterial penetration or strike-through, we proceeded with the goal of collecting some quantitative information on this correlation, using weight and time as variants.

Unopposed Weight-Support Test

A suspension of Serratia marcesens, 10^6 per ml. in water was used as the standard contaminant. A double hammock was made of the test material by attaching a cutting of the material, approximately 16 x 40 cm. in size, on six metal posts mounted on a base. Two identical hammocks, each measuring approximately 16 x 20 cm., were formed with about a one-inch sag. One-half ml. of the bacterial suspension was released from a pipette into the seat of each hammock. In various experiments, weights of 200 grams, 500 grams, and 2 kilograms were placed in one of the hammocks while the other hammock contained only the contaminant solution without a weight. After 5, 15 and 30 minutes, a Rodac* plate was

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*The word Rodac is a mnemonic for either Replicate Organism Determination And Counting, or Rapid One-Step Disposable Agar Contact plate.

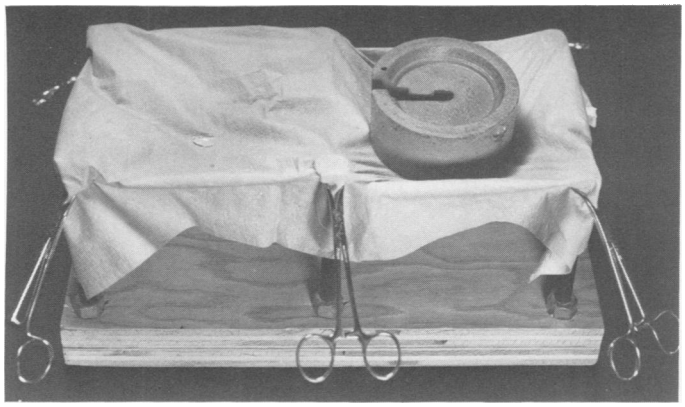

FIG. 1. Twin sling experimental setup with suspension of Serratia Marcesens 10.6 ml. in water in each hammock. A 2 kilogram weight is placed in one hammock while the other serves as a pressure-free control.

touched firmly to the underside of each hammock. Thus, we were able to determine the effects of various unopposed weights for various periods of time on wet strike-through contamination. Two kilograms was the estimated unopposed pressure of an elbow on the material of a gown sleeve during use, as well as approximately half the pressure applied against the front of a surgical gown when the surgeon leans intermittently against the operating table.

We compared results of the weight-support test with those of one of the most widely used contact tests, the Libman-Ullrich Rodac-sandwich test[1] in which the test material is compressed between two Rodac plates one of which contains a standardized bacterial culture. The sandwich is compressed with 100 grams of pressure. This test is ordinarily assayed at 5 seconds, 30 seconds and 1, 5, and 15 minutes. We extended this test to 30 minutes for comparison with our weight-support test.

Materials Tested

Woven materials

A. Linen cotton, double-layer*
   1. New
   2. Laundered and sterilized twice
B. Pima cotton†
   1. Untreated, new
   2. Quarpel treated‡

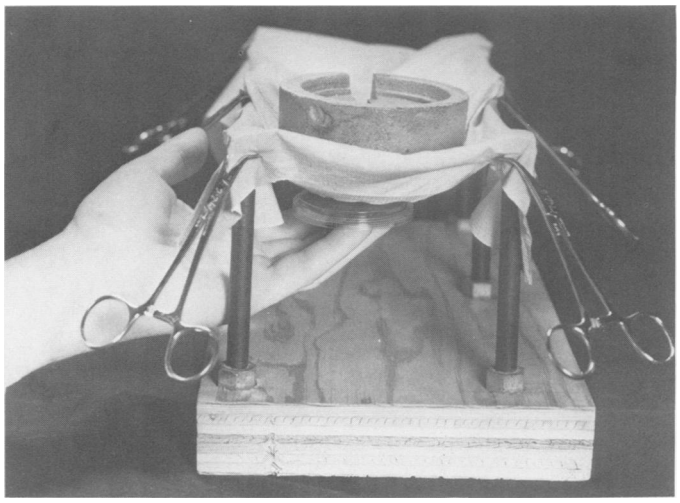

FIG. 2. Rodac plate cultures are taken from the underside of each hammock at varying periods of time.

   a. New
   b. Laundered and sterilized 2, 25, 55 and 75 cycles

Nonwoven materials

A. J & J (Barrier; Softcel)
   1. Mayo stand cover; table cover
      Wet-laid nonwoven fabric laminated to polyethylene film
   2. Utility drape
      Scrim reinforced, embossed tissue
   3. Drape sheet; laparotomy sheet
      Scrim reinforced, creped tissue
   4. Gown
      Spunlace nonwoven fabric
B. Convertors (Surg-O-Pak and Shield gown; Amerilon)
   Scrim reinforced tissue
C. 3-M (Packs and gowns)
   Spread tow plastic film composite

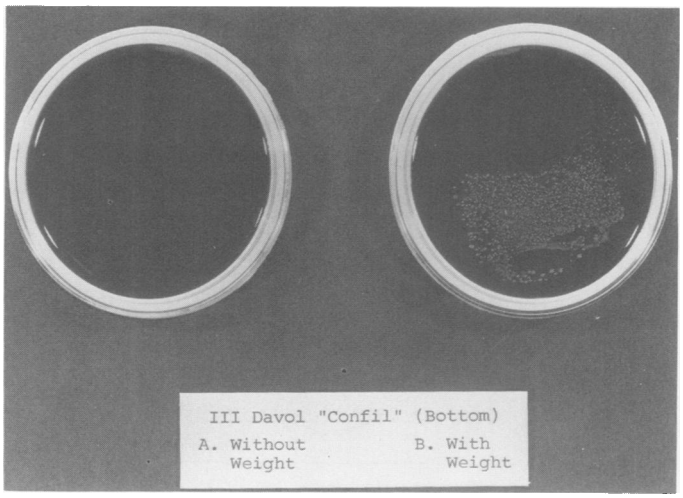

FIG. 3. Rodac plate cultures at 48 hours showing no moist bacterial strike-through when the material was not stretched by a weight. Plate on right shows positive culture in weight bearing hammock.

*Type 140 muslin of carded yarns with warp of 68 and fill of 72 per inch and Class A sheeting of carded yarns with warp of 48 and fill of 52, 2.65 yards per pound.

†100% cotton; 270 threads, 1 sq. in.; 2-ply warp; single fill; interstices 5 micra. Trade names: Barbac, Liquashield. Barbac and Liquashield are identical products of different manufacturers. Through differences in sizing, Liquashield is somewhat softer than Barbac.

‡Quarpel is a development of the U.S. Army Quartermaster. It is a fluorochemical finish in combination with a pyridinium or melamine hydrophobe which produces an exceptionally durable water-repellent finish.

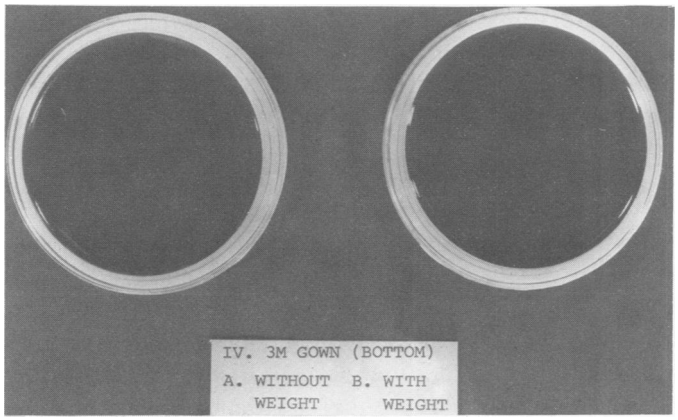

FIG 4. No bacterial strike-through in either the material not stretched by weight or that subjected to the stretch stress of the weight. This is considered a most satisfactory result demonstrating barrier effect.

D. Macbick (Vigilon)
Spunbonded polyethylene nonwoven fabric
E. Davol (Confil; gowns)
Wet-laid nonwoven fabric
F. Kimberly-Clark (Kimlon Kaycel; packs and gowns)
Fiber reinforced tissue

Results

Woven materials

A great difference in wet bacterial strike-through was found between Quarpel-treated Pima tight-woven cotton cloth, on the one hand, and either ordinary linen or untreated Pima cloth, on the other. The treated Pima cloth resisted the transmission of moist contamination in all tests up to 30 minutes of stress time equally well through fifty-five washings and autoclavings. Some barrier effect was seen after as many as 75 cyclings (Table I). The ordinary linen and the untreated Pima cloth permitted bacterial permeation in all tests almost immediately, usually without pressure or unopposed weight stress.

TABLE 1. *Unopposed Weight-Support Test (2 Kg. Weight) Bacterial Penetration = + Wovens*

Material	5 min.	15 min.	30 min.
Tight weave Pima, Quarpel treated	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
Tight weave Pima, Quarpel treated, 55 cyclings	0	0	0
	0	0	0
Tight weave Pima, Quarpel treated, 75 cyclings	0	0	0
	0	0	+
Tight weave Pima, Quarpel treated, 100 cyclings	0	0	+
	0	+	+
Tight weave Pima, untreated	+	+	+
Linen, new	+	+	+
Linen, cycled twice	+	+	+

TABLE 2. *Unopposed Weight-Support Test (2 Kg. Weight) Bacterial Penetration = + Nonwovens*

Material	5 min.	15 min.	30 min.
Spread tow plastic film composite	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
Wet-laid nonwoven fabric laminated to polyethylene film	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
Scrim-reinforced tissue	0	0	0
	0	+	+
	0	0	0
	0	0	0
	0	0	+
Scrim-reinforced embossed tissue	0	0	0
	0	0	0
	0	+	+
	0	+	+
	0	0	0
Spunbonded polyethylene fabric	0	0	0
	0	0	0
	0	0	0
	0	0	+
	0	+	+
Spunlace nonwoven fabric	0	0	0
	0	+	+
	0	0	0
	0	0	+
	0	0	0
Wet-laid nonwoven fabric	0	+	+
	0	0	0
	+	+	+
	0	+	+
	0	0	+
	0	0	+
Fiber reinforced tissue	+	+	+
	+	+	+
	+	+	+
	+	+	+
	0	0	+
	+	+	+

Nonwoven materials

Significant differences in wet bacterial strike-through were found between the various types of nonwoven materials used in the manufacture of disposable surgical gowns and drapes. Many of these differences were demonstrable by an existing test, the Libman-Ullrich compression test, but were more obvious with the authors' unopposed weight stress test.

Of the nonwoven materials, the one which withstood

TABLE 3. *Rodac-Sandwich Test Bacterial Penetration of Nonwovens (Libman-Ullrich)*

Material	5 sec.	30 sec.	1 min.	5 min.	15 min.
Spread tow plastic film composite	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
Scrim reinforced, crepe tissue	0	0	0	0	0
	0	0	0	0	0
Scrim reinforced, embossed tissue	0	0	0	+	0
	0	0	0	0	0
Spunlace, nonwoven fabric	+	+	+	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
Wet-laid nonwoven fabric laminated to polyethylene film	0	0	0	0	+
	0	0	0	0	+
Scrim reinforced tissue	0	0	+	+	+
	0	0	0	+	+
Wet-laid nonwoven fabric	0	0	+	+	+
	0	+	+	+	+
Fiber-reinforced tissue	0	0	+	+	+
	0	+	+	+	+
	0	+	+	+	+
	0	0	+	+	+

all tests was spread tow plastic film composite. This material is used by one manufacturer in both gowns and drapes. Next in barrier effect was wet-laid woven fabric laminated to polyethylene film, a material used in the fabrication of an instrument tray cover by one manufacturer but not used in gowns or drapes, apparently because of heat-retention properties.

Four other gown and drape materials were considered satisfactory when subjected to the unopposed-weight stress test for 30 minutes, although all of them permitted some bacterial strike-through on one of five tests at 15 minutes and two of five tests at 30 minutes. These materials were: scrim-reinforced tissue; scrim-reinforced embossed tissue; spunlace nonwoven fabric, and spunbonded polyethylene nonwoven fabric.

Two gown and drape materials, wet-laid nonwoven fabric and fiber-reinforced tissue, were found to be poor bacterial barriers. Both permitted wet bacterial penetration within five minutes in most runs of both the compression test and the unopposed weight stress test.

Tables II, III and IV show a rather close correlation between the Libman-Ullrich compression test and our unopposed weight stress test as far as the former test went. However, in separate runs, two of the materials, wet-laid nonwoven and wet-laid nonwoven-with-polyethylene could not withstand the 2 Kg weight without tearing. In other runs, these materials did not tear, but at the 30 minute reading with the 2 Kg weight test, permeation of bacteria occurred in almost twice as many specimens (7 as against 4) as had occurred at the 15 minute reading. It would appear that 15 minutes is an insufficient length of time to test for bacterial penetration if the test is to be applied realistically to the lasting barrier effect through lengthy surgical operations.

Not shown in the tables was the testing carried out for permeability of the stockinette cufflets found on virtually every surgical gown whether the gown was made of woven or nonwoven material. In every test the stockinette acted as a wick, permitting almost immediate strike-through of wet bacterial contamination without applying a stress factor.

Discussion

Bacterial impenetrability, freedom from hazard, and economy are considered to be the ideal characteristics of

TABLE 4. *Unopposed Weight-Support Test Average Bacterial Penetration at Indicated Periods Under Variable Weights*

	200g.			500g.			2Kg.		
Material	5 Min.	15 Min.	30 Min.	5 Min.	15 Min.	30 Min.	5 Min.	15 Min.	30 Min.
Pima treated with Quarpel	0	0	0	0	0	0	0	0	0
Spread tow plastic film composite	0	0	0	0	0	0	0	0	0
Wet-laid nonwoven with polyethylene	0	0	0	0	0	0	Could not withstand weight		
Scrim reinforced tissue	0	0	0	0.17	0.17	0.67	0.67	0.83	1.0
Scrim reinforced crepe	0	0	0.50	0.17	0.17	0.67	0.67	0.83	1.0
Scrim reinforced embossed	——	——	——	0.33	0.64	0.83	——	——	——
Spunlace, nonwoven	0	0.50	0.67	0.83	0.83	0.83	0.83	1.0	1.0
Wet-laid, nonwoven	0.17	0.50	0.83	0.33	0.83	0.83	Could not withstand weight		
Linen	——	——	——	0	0.33	0.83	1.0	1.0	1.0
Pima, untreated	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Spunbonded	0	0.33	1.0	——	——	——	——	——	——
Fiber reinforced	0.87	0.87	1.0	——	——	——	——	——	——

—— = Not assayed

TABLE 5. *Rodac-Sandwich Test (Libman-Ullrich) Average Bacterial Penetration After Specified Exposure Times*

Material	5 Sec.	30 Sec.	1 Min.	5 Min.	15 Min.
Pima cotton treated with Quarpel	0	0	0	0	0
Spread tow plastic film composite	0	0	0	0	0
Scrim-reinforced embossed tissue	0	0	0	1.0	0
Scrim-reinforced crepe tissue	0.25	1.25	0.50	0	0
Spunbonded polyethylene nonwoven	0.20	0.20	0.20	0.20	0.20
Wet-laid nonwoven laminated to polyethylene film	0	0.33	0.50	1.0	3.17
Spunlace nonwoven	0.80	1.20	1.60	1.60	2.60
Pima, untreated	0.20	0.60	1.20	1.60	4.0
Scrim-reinforced tissue	0	0	1.0	3.50	4.0
Wet-laid nonwoven	0	2.0	2.5	4.0	4.0
Fiber reinforced tissue	0.75	1.5	2.75	4.0	4.0
Linen	3.4	4.0	4.0	4.0	4.0

operating room apparel and drapes. Other sought-after goals are comfort, convenience, and dependable sterility. Manufacturers usually guarantee sterility upon shipping from the factory. The shelf-life of the sterile contents of a package is essentially a product of the packaging. From the user's point of view, first and foremost among the characteristics of barrier materials is the capability of the material to prohibit the transfer of bacteria under the conditions of use in the operating room. A number of tests have been devised by the single-use hospital product industry to assay the bacterial barrier properties of the various materials used for surgical apparel, drapes, and packaging materials for sterile products (Table VI).

Many of the nonwoven gown and drape materials are being promoted as barriers to wet contamination. However, in a random survey, Rodac plate cultures of some disposable gowns and drapes taken during actual surgical operations which lasted more than one hour, we found many positive cultures, especially in places on the gowns or drapes where moisture and physical stresses had occurred, such as the axillary region and front of nonwoven gowns and the unreinforced areas of woven gowns. Identification of organisms in these cultures yielded mainly Staph. epidermidis and occasional Staph aureus, indicating that the source of contamination was mainly the wearer. When members of the surgical team wore woven gowns in which the front and sleeves were reinforced with treated, tight-woven Pima cloth, positive cultures of Staph. epidermidis could only be obtained from areas of the gown which were not reinforced. Cultures of the enforced areas were either sterile or yielded growths of gram-negative types such as E. coli species, which were more likely to come from the surgical site, especially during operations on the intestinal tract, than from the surgeon's body. These findings aroused sufficient curiosity about barrier standards, we felt, to warrant a closer look at the tests being used to determine the barrier effect of these materials.

Our test provides continuous stress for up to 30 minutes. The conditions of the test can be criticized as being too stringent, since stresses during surgical operations tend to be intermittent. However, results at 30 minutes correlated well with cultures taken after one hour of actual use during surgical operations.

Inasmuch as the gown materials cannot be looked upon as bacterial filters, the transmission of moisture is tantamount to the transmission of contained bacteria. Beck and Mandeville[7] have described a continuous waterpressure test for testing barrier materials for moisture transmission but did not correlate results with bacterial strike-through. Transmission of dry particles containing bacteria through loosely woven gown material was demonstrated by Charnley and Eftekhar.[6]

The finding that some woven and some nonwoven materials can withstand actual and simulated operating room stresses without losing their barrier effect, while others retain a barrier effect only for limited periods of time or not at all, would appear to carry several practical implications for both manufacturers and users.

TABLE 6. *Industrial Testing Protocol*

Basis Weight	Taber Abrasion (Wire)	Fire Retardancy (Machine Direction)
Mullen (Bursting Strength)	Wet Taber Abrasion (Felt)	Fire Retardancy (Cross Direction)
Thickness	Wet Taber Abrasion (Wire)	Bacterial Penetrability
Air Permeability	Tear (Machine Direction)	Free Lint
Tensile (Machine Direction)	Tear (Cross Direction)	Surface Resistivity (front)
Tensile (Cross Direction)	Spray Rating	Surface Resistivity (back)
Stretch (Machine Direction)	Hydrostatic Head	Voltage Decay (front)
Stretch (Cross Direction)	Water Repellency	Voltage Decay (back)
Grab Tensile (Machine Direction)	Absorbency	Binder Analysis
Grab Tensile (Cross Direction)	Absorptive Capacity	Fiber Analysis
Grab Stretch (Machine Direction)	Fire Retardancy (Machine Direction)	Tensile Energy Absorption
Grab Stretch (Cross Direction)	Fire Retardancy (Cross Direction)	Bacterial Strike-Through
Cantilever Stiffness		
Taber Abrasion (Felt)		

Gowns made of ordinary linen or of nonwoven materials which are not barriers appear to be suitable for short or relatively dry operative procedures, but according to our data, are not suitable for more lengthy or wetter operations. Such in-use differences in bacterial permeability of various gown and drape materials have not heretofore been brought to the attention of the users.

Areas of greatest risk of moist strike-through contamination appear to be the sleeves and front of the surgical gowns and the roughly two-foot-wide area surrounding the fenestra of surgical drapes. Some commercially available gowns and drapes, both woven and nonwoven are reinforced in these areas with a relatively impermeable layer. Yet curiously, most surgical gowns, both woven and nonwoven, have stockinette cufflets whose wicking effect would tend to negate whatever barrier effectiveness the gown material may possess. Ideally, these cufflets remain covered by the surgeons glove during an operation and therefore should remain dry. But in practice the cufflets often become uncovered and wet, especially during lengthy major operations. Inquiry was made of manufacturers as to why they knowingly outfit their gowns with stockinette cufflets. The response was that this was the preference of surgeons because they hold snugly to the wrists. We would recommend a creping or pleating of impermeable material for a fitted cuff rather than stockinette. We would also recommend investigation of the possibility of treating nonwoven materials with a waterproofing process similar to that used for woven materials.[8]

Although lamination of nonwoven materials with a plastic layer provides a complete barrier effect, the lamination can only be used for instrument-table covers and similar uses not involving covering the body of the patient or the bodies of the members of the surgical team because of the great heat-retaining property of the plastic layer. Tightly woven materials have essentially the same heat-retaining qualities as plastic lamination. When plastic lamination or tightly-woven materials are used to make an entire gown or drape, it is essential to provide some form of ventilation for the body under the material. This is basically the rationale behind the vacuum apparatus used with the coverall surgical gown made completely of tightly woven waterproofed Pima cloth.

Conclusions

Not all woven and nonwoven surgical gown and drape materials are impermeable to moist contamination for equal periods of time. Under the conditions of our tests, Quarpel-treated Pima tight-woven cotton cloth was impermeable to moist bacterial strike-through equally well after up to 75 washing and sterilizing cyclings. Ordinary linen and untreated Pima cloth, on the other hand, permitted bacterial penetration almost immediately.

Among the nonwoven gown and drape materials, spread tow plastic film composite remained impermeable to moist bacterial penetration throughout all tests. Another material, wet-laid woven fabric laminated to polyethylene film also withstood the tests, but is used only in the fabrication of an instrument tray cover and not in gowns and drapes because of its heat-retaining properties. Four other nonwoven gown and drape materials were considered satisfactory, but not as consistently impermeable as the spread tow plastic film composite. These were scrim-reinforced tissue, scrim-reinforced embossed tissue, spunbonded polyethylene nonwoven fabric, and spunlace nonwoven fabric. Two gown and drape materials were found to be poor bacterial barriers, allowing wet bacterial penetration within five minutes in most test runs. These were wet-laid nonwoven fabric and fiber-reinforced tissue.

The stockinette material of gown cufflets permits immediate passage of wet contamination.

In our opinion, tests for bacterial permeability should be restudied from the standpoint of correlating bacterial permeation with the type of stresses encountered during actual surgical operations of varying length and complexity.

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