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The Liquid and Viral Barrier Properties of Reusable and Disposable Surgical Gowns

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수술가운의 방수성과 방균성에 관한 연구

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국문 초록

최근에 치명적인 바이러스, 특히 에이즈를 이르키는 Human Immunodificiency Virus (HIV), 또는 간에 심각한 병을 이르키는 Hepatitis B Virus (HBV)와 같은 무서운 바이러스가 환자의 피나 분비물을 통하여 의사에게 전염되는 사례가 늘어감에 따라 이제는 환자의 피나 분비물의 침투를 막기 위해 방수성과 방균성을 가진 수술복 착용이 절대적으로 필요하게 되었다. 따라서 본 연구의 목적은 1. 수술가운을 만드는 5가지 대표적인 직물의 방수성과 방균성을 측정하고 2. 세탁시 표백제의 사용유무가 그 직물의 방수성과 방균성에 미치는 영향을 알아보고 3. 반복세탁이 그직물의 방수성과 방균성에 미치는 영향을 알아 보는데 있다.

이 실험을 위해 3가지 재사용 수술가운과(Gore-tex^{R}, membrane reinforced; Compel^{TM}, fabric reinforced; Acep^{TM}, non-reinforced) 두가지 일회용 가운 (Evolution^{R} gown, fabric reinforced; Evolution^{R} Specialty, film reinforced)이 사용되었다. 표백제를 사용한 세탁이 직물의 방수성과 방균성에 미치는 영향을 알아보기 위해 재사용 가운을 세탁, 건조, 살균을 하였다. 세탁과 살균의 빈도수는 1, 20, 40, 50, 60, 70, 80번 이였다.

방수성 측정방법으로 1. Impact Penetration test (AATCC 42-1985), 2. Elbow Lean test, 3. Synthetic Blood Resistance test (ASTM F 23. 40. 01)가 사용되었고 방균성 측정방법으로 Viral Resistance test (ASTM F 23. 40. 02)가 사용되었다.

실험 결과는 다음과 같다. 1. Gore-Tex^{R} 가운과 Evolution^{R} Specialty 가운은 방수성과 방균성의 성질을 가졌다. 그러나 표백제를 사용하여 70번 세탁한 Gore-Tex^{R} 가운은 membrane의 구조가 파괴되어서 방균성을 상실했다. 2. Evolution^{R} 가운, Acep^{IM} 가운과 Compel^{IM} 가운은 오직 Impact Penetration test만 통과했다. 즉 이 직물들은 큰 압력의 가함이 없는 splash resistance만 가지고있다. 그러나 Acep^{TM} 가운과 Compel^{TM} 가운은 20번과 60번 세탁 후 각각 그들의 splash resistance 마져도 상실했다.

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I. INTRODUCTION

Surgical gowns have been worn since the late 1800's to protect patients from contamination from the surgical staff and objects in the operating room. Before then, there was little attention given to the role of surgical gowns as protective barrier clothing. In 1883, Neuber used clean linens for the first time during surgery to separate the aseptic areas from contaminated areas[1]. Since then, surgical gowns were used to protect patients form surgical staff and objects during operation. However, recently, as we recognized that a patient's blood can penetrate gown materials and directly contaminate the surgeon's skin, it is needed to protect surgical team from patients' infectious blood and other body fluids. Specifically, dangerous viruses including Hepatitis B Virus (HBV) which causes serious liver diseases and Human Immunodeficiency Virus (HIV), which causes Acquired Immunodeficiency Syndrome (AIDS), may be transmitted via the patient's blood. Only a small amount of contaminated "strike through" blood is needed to infect surgeons[2]. As a result, surgical gowns should provide resistance to the transfer of blood and other body fluids from the patients to the surgical team.

The Center for Disease Control (CDC) has issued guidelines for prevention of surgical infection, specifically that surgical gowns must resist the passage of aqueous liquids[3]. In addition, according to CDC recommendations[4], we should consider that all human blood and other potentially infectious materials are treated as if known to be infectious for HIV and HBV (Universal Precautions). The Association of Operating Room Nurses (AORN) has recommended that surgical gowns should be made of material that is resistant to blood and other liquids which cause contamination and should establish a barrier to minimize the passage of microorganisms between nonsterile and sterile areas[5]. In December, 1991, the Occupational Safety and Health Administration (OSHA) promulgated final rules to eliminate or minimize occupational exposure to HBV, HIV, and other blood borne pathogens. The rules recommended that personal protective clothing/equipment must be provided at no cost to employees who may be exposed to blood or other body fluids in the workplace. Personal protective equipment such as gowns, gloves, and face masks will be considered appropriate only if they do not permit blood or other potentially infectious materials to pass through to or reach the healthcare workers' clothes, skin, eyes, or mouth under normal conditions of use and for the duration of time which the protective equipment will be used. The type and characteristics of gowns will depend upon the task and degree of exposure anticipated[6].

It has been known that wet bacterial penetration occurs as a result of liquid strike-through. Therefore, if the liquid passes through the fabric, the suspended microorganisms in the liquid will follow. Therefore, there is a direct relationship between wetting by liquids and bacterial penetration of surgical gown fabrics. Thus, the rate of penetration of a barrier material by microorganism is directly related to the rate of liquid strike-through. Moreover, past research on surgical gowns has indicated that if the liquid will penetrate one layer, it will go through additional layers of the same fabric[7].

For the purpose of barrier testing, we should test under conditions which are as close as possible to actual use conditions. Therefore, we have to consider many situations that might happen in the operating room and develop the most appropriate test methods. In the operating room, people encounter various liquids that vary depending on their viscosity, surface tension, volume, etc. Since surgeons and nurses are performing all kinds of movements-stretching, rubbing, pressing, etc.-liquid penetration through the fabrics can be accelerated. In addition, there is an interaction between liquids and the surgi-

cal gown fabric. For example, depending on the contact angle between the liquid droplet and fabric surface, time of exposure, and pressure, the liquid penetration properties through the fabric can be varied. Therefore, several factors that affect liquid penetration should be considered when evaluating liquid barrier performance. Several different liquid barrier test methods have been developed by standards organizations, companies, and individual researchers. These methods are different with respect to the amount of challenge liquid, the exposure time, and the pressure exerted by and against the surgical gown fabrics. Therefore, the test results from different laboratories cannot easily be compared since they are using different test methods. One recent study showed that the Impact Penetration test (AATCC 42-1985), the Hydrostatic Pressure test (AATCC 127-1985), the Synthetic Blood Resistance test (ASTM Standard Test Method F 23. 40. 01, draft), and the Kimberly-Clark Blood Strike-through test were recommended for use[8]. In addition, the Elbow Lean test developed by W. L Gore and Associates, Inc. was highly and positively correlated with the new ASTM draft standard. The study also recommended that a viral challenge be used to test fabrics that pass liquid challenges to determine whether microorganisms are able to get through.

To perform the liquid barrier testing, it is important to select challenge liquid. The challenge liquids used in the liquid barrier tests should be representative of the liquids typically used in the operating room. To consider the worst case, alcohol should be used since it has a low surface tension. Realistically, however, blood should be used as a challenge liquid. Previous research has indicated that synthetic blood is a good substitute for real blood[2,8].

In addition to liquid barrier tests, a biological test should be performed to detect the penetration of microorganisms. Since the microorganisms that are suspended in liquid can be less than one micron in diameter, the microorganisms can penetrate through the fabric even if there is no liquid penetration through the fabric.

Therefore, it is very important to measure the liquid and viral barrier properties of the fabrics used to produce surgical gowns using different test methods. This information can be used to select surgical gowns according to the level of protection they provide.

Different types of surgical gowns have been developed in an attempt to provide protection. The gowns can be divided into two categories-reusable and disposable. Both types of gowns can be reinforced with a front panel and/or lower sleeve panel to resist the penetration of liquid in these areas. Films, coatings, membranes, or a double layer of the same fabric can be used to reinforce the gown. Both woven and nonwoven gowns reinforced with fabric or films/coatings can reduce liquid penetration greatly.

Reusable gowns must be laundered and sterilized for each use in order to remove stains and kill microorganisms. In addition, bleach can be added during laundering to help remove stains and microorganisms. However, it may cause the loss of the textile strength and liquid and viral barrier properties due to damage of the reinforcement treatment and fiber loss in the fabric structure. Therefore, an evaluation of the liquid and viral barrier properties of reusable gowns after repeated launderings with bleach should be made. In addition, liquid and viral barrier properties of the seam area of the sleeve of the surgical gown should be tested since this area can be subjected to blood and other body fluids.

There are advantages and disadvantages for using reusable and disposable gowns. Reusable gowns require more labor and facilities to launder and sterilize and may contribute to water pollution. Disposable gowns require a larger inventory and may cause a hazardous waste disposal problem. Consequently, factors such as economics, barrier properties, comfort, and the environmental impact should be considered when surgical gowns are

selected.

Therfore, the purpose of this study was 1) to evaluate the liquid and viral barrier properties of fabrics used to make reusable and disposable surgical gowns, 2) to evaluate the effect of laundering with and without bleach on the liquid and viral barrier properties of reusable surgical gowns, and 3) to evaluate the cumulative effects of laundering and sterilizing on the liquid barrier properties of reusable surgical gowns.

II. METHODS AND PROCEDURES

Five surgical gowns were included in the study. Each fabric description provided by the manufacturers and their physical properties were given in Tables 1 and 2, respectively. Three reusable surgical gowns included Gore-Tex^{R} membrane reinforced,

Table 1. Fabric/gown descriptions

1. Gore–Tex^{R}
   Gore–Tex^{R} bicomponent membrane reinforced, reusable (by W.L Gore & Associates, Inc.)
   Face : woven, 100% polyester, Core : expanded film of PTEE (polytetrafluoroethylene) partially impregnated with a hydrophilic oleophobic polymer, Back : knitted, woven, 100% polyester.
2. Compel^{TM}
   fabric reinforced, reusable (by Standard Textile Company Inc.)
   Woven, 100% polyester, 2 layers, continuous filament
3. Asep^{TM}
   regular, reusable (by Angelica Uniform Group)
   Woven, 100% polyester 1 layer, continuous filament
4. Evolution^{R} 90112
   fabric reinforced, disposable (by Kimberly–Clark Corporation)
   Face : spunbonded 100% polypropylene, Core : meltblown microfiber mat 100% polypropylene, Back : spunbonded 100% polypropylene
5. Evolution^{R} Specialty 90412
   film reinforced, disposable (by Kimberly–Clark Corporation)
   Coating : extrusion coated, 100% polyethylene, Face : spunbonded 100% polypropylene, Core : meltblown microfiber mat 100% polypropylene, Back : spunbonded 100% polypropylene

Table 2. Physical characteristics of the surgical gown fabrics

Fabric	Weight (g/m^2)	Thickness (mm)	Bulk Density (kg/m^3)	Air Permeability, ($cm^3/cm^2 \cdot s$)
1. Gore–Tex^{R}	184.88	0.47	393.36	0
2. Compel^{TM}	117.90	0.20	869.50	0
3. Asep^{TM}	92.95	0.12	774.58	0
4. Evolution^{R} (Front)	92.95	0.67	138.73	15.78
4. Evolution^{R} (Sleeve)	94.34	0.68	138.74	11.91
5. Evolution^{R} Specialty (Front)	56.71	0.32	177.22	0
5. Evolution^{R} Specialty (Sleeve)	114.02	0.83	137.37	0

Compel™, fabric reinforced, and Asep™, non-reinforced. Two disposable surgical gowns included Evolution® 90112, fabric reinforced and Evolution® Specialty 90412, impervious film reinforced. The reusable gowns were laundered once prior to be tested. Also, three reusable gowns (Gore-Tex®, Compel™, and Asep™) were laundered according to standardized procedures-with and without bleach-and sterilized in a commercial facility to determine the effects of number of laundry/sterilization treatments on the liquid and viral barrier properties of the gowns. This standardized laundry procedures were developed by researchers according to the procedures recommended by manufacturers, companies, organizations, etc. The gowns were laundered, dried, and steam sterilized 1, 20, 40, 50, 60, 70, and 80 times. The standardized procedures were given in Table 3. Therefore, five and three samples from reinforced and seam area of five surgical gown fabrics with seven laundry levels were tested to evaluate liquid and viral barrier properties, respectively.

1. Liquid Barrier Test Methods

Synthetic blood was used as the challenge liquid for measuring the liquid barrier properties with liquid barrier test methods. The synthetic blood was made according to ASTM Standard Test Method F 23. 40. 01 (Draft) for the Resistance of Protective Clothing Materials to Synthetic Blood. The procedure for making synthetic blood was as follows:

Distilled water was boiled for 5 minutes to reduce biological contamination and allowed cool down to room temperature before mixing. Surfactant (Acrysol G110) was added to the distilled water and mixed 45 minutes at room temperature on a magnetic stirring plate. Red dye (Direct Red 081 dye) was added and mixed 15 minutes more. The surface tension of synthetic blood was around 40 dynes/cm which is about real blood's surface tension.

Three different methods were used to evaluate each fabric's resistance to liquid penetration as follows:

1) Impact Penetration Test (AATCC 42-1985, Water Resistance: Impact Penetration Test): A 17.8×33 cm^2 sample (outside surface up) with preweighed blotting paper was placed on an inclined surface and clamped with a 0.5 kg clamp. A 500 ml of synthetic blood was pored into the funnel of the tester to allow it to spray onto the sample (61 cm of height). Then the sample and blotting paper were removed, and the blotting paper was weighed. The difference in weight was used to determine the amount of synthetic blood penetrated.

2) Elbow Lean Test (developed by W. L. Gore and Associates, Inc.): This test method is a human factors approach to the liquid barrier test method that

Table 3. Wash formula for the study

Operation	Temp. (°C)	Time (min)	Water Level	pH	Chemical Titration
Flush 1	37.8	2	High	–	–
Flush 2	37.8	2	High	–	–
Break	71	8	Low	11.0 – 12.0	500 – 1,000 ppm Na_2O
Suds	71	6	Low	–	–
Bleach	65.6	8	Low	10.2 – 10.8	100 ppm Cl
Rinse 1	65.6	2	High	–	–
Rinse 2	54.4	2	High	–	Antichlor
Rinse 3	48.9	2	High	–	–
Rinse 4	37.8	2	High	–	–
Sour	37.8	5	Low	5.5 – 6.5	Cationic softener

is quick and easy to perform. A 7.6×12.7 cm^2 fabric sample (face side down) was placed over an ink pad saturated with synthetic blood and covered with a blotter. Pressure was applied quickly with an elbow to simulate actual use and the blotter was examined whether any blood penetrated. If any penetration occurred, it was reported as a failure.

3) Synthetic Blood Resistance Test (ASTM Standard Test Method F 23. 40. 01 (Draft) for the Resistance of Protective Clothing Materials to Synthetic Blood): A fabric 7×7 cm^2 was used as a barrier between 60 ml of synthetic blood and the viewing chamber. Then, 60 ml of synthetic blood was charged to fill the test cell chamber, and the test cell chamber was positioned vertically. The fabric was subjected to synthetic blood at the ambient condition (0 psi) for 5 minutes, the air pressure was raised to 2 psi of pressure for 1 minute, an then the air pressure was released and it returned to the ambinet condition (0 psi) for 54 minutes. The viewing chamber was monitored continuously durig the test period, and the test was stopped if visible penetration occurred. Results were reported as pass/fail.

2. Viral Barrier Test Method

The Viral Resistance Tests were performed according to the ASTM F 23. 40. 02 (Draft) Standard Test Method for the Resistance of Protective Clothing Materials by Blood-Borne Pathogens using Viral Penetration as a Test System. The procedure was the same as ASTM F 23. 40. 01 (Draft) except for the type of challenge. Thus, instead of synthetic blood, 10^8 PFU/ml of Phi-X174 bacteriophage suspension (adjusted to surface tension of 40 dynes/cm by adding 0.01% by volume surfactant-type Tween 80) was used to detect minute amounts of liquid containing microorganisms. This challenge liquid is one of the smallest known viruses (27 nm in diameter) and its size and shape were similar to those of the HBV and HIV. First, the test cell was autoclaved at 15 psi for 15 minutes. Then the fabric was subjected to a Phi-X174 bacteriophage suspension for one hour according to the procedure given by ASTM F 23. 40. 01. After exposed for one hour, the test sample was taken out of the test chamber and 5 ml sterile nutrient broth with 0.01% Tween 80 were added onto the viewing side of the test sample. The assay media was then pipetted off, transferred to a sterile container, and assayed for phage. This assay fluid was mixed with agar containing 0.5 ml assay media and 2 drops of *E. Coli C.* bacteria and was then poured over a petri plate and incubated at 37 C for 4-18 hours. Any viable virus which penetrated the test material and was picked up by the assay fluid formed a clear area, or plaque, on the petri plate. The clear areas represent bacteria which have been destroyed by the bacteriophage. Thus, the plaques were counted to determine the number of virus particles that penetrated the fabric. These tests were conducted at Nelson Laboratories in Salt Lake City, Utah.

III. RESULTS AND DISCUSSION

Since there was almost no variance among specimens of each gown fabric on each test, no statistical analysis was used. Thus, percentage of pass for each gown fabric was examined to compare fabric types with respect to their liquid and viral barrier properties. If any visible synthetic blood penetrated through the fabric, it was considered as a failure.

1. Results of Reinforced Area of New Surgical Gown Fabrics

The results for the liquid and viral barrier testing for the gown fabrics before laundered, dried, and sterilized are given in Table 4 and discussed with test methods as follows.

1) Impact Penetration Tests

The results indicated that no synthetic blood penetrated any of the new (i.e., unused) specimens of the surgical gown fabrics. Therefore, there was no difference in the liquid barrier properties of the

Table 4. Comparison of the liquid and viral barrier properties of new surgical grown fabrics

Fabric	Test Method			
	Impact Penetration	Elbow Lean	Synthetic Blood Resistance	Viral Resistance
Gore-Tex®	100[1]	100	100	100
Compel™	100	0	0	–
Asep™	100	0	0	–
Evolution®	100	0	0	–
Evolution Specialty®	100	100	100	100

[1] Percentage of pass ; 5 specimens were tested except for the Viral Resistance tests where only 3 specimens were tested.

surgical gown fabrics when they were splashed with the synthetic blood. Consequently, the surgical gown fabrics tested in this study initially have resistance to blood when it is splashed on the gown and no pressure is applied.

2) Elbow Lean Tests and Synthetic Blood Resistance Tests

The results for both tests were the same. The results indicated that no penetration occurred for the fabrics reinforced with the membrane or impervious film (Evolution® Specialty and Gore-Tex®). However, the fabric reinforced gowns (Compel™ and Evolution®) and the regular gown (Asep™) failed this test consistently. Consequently, this test was able to clearly differentiate the nonreinforced and fabric reinforced gowns from this impervious film or membrane reinforced gowns.

3) Viral Resistance Tests

Three samples of the Gore-Tex® and Evolution® Specialty gown fabrics that passed the Synthetic Blood Resistance test were subjected to this test. The results showed that the Gore-Tex® gown and Evolution® Specialty gown had no virus penetration at all. Thus, these impervious gowns provided perfect barrier protection.

2. Results of the Seam Area of New Surgical Gowns

Five fabric samples from the seam area in the sleeves were cut and tested to determine their liquid

Table 5. Comparison of the liquid and viral barrier properties of seam area of new surgical gown fabrics

Fabric	Test Method			
	Impact Penetration	Elbow Lean	Synthetic Blood Resistance	Viral Resistance
Gore-Tex®	100[1]	100	100	100
Compel™	100	–	–	–
Asep™	0	–	–	–
Evolution®	100	–	–	–
Evolution Specialty®	100	100	0	–

[1] Percentage of pass , 5 specimens were tested except for the Viral Resistance tests where only 3 specimens were tested.

and viral barrier properties since seams may have needle holes or unglued parts, and they may be subjected to splashes or pressure during an operation. The results for the liquid and viral barrier testing for the gown fabrics are given in Table 5 and discussed with test methods as follows.

1) Impact Penetration Tests

The results of this splash test showed that synthetic blood only penetrated the seams of the regular gown (Asep™). The Gore-Tex® gown has its seams attached with imperivious tape (Gore-seam™) to prevent any liquid and viral penetration through the seam area. The Compel™ gown has two layers of the fabric in the seam area, where the outer layer has the seam and inner layer has no seam. The synthetic blood penetrated through the outer layer seam, but the small amount liquid did not penetrate the inner layer that had no seam. Consequently, the Compel™ gown seams resisted the synthetic blood penetration because of its construction. No penetration occurred through the seams of the two disposable gowns (Evolution® and Evolution® Specialty) which are attached with adhesives.

2) Elbow Lean Tests

The Elbow Lean test was conducted on the seams of the surgical gowns that passed this test on the reinforced area. Therefore, the Gore-Tex® and Evolution® Specialty seams were tested. The results indicated that there was no liquid penetration through the Gore-Tex® and Evolution® Specialty gown seams.

3) Synthetic Blood Resistance Tests

The synthetic blood resistance test was performed on the seams of the surgical gowns that passed this test on the reinforced area. Therefore, Gore-Tex® and Evolution® Specialty seams were tested. The results indicated that the Gore-Tex® gown fabric had no liquid penetration through the seam area. However, liquid penetration occurred through the seams of the Evolution® Specialty gown. Consequently, it appears that gluing the seams in not sufficient to prevent liquid penetration under pressure.

3. Results of Laundering and Bleaching

The results for the effect of laundering, bleaching, and the number of laundering on the liquid and viral barrier properties of three reusable gown fabrics (Gore-Tex®, Compel™ and Asep™) are given in Table 6 and discussed below.

1) Effects of Laundering

The results of the Impact Penetration tests indicated that no liquid penetrated through the Gore-Tex® fabric after 80 processings. However, the Compel™ gown fabric only maintained its barrier properties up to 50 launderings, but after 60 launderings the specimens began to fail; and eventually, after 80 launderings, they had no barrier properties (i.e., all failures). The Asep™ gown fabric retained its barrier properties only at 1 laundering. After 20 launderings, the specimens began to fail, and they had no barrier properties after 40 launderings.

The results of the Elbow Lean tests and the Synthetic Blood Resistance tests showed that the synthetic blood penetrated the Compel™ and Asep™ gown fabrics at all laundry levels. However, the Gore-Tex® gown fabric passed after 80 processes. Therefore, the Gore-Tex® gown fabric has liquid barrier protection for at least 80 laundering and sterilizing processes.

Only the Gore-Tex® gown fabrics were tested for viral penetration since the Compel™ and Asep™ gown failed the Synthetic Blood Resistance tests. The results indicated that there was no failure for the Gore-Tex® gown fabric without bleach up to 80 processings except for only one failure at 80 processings (67% pass).

2) Effects of Bleaching

The results of the Impact Penetration tests indicated that the Compel™ gown fabrics treated with and without bleach began to fail after 60 launderings, although the number of failures with and without bleach was different (4 failures for samples

Table 6. Effects of laundering and bleaching on the barrier properties of reusable surgical gown fabrics

Fabric	Test Method							
	Impact Penetration		Elbow Lean		Synthetic Blood Resistance		Viral Resistance	
	B[1]	NB	B	NB	B	NB	B	NB
Gore-Tex[R]								
1	100[2]	100	100	100	100	100	100	100
20	100	100	100	100	100	100	100	100
40	100	100	100	100	100	100	100	100
50	100	100	100	100	100	100	100	100
60	100	100	100	100	100	100	100	100
70	100	100	100	100	100	100	0	100
80	100	100	100	100	100	100	0	67
Compel[TM]								
1	100	100	0	0	0	0	0	0
20	100	100	0	0	0	0	0	0
40	100	100	0	0	0	0	0	0
50	100	100	0	0	0	0	0	0
60	20	60	0	0	0	0	0	0
70	20	20	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
Asep[TM]								
1	100	100	0	0	0	0	0	0
20	40	60	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0

[1] B = Bleach used ; NB = No bleached used.

[2] Percentage of pass ; 5 specimens were tested except for the Viral Resistance tests where only 3 specimens were tested.

with bleach and 2 failures for samples without bleach). After 70 launderings, the results of liquid penetration were the same for samples with and without bleach. In the Asep[TM] gown fabrics, the samples with and without bleach began to fail at 20 launderings (3 failures for samples with bleach and 2 failures for samples without bleach). The Gore-Tex[R] gown passed the Impact Penetration test after 80 launderings, with and without bleach. Therefore, there was no meaningful effect of bleaching on the liquid barrier properties of three reusable gown fabrics tested on the Impact Penetration tests.

The results of the Synthetic Blood Resistance tests and Elbow Lean tests showed that there was no effect of bleaching on the barrier properties of the gowns. The Gore-Tex[R] gown fabric laundered with and without bleach passed both tests all of the time.

The results of the Viral Resistance tests indicated that the Gore-Tex[R] gown fabrics laundered without bleach failed at 80 launderings. However, the Gore-

Tex^R gown specimens laundered with bleach began to fail at 70 processings. Therefore, after 60 launderings, the membrane was deteriorating so they lost their viral resistance due to cumulative laundering, specially bleaching. Consequently, microorganisms penetrated the impervious membrane even though the synthetic blood did not.

4. Comparison of Test Methods

The test methods were compared based on the test results of five surgical gown fabrics (Tables 4 and 6). The results of the Synthetic Blood Resistance test and the Elbow Lean test were exactly the same for all fabrics. These tests were able to clearly differentiate the nonreinforced (regular) and fabric reinforced gowns from the impervious film or membrane reinforced gowns. One previous study also showed that the Synthetic Resistance test and the Elbow Lean test were albe to differentiate impervious gowns from regular gowns[8]. however, the Impact Penetration test could not differentiate between the different types of the gowns. This test only simulates the liquids splashing onto the gown fabrics without pressure. In actual conditions, the gowns might be subjected to pressures as well as splashes. Thus, the other test methods are better indicators of relative fabric protection. For the viral barrier testing, the Viral Resistance test was able to detect the microorganism even if liquid penetration did not occur.

IV. CONCLUSIONS AND IMPLICATIONS

Liquid and viral barrier properties of surgical gowns are very important. Most surgical team members want to be protected from contamination from the patient's bloodborne pathogens, and now this protection is required by law. Thus, in terms of liquid and viral barrier properties of surgical gowns, several conclusions and implications of this study can be made.

Liquid proof gowns should be used in the operating room rather than regular gowns or gowns reinforced with fabric since they provide comprehensive liquid and viral barrier protection. Regular or fabric reinforced gowns should be used only when exposure to blood and other fluids will be minimal and when only a potential splash of the body fluids is expected. Reusable gowns lose their barrier properties with cumulative launderings and sterilizations. If a hospital uses these types of gowns, the integrity of the barrier in the front and sleeves should be checked periodically after processing to insure that the gown is still providing the expected level of protection. A quality assurance program of this type is available for the Gore-Tex^R gown. In addition, this gown initially passed all liquid and viral barrier tests in the reinforced areas and sleeve seam areas. These barrier properties can be expected to last through at least 70 launderings and sterilizations. Consequently, it is the safest reusable gown available. The nonreinforced (Asep^{TM}) and fabric reinforced (Compel^{TM}) reusable gowns only provided splash protection initially, and this protection deteriorated after 20 and 60 launderings and sterilizations, respectively. Consequently, their use should be limited to low risk situations. The disposable Evolution^R Specialty was comparable to the Gore-Tex^R gown with respect to its barrier protection, except in the sleeve seam area. The disposable Evolution® gown was roughly equivalent to the Asep^{TM} and Compel^{TM} gowns. Again, if the surgical staff is at low risk, the regular and fabric reinforced gowns are appropriate. However, if protection is needed, a film or membrane reinforced gown is required.

Recommendations for Further Study

In actual use, we have encounted various situation in terms of types of liquids, including soiling and staining agents and movement of surgical staff (abrasion, stretching, and flexing). Therefore, we recommend that a hospital wear study be conducted where reusable gowns are worn by surgical person-

nel in the operating room, are laundered and sterilized, and are removed periodically for barrier testing.

The two ASTM methods-the Synthetic Blood Resistance test and the Viral Resistance test can distinguish differences in the levels of protection provided by single-layer, regular gowns and fabric reinforced gowns as compared to gowns reinforced with imperivous films, coatings, and membranes. However, this high level of protection is probably not necessary in all surgeries. It would be interesting to conduct a study in several large hospitals, where variables relating to the risk of contracting a bloodborne disease are documented and correlated (i.e., type of surgical procedure, length of the operation, type of procedures done by each person in the operating room, type of gown worn, barrier properties of the gown fabrics, amount of fluid penetration through the gown during surgery, areas of penetration, patient characteristics, etc.). In this way, gowns with lower levels of protection could be used for some surgical procedures, whereas, gowns which provide high levels of barrier protection could be selected for others. Consequently, much more work is needed if we are to provide our healthcare professionals with clothing that provides adequate protection from bloodborne pathogens and does not increase the cost of healthcare substantially.

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