Comparison of Prosthetic Materials for Abdominal Wall Reconstruction in the Presence of Contamination and Infection

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Abdominal wall defects resulting from trauma, invasive infection, or hernia present a difficult problem for the surgeon. In order to study the problems associated with the prosthetic materials used for abdominal wall reconstruction, an animal model was used to simulate abdominal wall defects in the presence of peritonitis and invasive infection. One hundred guinea pigs were repaired with either polytetrafluorethylene (PTFE) or polypropylene mesh (PPM). Our experiments included intra-operative contamination with *Staphylococcus aureus*. We found significantly fewer organisms (p < 0.05) adherent to the PTFE than to the PPM when antibiotics were administered after surgery, as well as when no antibiotics were given. In the presence of peritonitis, we found no real difference in numbers of intraperitoneal bacteria present whether PTFE or PPM was used. In all instances, the PTFE patches produced fewer adhesions and were more easily removed. From these experiments, it appears that PTFE may be associated with fewer problems than PPM in the presence of contamination and infection.

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SYNTHETIC MATERIALS have been used to replace and to reinforce the abdominal wall for many years.[1,2] The necessary chemical and physical properties of an abdominal wall prosthesis include: (1) hypoallergenicity; (2) a lack of proven carcinogenicity and inflammatory response; (3) the ability to withstand sterilization; (4) the ability to not be modified by body fluids; (5) the ability to not induce a foreign body response; and (6) adequate strength.[3,4] Many materials have been compared on the basis of strength[5] and histologic tissue response;[6] however, few investigators have studied the properties of different prosthetic materials in the presence of bacterial contamination or overt infection.

The most widely used material for abdominal wall replacement and reinforcement during hernia repair is polypropylene mesh (PPM) or Merlex®.[7] In 1976, we undertook a clinical study of polypropylene mesh and noted certain characteristics that caused difficulties in the presence of infection.[8] Since then, microporous polytetrafluoroethylene (PTFE), or Gore-Tex®, has gained widespread use as a vascular prosthetic material[9] and has demonstrated satisfactory tissue acceptance, ingrowth, and strength. In our present study, we compared PTFE to PPM for abdominal wall replacement in the presence of graded bacterial contamination.

One goal of this study was to compare the number of bacteria found on both PTFE and PPM after intra-operative contamination, similar to what might occur during elective ventral hernia repair. In a second series of experiments, we performed abdominal wall replacement in the presence of peritonitis. The bacterial concentration of intraabdominal fluid was obtained in an effort to determine if PTFE decreased peritoneal drainage in comparison to PPM in the presence of peritonitis, as has been suggested by others.[10] Qualitative assessments were made as to the degree of adhesion formation produced by each prosthetic material.

Materials and Methods

Experimental Bacterial Contamination

Adult female Hartley guinea pigs, weighing 350–400 grams, were anesthetized with ketamine (37.5 mg/kg) and xylozine (5 mg/kg) administered intramuscularly. Using sterile technique, a 4-cm midline skin incision was made to the linea alba, and the surrounding subcutaneous tissues were dissected free from the abdominal wall. A 2-cm² full-thickness segment of midabdominal wall was excised. The defect was repaired by suturing a 2-cm² patch of prosthetic material to the abdominal wall margins with 4-0 running polypropylene suture placed 4 mm from the edge of the defect. Forty animals

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TABLE 1. *Adhesion Formation Indices for All Animals*

Group	PTFE*†	PPM*†	n
Group A (contamination without antibiotics)	1.8 ± 0.1	3.9 ± 0.1	20
Group B (contamination with postoperative antibiotics)	1.2 ± 0.2	3.1 ± 0.2	20
Group C (contamination with preoperative antibiotics)	1.4 ± 0.2	3.7 ± 0.3	20
Group D (peritonitis)	1.5 ± 0.2	3.8 ± 0.1	16
Controls	1.0	3.0	20

* Each value or adhesion index is determined from the average of the qualitative numerical grade assigned to each animal within the individual groups at the time of patch removal (±SD). 1 = no adhesions; 2 = minimal adhesions; 3 = moderate adhesions; 4 = dense adhesions.
† $p < 0.05$, $\tau = 1.06$ − Kendall's rank coefficient.

had abdominal wall reconstruction with polypropylene mesh (Marlex), and 40 animals had abdominal wall reconstruction with polytetrafluoroethylene soft tissue patch (Gore-Tex).

Prior to skin closure, 30 animals that were repaired with PPM and 30 animals that were repaired with PTFE received an injection of 10^8 *Staphylococcus aureus* in 0.5 ml phosphate buffered saline (PBS) on the surface of the prosthetic patch. The skin was closed over the patch with 4-0 interrupted dermalon sutures. The remaining 10 animals that were repaired with PTFE and the remaining 10 animals that were repaired with PPM received no bacterial challenge and served as noninfected controls.

The animals were housed individually, fed laboratory chow (Purina® #5025) and given water *ad libitum*. On the fifth day after surgery, the animals were sacrificed with an intracardiac injection of 1 ml of T61 Euthanasia Solution (Hoechst Pharmaceuticals, Somerville, NJ). The patches were immediately removed under sterile conditions and placed in a glass mortar containing 5 ml of PBS. The patches were homogenized for 5 minutes, and the homogenate was serially diluted, plated on nutrient agar, and incubated overnight at 37 C. The bacterial counts obtained were expressed as the logarithm of the number of organisms per square centimeter of prosthetic patch.

At the time of sacrifice, all wounds were examined for qualitative assessment of adhesion formation by a

TABLE 2. *Quantitative Bacterial Cultures from Group D for Peritoneal Fluid and Prosthetic Material*

	PTFE*	PPM*
Peritoneal fluid $\log_{10}$ organisms/ml	6.0 ± 0.4	6.3 ± 0.5
Prosthetic patch $\log_{10}$ organisms/cm^2	5.7 ± 0.6	6.1 ± 0.5

* Each value is determined from the average of the individual counts for each animal (N = 16) (±SD).

classification of four grades: grade 1, no adhesions present; grade 2, minimal adhesions requiring very little blunt dissection; grade 3, moderate adhesions requiring aggressive dissection; and grade 4, dense adhesions requiring meticulous sharp dissection to free the prosthetic graft from the abdominal viscera. Each animal received a numerical assessment at autopsy for the degree of adhesion formation, and these values were subsequently averaged within each group with a resultant adhesion index for each group (Table 1).

The animals were placed in one of four groups; each group contained 20 guinea pigs, of which 10 were reconstructed with PTFE and 10 with PPM. Group A animals were contaminated with *Staphylococcus aureus* and received no antibiotics. Group B animals were contaminated with *S. aureus* and treated with an antibiotic (gentamicin, 8 mg/kg) administered intramuscularly 24 hours after implantation and every 12 hours thereafter until sacrifice. Group C animals were contaminated and given a single dose of antibiotic (gentamicin, 8 mg/kg) 1 hour prior to implantation. The remaining 20 animals were not contaminated and served as noninfected controls for the assessment of adhesion formation. Sensitivity of the *S. aureus* to gentamicin was confirmed by Bauer-Kirby disc diffusion techniques.

Experimental Peritonitis

Group D consisted of 20 animals that were injected intraperitoneally with 10^3 *Streptococcus faecalis*, 10^4 *Escherichia coli*, and 10^5 *Bacteroides fragilis* in 2 ml of 2.5% sterilized fecal solution. Forty-eight hours after injection, in the presence of fibrinopurulent peritonitis, the animals underwent abdominal wall excision and reconstruction as previously described for groups A, B, and C. Ten animals were repaired with PPM and 10 animals with PTFE. These animals received no antibiotics.

Five days after implantation, the animals were sacrificed and quantitative bacterial cultures performed on the peritoneal fluid and the respective patches. We chose this sampling period based on our observations in a pilot set of experiments, in which a high incidence of wound dehiscence and graft extrusion was observed after 5 days, producing spurious bacteriologic data. This pilot study was not included in our present study. The number of organisms within the peritoneal fluid was expressed as the logarithm of organisms per milliliter, and the bacterial counts from the prosthetic patched were expressed as the logarithm of organisms per square centimeter of prosthetic patch (Table 2). In groups A, B, C, and D, full-thickness, cross-sectional samples of intact graft or mesh were taken for histologic sampling from each animal.

Results

Experimental Bacterial Contamination

There was very little qualitative difference in the appearance of the incisional wounds between those animals implanted with PTFE and those implanted with PPM in groups A, B, and C during the 5-day postoperative period. All wounds became erythematous and indurated, and a similar proportion of wounds in each group spontaneously drained purulent material.

At autopsy, all wounds had fibrinopurulent encasement of the prosthetic patch and frank pus between the patch and abdominal skin closure. In groups A, B, and C, the PTFE patches were significantly easier to remove than the PPM patches. The underlying viscera were consistently adherent to the PPM patches with grade 4 adhesions occurring in group A (Fig. 1). The adhesions surrounding the PTFE patches could easily be lysed with gentle blunt dissection. The adhesions attached to the PPM patches frequently required sharp dissection for removal. By creating an adhesion index from qualitative assessment at the time of patch removal, it was possible to show a significant difference between the PTFE and PPM groups ($p < 0.05$; $\tau = 1.06$ Kendall's rank coefficient) (Table 1). The wounds in the control group were similarly examined and fewer adhesions were found than in the infected groups. Even in the absence of infection, the PPM patches were much more adherent than the PTFE patches (Table 1). There was no bacterial growth found in the control patches. Comparison of the bacterial counts between the PTFE and PPM patches was statistically different in group A (Fig. 2). The PTFE patches contained 100-fold fewer organisms per centimeter squared than did the PPM patches ($p < 0.05$ Student's paired t test). In group B, the overall counts were less than in group A. The PTFE patches in group B contained significantly fewer organisms per square centimeter than did the PPM prosthetic group ($p < 0.05$ Student's paired t test) (Fig. 2). In group C, there was no statistical difference between the bacterial counts for the two types of prosthetic patch. The $\log_{10}$ organisms per square centimeter for PTFE and PPM were 5.8 ± 0.6 and 6.4 ± 0.9, respectively.

Histologic sampling revealed very little difference between animals reconstructed with PTFE and those reconstructed with PPM in groups A, B, and C. All specimens showed an acute inflammatory response with a large amount of purulent exudate.

Experimental Peritonitis

Animals in group D exhibited a generalized purulent peritonitis at 48 hours after injection of bacteria-fecal solutions. Bacterial cultures revealed all three of the
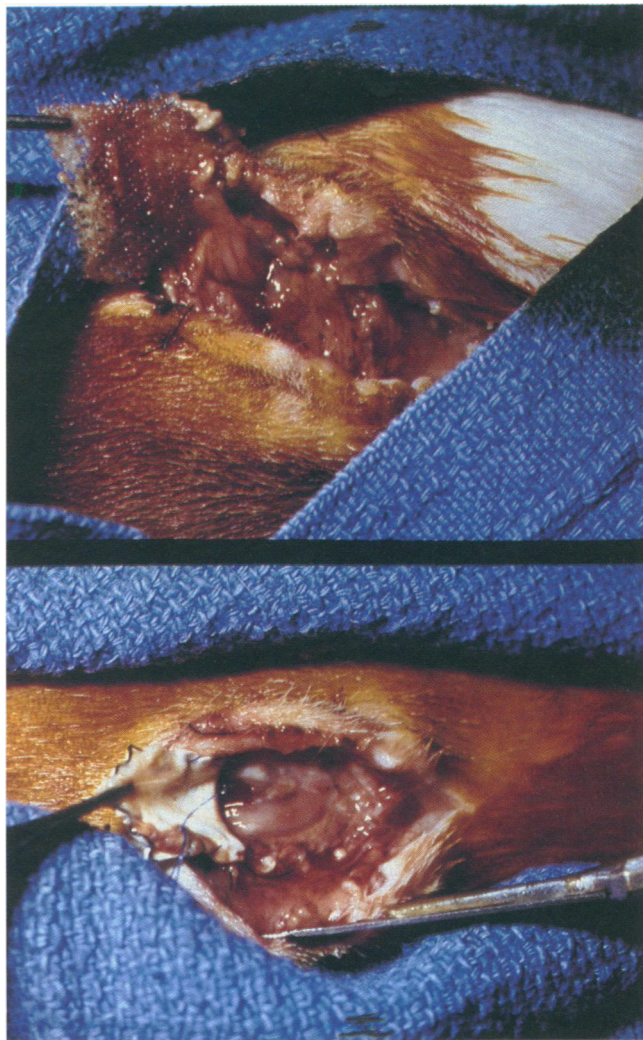

FIG. 1. PPM removed from an animal in group A at 5 days after implantation (top). PTFE removed from an animal in group A at 5 days after implantation (bottom).

inoculated organisms to be present. Fibrinous exudates were present on the viscera along with serosanguinous peritoneal fluid at the time of abdominal wall excision and reconstruction.

No subjective differences were noted in the skin surrounding the incision between animals repaired with PTFE and animals repaired with PPM. All wounds had less surrounding erythema and induration than those in groups A, B, or C. Two animals from the PTFE group and two animals from the PPM group died after the reconstructions. Death appeared to be related to sepsis as the animals had ruffled coats and crusting of both eyes prior to death.

At autopsy, the adhesions were significantly reduced in those animals implanted with PTFE. As in groups A, B, and C, the removal of PPM required sharp dissection,
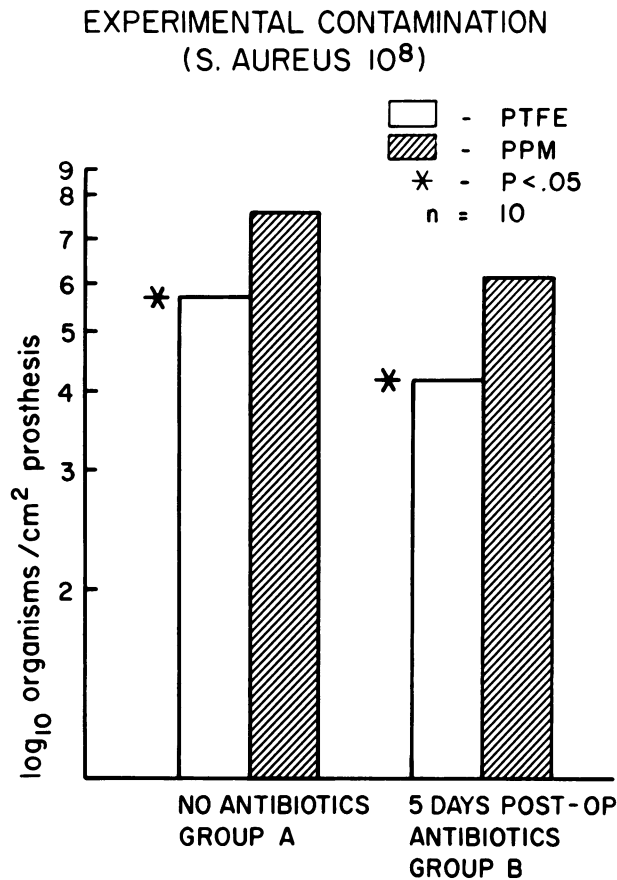
FIG. 2. Quantitative bacterial counts of the two different prostheses at 5 days after contamination.

whereas PTFE simply peeled out once the surrounding suture was cut (Table 1).

The amount of peritoneal fluid present at autopsy was similar for both prosthetic groups, varying from 0.15 ml to 0.2 ml. There were no significant differences between bacterial counts of the peritoneal fluid and the prosthetic patches for the two groups (Table 2).

Histologic sampling revealed very little difference between the two prosthetic materials. All specimens showed an acute inflammatory response with a large amount of purulent exudate present.

Discussion

Very little information is available regarding specific properties of prosthetic materials for abdominal wall reinforcement in the presence of infection. It was the purpose of this experiment to compare PPM and PTFE in two situations of simulated specific clinical problems.

The study was designed to simulate contamination as it might occur while using these prosthetic materials for elective abdominal wall reinforcement (i.e., herniorrhaphy). We chose S. aureus as the infecting organism because it is frequently associated with intraoperative contamination. Elek et al.[11] showed that, when foreign materials are present, fewer organisms are required to produce a clinical infection. The foreign material acts as an adjuvant by decreasing the number of bacteria necessary to produce an infection. Some materials seem to be more effective than others when used as adjuvants in infection.

In the first portion of this experiment, PTFE prostheses in groups A and B grew significantly fewer organisms after contamination than did the PPM patches. When antibiotics were administered after contamination, the overall total bacterial counts in each group were reduced; however, the PTFE prostheses continued to contain statistically fewer organisms. Surprisingly, when antibiotics were administered prior to contamination (group C), there was not as large a difference between bacterial counts for the two prosthetic materials. Although the PTFE patches continued to contain fewer organisms, the difference was not statistically significant, and the overall counts were greater than group B. Our experiments did not indicate that the "decisive period," as described by Miles,[12] affected our outcome. From our data, postoperative antibiotics produced lower bacterial concentrations per square centimeter than did a single preoperative dose, which suggests that postoperative, in addition to preoperative, antibiotics are indicated for abdominal wall reconstruction if contamination occurs.

It may be that PTFE is more resistant to the production of a clinical infection if contamination occurs intraoperatively. This seems to be a logical assumption since, in the absence of antibiotics or with antibiotics administered after contamination, the PTFE patches consistently had 100-fold fewer organisms per square centimeter than did the PPM patches (Fig. 2). Bacterial adherence is a complex phenomenon involving stereospecific interaction between bacterial ligands and receptor sites on the foreign body surface.[13] The magnitude of adherence is related to the type of bacteria and foreign body involved in the interaction.[14] Therefore, because of the microporous structure (30μ) of PTFE and its decreased wetting properties, compared to the macroporous surface of PPM, PTFE may serve as a less hospitable nidus for bacterial adherence than does PPM.

Marlex (PPM) gained widespread use in clinical situations during the Vietnam War.[15] However, there have been long-term complications associated with PPM that include fistula formation, draining sinuses, and mesh extrusion.[8,16,17] A commonly ascribed basis for using PPM for acute abdominal wall reconstruction is that it

may, by virtue of its porosity, allow macromolecular substances to drain from the infected peritoneal cavity. The use of a microporous material, such as PTFE, in this clinical setting has been questioned because of possible inhibition of peritoneal drainage. However, there is evidence that the peritoneal cavity is sealed and becomes impermeable to drainage within 12 hours even when PPM is used.[18] This fact supports the finding by others[19] that it is impossible to drain the entire peritoneal cavity in diffuse peritonitis. Because of this, we created an animal model to simulate abdominal wall defects in the presence of peritonitis or invasive infection. In our study, animals reconstructed with PTFE in the presence of peritonitis had the same mortality and intra-abdominal bacterial concentrations as did animals reconstructed with PPM (Table 2). As there was no statistical difference between bacterial counts and mortality, we concluded that PPM does not promote greater peritoneal drainage.

The bacterial counts obtained from the patches in the peritonitis model were similar, with the PTFE values slightly less than the PPM counts; there was no statistical difference (Table 2). This is somewhat at odds with the previous finding from the contamination model but may be due to a difference in adherence properties associated with gram-negative organisms compared to S. aureus.

The fact that PTFE reconstruction did not enhance mortality or increase intra-abdominal bacterial counts associated with peritonitis is an important finding in that it does not preclude the use of PTFE for abdominal wall replacement associated with invasive sepsis. This finding, along with significantly fewer adhesions produced by PTFE (Table 1), suggests PTFE may be as useful as, if not more useful than, PPM for acute abdominal wall reconstruction secondary to infection and traumatic abdominal wall loss.

The lack of differences in histologic findings between the prosthetic groups may be related to the short sampling time (5 days) and the presence of infection. Others[20] have shown a much more desmoplastic response to PPM than to PTFE; however, these studies performed histologic sampling several weeks after implantation and in the absence of sepsis.

In conclusion, PTFE produced less bacterial adherence in an intraoperative contamination model and created fewer adhesions in control wounds, contaminated wounds, and peritonitis. In addition, PTFE does not appear to worsen the course of peritonitis when used as an abdominal wall prosthesis. From these experiments, it appears PTFE may be preferred to PPM in certain clinical situations; however, well-controlled clinical trials are required before the long and generally favorable experience with PPM can be discounted.

References

1. Ogilvie WH. The late complications of abdominal war wounds. Lancet 1940; 2:253–256.
2. Usher FC, Fries JG, Oschner JL, Tuttle UD. Marlex mesh—a new plastic mesh for replacing tissue defects. Arch Surg 1959; 78:138–145.
3. Cumberland VH. A preliminary report on the use of prefabricated nylon weave in the repair of ventral hernia. Med J Aust 1952; 1:143–144.
4. Scales JT. Discussion on metals and synthetic materials in relation to tissues. Tissue reactions to synthetic materials. Proc Roy Soc Med 1953; 46:647–652.
5. Jenkins SC, Klamer TW, Parteka JJ, Condon RE. A comparison of prosthetic materials used to repair abdominal wall defects. Surgery 1983; 94:392–398.
6. Lamb JP, Vitale T, Kaminski DL. Comparative evaluation of synthetic meshes used for abdominal wall replacement in femoral-distal reconstruction. Surgery 1982; 92:921–930.
7. Calne RY. Repair of bilateral hernia with mersilene mesh behind rectus abdominus. Arch Surg 1974; 109:532–536.
8. Voyles CR, Richardson JD, Bland KI, et al. Emergency abdominal wall reconstruction with polypropylene mesh. Ann Surg 1981; 194:219–223.
9. Bergman JJ, Veith F, Bernard VM, et al. Randomization of autogeneous vein and PTFE grafts in femoral distal reconstruction. Surgery 1982; 92:921–930.
10. Goris RA. Ogilvie's method applied to infected wound disruption. Arch Surg 1980; 115:1103–1107.
11. Elek SD, Conen PE. The virulence of Staphylococcus pyogenes for man: a study of the problem of wound infection. Br J Exp Pathol 1957; 38:573–579.
12. Miles AA. Nonspecific defense reactions in bacterial infections. Ann NY Acad Sci 1956; 66:356–369.
13. Franson TR, Sheth NK, Rose HD, Sohnle PG. Scanning electron microscopy of bacteria adherent to intravascular catheters. J Clin Microbiol 1984; 20:500–505.
14. Sugarman B. In vitro adherence of bacteria to prosthetic vascular grafts. Infection 1982; 10:2–11.
15. Schmitt HJ Jr, Grinnan GLB. Use of Marlex mesh in infected abdominal war wound. Am J Surg 1967; 113:825–828.
16. Mathes SJ, Stone HH. Acute traumatic losses of abdominal wall substance. J Trauma 1975; 15:386–390.
17. Stone HH, Fabian TC, Turkleson ML, Turkleson ML, Jurkiewicz MJ. Management of acute full-thickness losses of the abdominal wall. Ann Surg 1981; 193:612–618.
18. Boyd WC. Use of Marlex mesh in acute loss of the abdominal wall due to infection. Surg Gynecol Obstet 1977; 144:251–252.
19. Haller JA, Shaker IJ, Donahoo JS, et al. Peritoneal drainage versus non-drainage for generalized peritonitis from ruptured appendix in children. Ann Surg 1973; 177:595–599.
20. Elliott MP, Juler GL. Comparison of MARLEX mesh and microporous TEFLON sheets when used for hernia repair in the experimental animal. Am J Surg 1979; 137:342–344.

DISCUSSION

DR. MARK M. RAVITCH (Pittsburgh, Pennsylvania): I have three or four options. I can discuss the paper presented in the abstract; I can discuss the paper that was given so deftly and smoothly on this platform; or I can discuss the manuscript. As has already been suggested, no one of these bears any relationship to the others, and I can give my own paper.