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SURGICAL ENDOSCOPY and Other Interventional Techniques

A lightweight polypropylene mesh (TiMesh) for laparoscopic intraperitoneal repair of abdominal wall hernias

Comparison of biocompatibility with the DualMesh in an experimental study using the porcine model

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Abstract
Background: Despite numerous experimental studies, conducted most often with the open small-animal model, the ideal structure for a mesh with maximum biocompatibility in the intraabdominal region has yet to be found. To date, few experimental models have been concerned with the laparoscopic intraabdominal implantation of meshes. Numerous experimental and clinical studies appear to have identified expanded polytetrafluoroethylene (ePTFE), in the form of DualMesh, as the gold standard. Since publications have reported fistula formation and marked adhesions to be associated with the use of polypropylene meshes, only few studies have investigated meshes made of this material. It is known, however, that a reduction in the amount of material and an increase in pore size results in better mesh biocompatibility.
Methods: Six pigs each underwent laparoscopic intraabdominal placement of either a TiMesh or a DualMesh, both of which were prepared for implantation in standardized fashion. After 87 ± 2 days, the pigs were killed, and postmortem laparoscopy was performed, followed by the removal of the tissue embedding the mesh for assessment of adhesions and shrinkage, and for histologic workup. The specimens were processed both histologically and immunohistochemically.
Results: In all but one case, the greater omentum adhered, usually over discrete areas, to the mesh. In every case the omentum was separable from the mesh surface only by sharp dissection. With the titanium-coated polypropylene meshes, the average total adhesion area was only 0.085, as compared with 0.25 for the GoreTex meshes ($p = 0.055$). The GoreTex meshes showed an average shrinkage to almost half of the original surface area (median, 0.435). The average shrinkage of the TiMesh, was to 0.18 of the original area ($p = 0.006$), which thus was significantly smaller. Determination of the partial volume of the inflammatory cells showed significantly lower median figures for the TiMesh ($p = 0.009$). Measurements of the proliferation marker Ki67 showed significantly higher values for ePTFE than for TiMesh ($p = 0.011$). The apoptosis index was significantly higher for the ePTFE membranes ($p = 0.002$).
Conclusion: Titanium-coated polypropylene mesh (TiMesh) is clearly superior to the DualMesh in terms of biocompatibility, and is thus suitable for the laparoscopic intraperitoneal repair of abdominal wall and incisional hernias.

Key words: Abdominal wall hernia — Biocompatibility — ePTFE — Laparoscopic hernia repair — Mesh — Polypropylene

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Despite numerous experiments, the search to find an ideal mesh for laparoscopic intraperitoneal use has not yet been concluded. In the search for maximum biocompatibility, i.e., good integration into the surrounding tissue with minimal inflammatory reaction and no formation of adhesions to intraabdominal structures, numerous experiments have been conducted with the rodent model using the open technique [1–6, 13], and, rarely, also with the canine model [13]. Highly practicable, laparoscopic implantation in the pig has only rarely been reported [9].

To date, little has been published on long-term clinical results with laparoscopic or histologic evaluation [16, 17]. If we follow the reported experimental and clinical results of these studies, expanded polytetrafluoroethylene (ePTFE) is considered the gold standard for

intraperitoneal application. In its DualMesh form (GoreTex), it has already been used in several thousand repairs of abdominal wall hernias. However, here too, the results leave room for much improvement, and, as LeBlanc et al. [19] have been able to show, improvement can indeed be achieved. Seromas, although only rarely requiring treatment, occur in some 8% of the cases receiving ePTFE mesh. Increasingly, reports of complications including extensive infection, migration as a result of inadequate fixation, and recurrences are being published [8, 12, 18, 21]. In such cases, the follow-up periods are, on the average, still very short (frequently only 12–24 months), with longer follow-up periods showing even higher recurrence rates of approximately 10% to 15% [18, 19]. It appears that by providing 3 to 6 cm more overlap at the margins of the hernial orifice, and more extensive fixation with transfascial sutures and additional stapling, the recurrence rates can be reduced by about one-half [19]. In the clinical setting, the short- and long-term complication rates show no material-related differences [18].

Polypropylene meshes, generally considered the standard for the open repair of abdominal wall hernias, are reported to be associated with abundant adhesions and the formation of bowel fistulas, in both experimental and clinical settings, and thus are not considered suitable for use in the intraperitoneal space. For this reason, only a few reports on their successful laparoscopic application are to be found in the literature [8, 26]. Also used are meshes made of polypropylene and ePTFE combined, in some cases also with differing structures. A search through the literature for the "ideal mesh" turns up publications of experimental results, admittedly in the open model, showing that both the material of the mesh and its structure are of essential importance for the development of adhesions [6]. In our view, not only the problem of adhesions, but also that of "shrinkage," has to date received too little attention [7, 14]. Triggering factors appear to be not only chronic remodeling processes in the tissue surrounding the mesh, but also simply contact with different fluid media such as blood, saline solution, and water, so that the interaction of the surroundings with the mesh materials seem to be more complex that has been assumed previously. For this reason, shrinkage of the implanted material appears to play a major role in the development of recurrences.

To properly account for the aspects of laparoscopic feasibility and the tissue reaction to the implanted mesh, including macroscopic and histologic evaluation of adhesions and shrinkage, we used the following experimental design.

Materials and methods

Mesh types

Two different types of mesh were implanted: (a) in the first group, a 10 to 15-cm large titanium-coated polypropylene mesh weighing 35 g/m^2 (TiMesh) from GfE (Medizintechnik GmbH, Nuremberg, Germany) was used, and in the second group, a 10 × 15-cm ePTFE mesh with a (b) smooth or (c) textured surface (DualMesh) from W.L. Gore (Flagstaff, AZ, USA) was used.

Experimental protocol

The animal experiment was officially approved in accordance with the animal protection law, under AZ 22-2684-04-08-65-02. Before implantation, each mesh was provided with 10 sutures, and the two ends of each of which were clipped together for identification purposes. The polypropylene meshes were fixed with no. 1 titanium-coated polypropylene sutures, and the ePTFE meshes with no. 0 PTFE sutures.

A total of 12 domestic pigs, 6 per group, with an average weight of 28 kg were used. Intraabdominal implantation of the meshes was accomplished laparoscopically using two 5-mm working trocars and a 12-mm optic trocar. After disinfection, the 12-mm trocar was placed in the right lower abdomen via a minilaparotomy together with a 5-mm trocar after the establishment of a pneumoperitoneum. The second 5-mm trocar was placed in the left lower abdomen.

The meshes were introduced into the abdominal cavity via the 12-mm trocar and unfolded. Via tiny incisions, the sutures were drawn through the fascia and abdominal wall to the outside with the aid of a suture passer, and the mesh was positioned in the middle/upper abdomen. To check for tension-free positioning of the implant, the pneumoperitoneum was reduced, and the sutures were knotted on the fascia. The trocars were removed under direct vision, and the fascia at the minilaparotomy was closed. Finally, the skin was closed.

After 87 ± 2 days the animals were killed with an overdose of potassium and trichloroethanediol. The animals then were submitted to an autopsy, which included a diagnostic laparoscopy followed by removal of the mesh plus tissue (specimen). Adhesion areas and the dimensions of the mesh were measured in the fresh specimen. The documented areas were entered into a computer and submitted to a morphologic analysis using planimetric computation software (Image Tool for Windows (UTHSCSA), Version 3, Department of Dental Diagnostic Science, University of Texas Health Science Center, San Antonio, Texas, USA).

Histology and immunohistochemistry

From each of the five tissue samples, more than 10 histologic 5-μm-thick sections were prepared and stained with hematoxylin and eosin (H&E), elastic-van Gieson's (EvG) stain, Goldner's stain, and Prussian blue stain. The morphometric analysis was performed at the interface within a distance of 1,000 μm from the fibers of the mesh with four series of measurements, each made at defined sites in the interface.

The partial volume of the inflammatory infiltrate (%PV) of the connective tissue and the proportion of macrophages, monocytes, and B- and T-lymphocytes were determined manually after labeling with appropriate monoclonal mouse/rabbit antibodies (ChemMate, Dako Cytomation, Glostrup, Denmark).

Immunohistochemical analysis

Specimens free of necrosis and hemorrhage were obtained from all the animals. The material was routinely fixed in 4% formaldehyde solution and embedded in paraffin. After slicing into 4-μm-thick sections, the preparations were dewaxed in xylene and then rehydrated. Endogenous peroxidase activity was blocked by 3% hydrogen peroxide in methanol for 30 min. After brief rinsing in phosphate-buffered saline, sections were preincubated with avidin-biotin (Camon Laboratory Service (SP 2001), Wiesbaden, Germany) for 15 min to reduce nonspecific background staining. The preparations were covered with normal goat serum for 20 min and then incubated with the primary antibodies (Ki-67 [Clone MIB1], dilution 1:1000; Dianova, Hamburg, Germany). The sections were then washed with phosphate-buffered saline, incubated with biotinylated goat antimouse immunoglobulin G (BioGenex, Hamburg, Germany) for 30 min, and covered with peroxidase-conjugated streptavidin (DAKO Cytomation, Glostrup, Denmark). The peroxidase reaction was allowed to proceed for 8 min, with 0.05% 3,3-diaminobenzidine tetrahydrochloride solution as a substrate. Slides were counterstained with hematoxylin and finally mounted.

Sections known to stain positively were included in each batch, and negative controls also were obtained by replacing the primary antibody with mouse or goat ascites fluid (Sigma-Aldrich Biochemicals, St. Louis, MO, USA).

In situ end labeling (ISEL) for detection of apoptotic cells was performed according to previously published methods [12] and adopted for paraffin-embedded tissue [14]. Tissue sections (4 μm) were dewaxed, dehydrated, and air-dried for 15 min. The sections then were incubated for 30 min at 37°C with 5.0-μg proteinase K (Sigma-Aldrich Biochemicals) diluted in 50 mmol/l Tris-HCl buffer (pH 8.0) containing 1 mmol/l of ethylenediaminetetraaetic acid (EDTA). Blocking of endogenous peroxydase then was effected. Next, 40 μl of the following labeling mixture was applied to each section: 0.01 mmol/l of deoxyadenosine triphosphate, deoxycitidine triphosphate, deoxyguanosine triphosphate, and fluorescein-labeled deoxyuridine triphosphate (dUTP) (Boehringer Mannheim, Germany) made up on 50 mmol/l Tris-HCl (pH 7.5) containing 5 mmol/l $MgCl_2$ 10 mmol/l o-mercaptoethanol, 5 mg/ml bovine serum albumin, and 20 U/ml Klenow DNA polymerase fragment (Boehringer Mannheim, Germany). Siliconized coverslips then were placed over the sections to minimize drying. Incubation was continued for a further 1 h at 37°C. The reaction was terminated by 3 × 5-min washes with distilled water. Control sections omitting the DNA polymerase were included. In preliminary experiments, a range of proteinase K and Klenow fragment concentrations was tested. The one described this report gave optimum positivity with a minimum of nonspecific staining. Positive controls comprising sections treated with DNAse I to introduce DNA breaks in all nuclei were used.

Fluorescein-labeled cells were identified using an antifluorescein Fab fragment conjugated with horseradish peroxydase. The antibody was diluted 1:200 in 50 mmol/l Tris-HCl (pH 7.4) containing 0.15 m NaCl (TRIS-NaCl buffer). Sections then were washed 3 × 5 min in TBS. The peroxydase reaction was allowed to proceed for 8 min, with diaminobenzidine (DAB) tetrahydrochloride as a substrate, before mounting. With all staining procedures, two sections from two different paraffin-embedded tissue blocks were stained for each animal.

Assessment of ISEL-positive cells

Slides were coded and assessed independently for the presence of positively staining ISEL-positive cells. Under ×40 magnification, the entire section was scanned, evaluating about 150 square fields using an eyepiece integration grid. Diaminobenzidine (DAB)-positive nuclei or bodies indicating the presence of fragmented DNA were scored. In the case of cytoplasmic staining, the cell was scored only when there was concomitant staining of the nucleus. Apoptosis was expressed as an apoptotic index (AI), which is the number of apoptotic cells among 100 tumor cells counted.

Immunohistochemical assessment

Assessment of MIB-1 positivity was accomplished by counting an average of 800 cells (200 cells in each of four different fields) per sample. Two slides were counted in every case, giving a total of 1,600 evaluated cells. An eyepiece integration grid was used to ensure that cells were evaluated once only. Stained cell nuclei were considered to be positive under a light microscope (magnification ×40).

We calculated the MIB-1 index as the percentage of cells with positive nuclear staining in the total number of cells counted. Regions exhibiting the highest positivity for MIB-1 in a given case were selected for evaluation. Areas within each section showing maximum reactivity were identified and confirmed by a preliminary counting of 200 cells.

The intraobserver error was calculated in a preliminary examination using the same material. It was shown that at least 190 cell nuclei needed to be assessed to have the results fall within 5% of the estimated real mean with a probability of 95%.

To minimize interobserver error, all countings were performed separately. For 12 cases in which conflicting numbers were evaluated, a recount was done to obtain concordance of opinion.

Statistical analysis

The graphic and statistical evaluation of the macroscopic and histologic results was performed with the aid of the statistics program SPSS 8.0 for Windows (SPSS, Chicago, IL, USA). Significances were determined with the Tukey unifactorial variance analysis, with p values less than 0.05 considered significant.

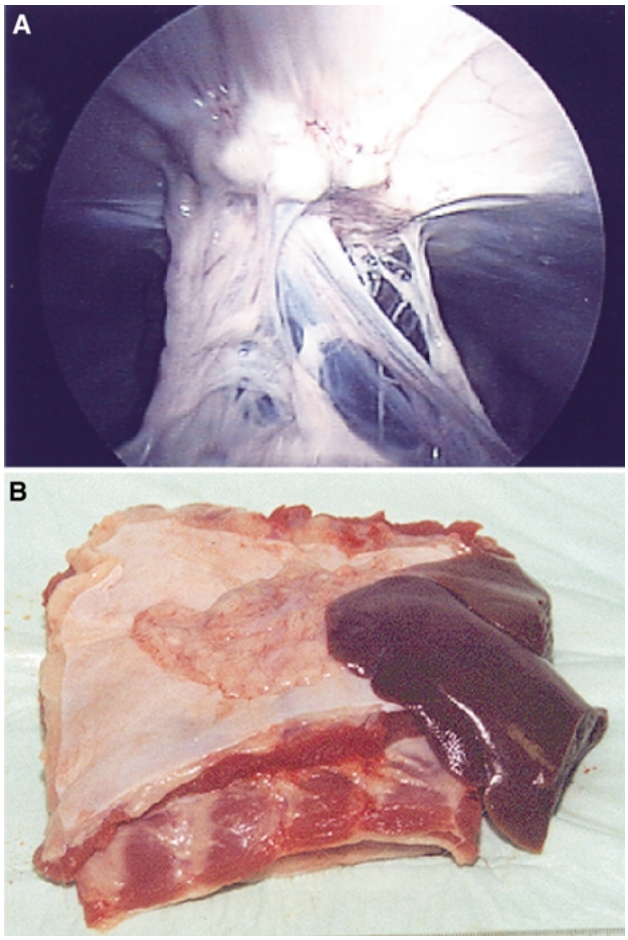

Fig. 1. DualMesh at autopsy. **A** laparoscopic aspect. **B** explanted specimen.

Results

Laparoscopy and macroscopy

All the pigs survived the 3 postoperative months without complications. In none of the cases did the diagnostic laparoscopy performed at autopsy show adhesions to the small bowel. With a single exception in the GoreTex group, the greater omentum adhered in discrete manner to all implants (Fig. 1a). In all cases, sharp dissection was needed to separate the omentum from the mesh surface. Particularly in the group receiving GoreTex mesh, shrinkage as a result of folding was evident already at laparoscopy, and even more evident in the explanted specimen (Fig. 1b), whereas in the group receiving titanium-coated meshes, the meshes were in good contact with the tissue and showed little folding (Fig. 2a and b). In the region of the upper abdomen, all the meshes had developed adhesions, in particularly to the liver, and these had be separated by sharp cutting. At macroscopic inspection, the meshes were covered

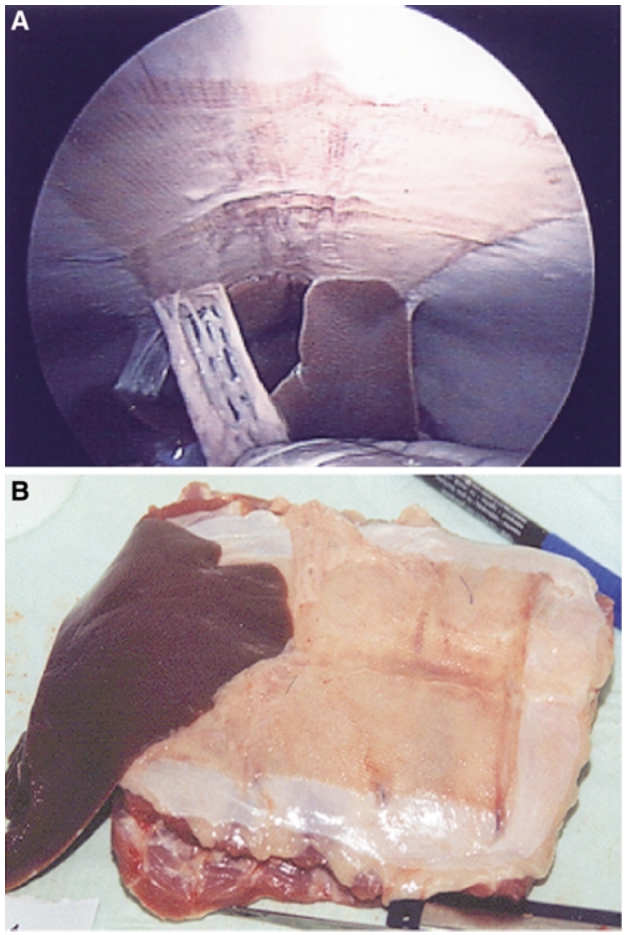

Fig. 2. TiMesh at autopsy. **A** laparoscopic aspect. **B** explanted specimen.

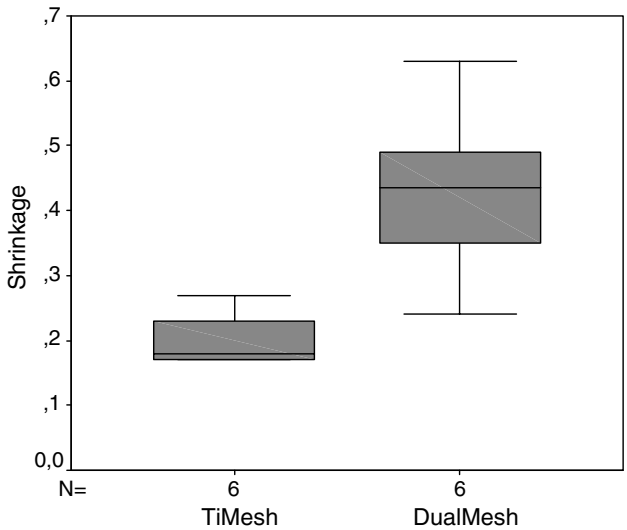

Fig. 3. Mean shrinkage of expanded polytetrafluoroethylene (ePTFE) to approximately one-half of the original surface area (median, 0.435). In comparison, the mean shrinkage of the titanium-coated mesh was 0.18 ($p = 0.006$).

with a shiny layer in the adhesion-free areas, but the underlying layer differed in consistency on palpation.

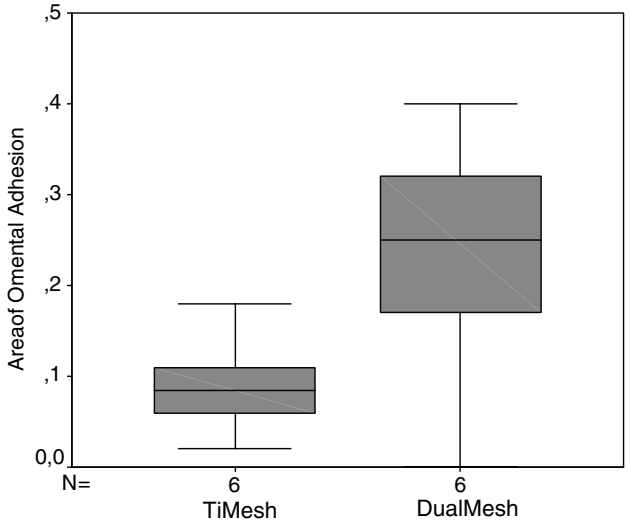

Fig. 4. Adhesion areas of the greater omentum (mean, 0.085) with titanium-coated meshes, as compared with GoreTex meshes (mean, 0.25) ($p = 0.055$).

This induration was seen in particular with the PTFE implants. A GoreTex mesh adhering to the abdominal wall and showing no significant shrinkage also evidenced reperitonealization, but with clearly recognizable vascularization macroscopically.

The morphometric evaluation of the preoperative and postoperative mesh dimensions showed a significantly smaller contact area for the DualMesh, attributable in the first instance to the pronounced folding of the mesh. In contrast to the titanium-coated polypropylene mesh, average shrinkage to almost one-half of the initial area (median, 0.435) was observed. The mean shrinkage of titanium-coated mesh was 0.18 ($p = 0.006$) (Fig. 3).

Although the total area of adhesions to adjacent structures was smaller (0.32) for the polypropylene mesh than for the PTFE mesh (median, = 0.62), the difference was not significant ($p = 0.159$). Taking into account the adhesions to the liver attributable to the position of the mesh in the upper abdomen and comparable in both groups (TiMesh, 0.25; DualMesh, 0.20), we could see, after subtracting this area from the total adhesion area, an appreciable difference in the adherent areas of the greater omentum: on the average, 0.085 for the titanium-coated polypropylene meshes in comparison with 0.25 for the GoreTexR meshes ($p = 0.055$) (Fig. 4).

Histology

For further quantification the macroscopic changes, the tissue specimens were subjected to a histologic workup. The microscopic slides showed the polypropylene meshes firmly integrated within the surrounding tissue, with only mild scar formation as well as formation of a neoperitoneum, and with each individual fiber surrounded by connective tissue (Fig. 5). As a result, the connective tissue structures were not always uniformly

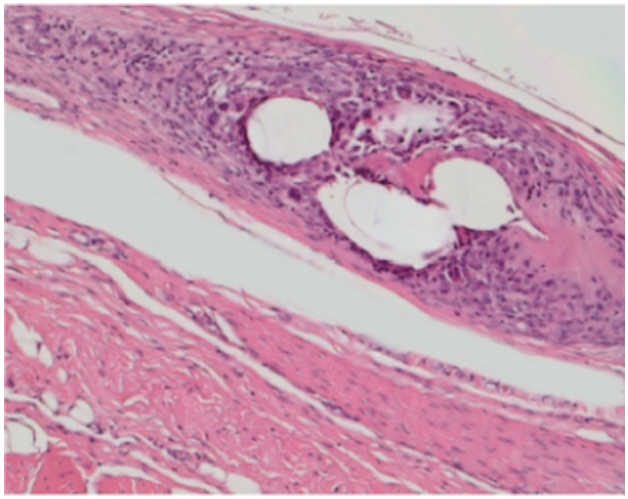

Fig. 5. Firm integration of the mesh structure within the surrounding tissue, with only mild scar formation (H&E stain, magnification ×25).

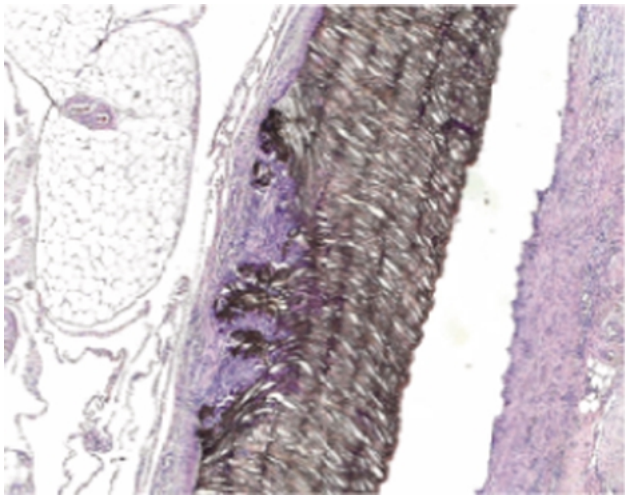

Fig. 6. Expanded polytetrafluoroethylene (ePTFE) material embedded in scar tissue and surrounded by strong inflammatory reaction (H&E stain, magnification ×2.5).

arranged. No foreign body giant cells were to be seen in the vicinity of the meshes.

In the case of PTFE, the shrunken meshes were embedded within scar tissue, and a strong inflammatory reaction was to be seen. Because of the small size of the pores in the membrane, however, a permanent "through-growth" of connective tissue had not taken place, so that there was no firm fixation to the peritoneum. Rather, the picture was of an encapsulated membrane with additional calcifications also seen. Because of the membrane's smooth surface, the connective tissue fibers were mainly arranged in parallel (Fig. 6).

Immunohistochemistry

The semiquantative evaluation of inflammatory cells using the CD68 marker showed the most pronounced inflammatory infiltrate to be associated with the Gore-Tex meshes, and located particularly at the interfaces. In the TiMesh group, appreciably less pronounced inflammatory changes were to be seen.

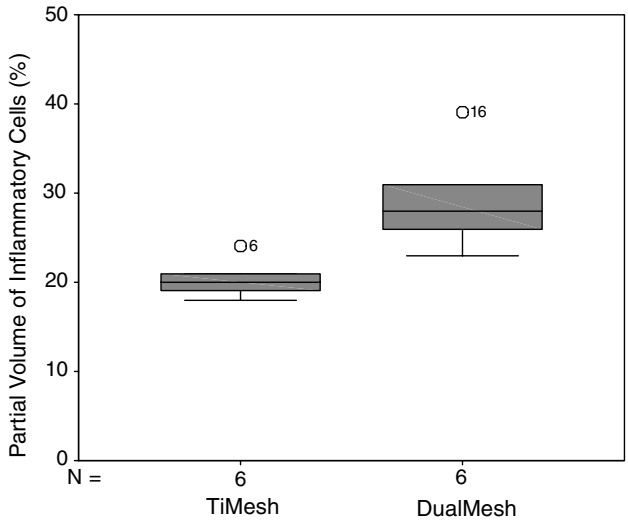

Fig. 7. Determination of the partial volume of the inflammatory cells. The median figures were lowest for TiMesh (20%), and significantly higher for DualMesh (20%; $p = 0.009$).

With regard to the partial volume of the inflammatory cells, the median figures were lowest for TiMesh (20%), and (28%) were significantly higher; ($p = 0.009$) (Fig. 7) for DualMesh.

Investigations with the proliferation marker MIB 1 (KI67), a sign of cell activity, again showed the highest figures for DualMesh (median, 13%), which were thus also significantly higher ($p = 0.011$) than for TiMesh (median, 7.5%) (Fig. 8). Finally, evaluation of the apoptosis index as a sign of cell turnover with consecutive cell death again showed the highest figures for the ePTFE membranes. The median here was 9.5, which again was significantly higher ($p = 0.002$) than for the titanium-coated polypropylene meshes (median, 3.0) (Fig. 9).

Discussion

Mesh adhesions

Numerous publications, including those of an experimental nature, concentrate mainly on the extent and pathology of adhesions. In this regard, polypropylene meshes prove to be considerably inferior to ePTFE meshes. The latter usually are associated with only a few or no adhesions, which also are easier to break down.

In these studies, however, a number of factors remain unconsidered. In the first place, the meshes are comparatively heavy, with small pores (e.g. Marlex) [1, 3–5], whereas on the other hand, the factor laparoscopy, in contrast to laparotomy, is not taken into account. After all, it is generally known that laparoscopic interventions trigger fewer adhesions than open interventions [10, 29]. In our study we were able to show that the

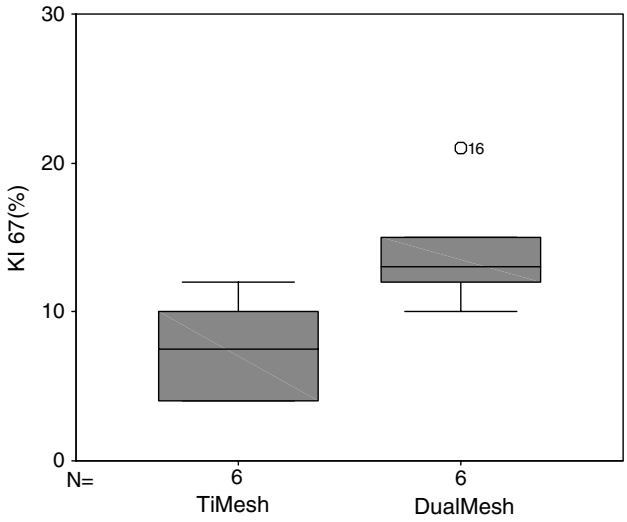

Fig. 8. The proliferation marker MIB1 (KI67) was highest for DualMesh (median, 13.9%), and thus was significantly higher ($p = 0.011$) than for the TiMesh (median, 7.5%).

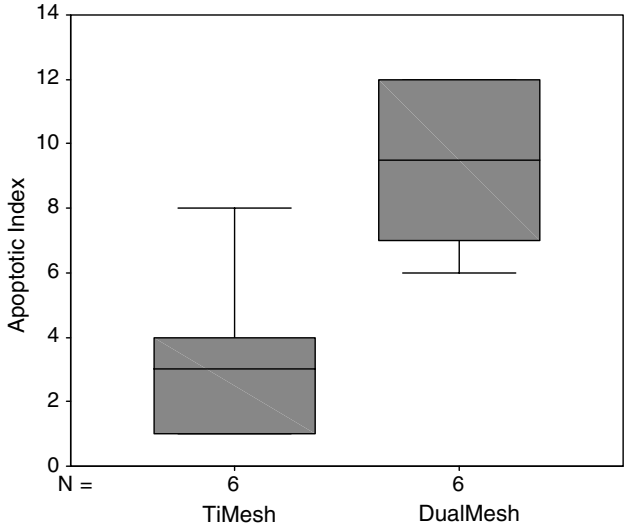

Fig. 9. Apoptotic index with the highest values (median, 9.5) for Expanded polytetrafluoroethylene (ePTFE), which were significantly higher ($p = 0.002$) than for the titanium-coated meshes (median, 3.0).

lightweight and large-pore TiMesh is associated not with more, but with fewer adhesions than ePTFE mesh, and in no case were intestinal adhesions to be seen. This confirms that the structure of the material used is of decisive importance for this phenomenon. The reduction in material and the increase in pore size represent a considerable improvement over the original heavier polypropylene mesh. The adhesions of the intestine to the mesh described in other publications [1–5, 20] were not seen in our experiments. A major factor certainly is the minimally invasive placement of the mesh. Adhesions develop when tissue reactions occur, which in turn create an imbalance between fibrinogenesis and fibrinolysis [25, 29]. Such reactions include that of the tissue to foreign material, which, in the case of intraperitoneal meshplasty, take place at the peritoneum–mesh interface.

Mesh shrinkage

Greater attention must be paid to the effect of shrinkage. The pathophysiologic reactions involved in this phenomenon are extremely complex. Shrinkage of the material is actually the last link in the body's chain of reactions to the foreign material. These reactions appear to be clearly related to the site of mesh placement, and also to the amount and structure of the material [11, 13–15, 27]. This also would explain the observation that over the long-term, polypropylene mesh fixed in an identical manner shows considerably less tendency to shrink than ePTFE. These reactions appear to persist over a period of years, as Klinge et al. [15] and Klosterhalfen et al. [16] were able to show in explanted meshes.

Because PTFE is not really a mesh, but rather, a membrane, it cannot be completely integrated, despite the texturing of the surface in contact with the abdominal wall. In the absence of pores, newly formed connective tissue is unable to develop a direct connection between neoperitoneum and peritoneum. The connective tissue fibers join together to form a layer, thus resulting in a connective tissue bridge that subsequently encapsulates the foreign material, the so-called bridging effect [13, 14, 23]. The presence of pores in the mesh makes it possible for the individual mesh fibers to become incorporated in the process of neoperitoneum formation. Ensheathment of the individual fibers occurs, with formation of neoperitoneum over the entire surface, thus firmly anchoring the mesh in place [3]. The initial apparently unorderly formation of connective tissue becomes more and more structured during the course of time.

In contrast, a capsule formed around the foreign material is consolidated by the chronic inflammatory reaction that occurs. The cellular reaction induced by the material is considerably greater in the case of implanted membranes than in the case of lightweight structured meshes, as we were able to demonstrate by examining the partial volume of the inflammatory cells. Increased inflammatory activity is accompanied by an increase in cell proliferation. During the course of this process, cell death (apoptosis) also is increased, which is reflected in an increase in the apoptosis index.

All three factors are significantly elevated in the case of the ePTFE membrane. As a result of the persisting inflammatory activity, the connective tissue contracts during the consolidation of scar tissue. Contraction of the cicatricial tissue, in turn, results in folding of the membrane, and thus shrinkage of the surface area covered by the implant. This "shrinking" process probably is helped forward by inadequate fixation of the membrane, which the results of our experiments have shown to be better with suturing than with tacking. This is not the least reason why, in the literature, tight suturing of the mesh using sutures and tacks is recommended. An additional factor involved is the frequently large seroma that forms in the region of the impermeable membrane,

which, unable to drain through the latter, must also provoke additional tension.

Currently, the literature contains no concrete information on the degree of ePTFE membrane "shrinkage" because most models were developed to investigate implantation in the preperitoneal space, in which PTFE plays only a limited role. In the preperitoneal space, polypropylene meshes "shrink" by as much as 40% [24]. In the case of the titanium-coated mesh we use in the preperitoneal space, average shrinkage is only 18%, which is in contrast to the 43% for the GoreTex mesh. It also must be assumed that the position of the mesh (i.e., intraperitoneal, extraperitoneal, or even fascial/subcutaneous) will have a varying impact on the tissue reaction, shrinkage, or both.

The light weight and the large pores of the titanium-coated mesh apparently bring a number of benefits. Because of the large pore size, the bridging effect is absent, and the titanium further improves biocompatibility, as shown in a comparable model investigating totally extraperitoneal patchplasty in the pig [22]. In that study, the shrinkage of the TiMesh was only 5%.

When identical mesh fixation is used shrinkage is virtually nonexistent because many of the aforementioned risk factors no longer apply. The mesh is integrated into the surrounding tissue, and is thus reperitonealized without, over the middle term, provoking any major inflammatory reactions or remodeling to scar tissue.

Tissue reaction

It is apparent that the extent of the tissue reaction is of decisive importance. The reaction of the surrounding tissue varies in relation to the amount of material present and its surface structure. The meshlike structure confers an advantage in that the material can be integrated into the surrounding tissue. In the case of heavyweight mesh, this is associated with a more pronounced inflammatory reaction. In contrast, large-pore, lightweight meshes provoke a reduced inflammatory reaction, and thus less scar formation [11, 13]. The greater the inflammatory reaction, however, the more massive the formation of adhesions. A further factor is the rough surface, which also appears to promote the development of adhesions. As Baptista et al. [1] were able to show, the inflammatory reactions and the formation of adhesions peak on the postoperative day 7. After 1 month, only a small inflammatory reaction persists, and no further adhesions develop. Inflammatory reactions persist over years, as Klosterhalfen et al. [6] demonstrated in a study of explanted meshes.

The largest amount of material is associated with the ePTFE membrane, and this is reflected in a significantly higher inflammatory reaction and cellular activity, which finally leads to enhanced connective tissue formation and an increase in apoptosis. Because of the smooth, poreless membrane-like surface, the adhesion area is not significantly increased, but integration into the surrounding tissue is clearly reduced, and the mechanical stability of the bowel wall is less than that seen with polypropylene meshes [23, 28].

A reduction in the amount of material, together with large pore size, brings us closer to the "ideal mesh," which is integrated into the surrounding tissue, reliably ensuring the mechanical stability of the bowel wall, and triggering the fewest possible adhesions. The basis for this lies in the only mild inflammatory reactions attributable to the reduction in material and the porosity of the mesh.

Our results show that multiple factors are involved in mesh "shrinkage" and the formation of adhesions, so that the structure of the mesh appears to be of greater importance than the material itself. This is consistent with numerous results obtained using experimental open mesh repair of abdominal wall and incisional hernias, but to date, has not been investigated specifically. In this connection, the pronounced shrinkage of the ePTFE meshes appears to be of crucial importance for the development of recurrences.

On the basis of our results, we must conclude that the titanium-coated polypropylene mesh is suitable for laparoscopic intraperitoneal repair of abdominal wall and incisional hernias, is comparable with the DualMesh in terms of adhesions, but clearly is superior in terms of shrinkage, so that over the long term, it is likely to be associated with a reduction in rates of recurrence.

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