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The behavior of different types of polytetrafluoroethylene (PTFE) prostheses in the reparative scarring process of abdominal wall defects

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Summary. Currently one of the most widely used prosthetic materials in the repair of abdominal wall defects, is expanded polytetrafluoroethylene (ePTFE). It has been suggested that its behavior with respect to the reparative process may depend on its structure. The aim of the present study was to evaluate the effect of the structure of 3 ePTFE prostheses on the scarring process in an abdominal-wall-defect experimental model. The prostheses employed were the Soft Tissue Patch (STP) which is laminar in structure, Mycro Mesh (MM) which is multilaminar with perforations, and the Dual Mesh (DM) prosthesis which has one non-porous surface. Abdominal wall defects (7x5cm) were created in 36 New Zealand rabbits and repaired using fragments of STP, MM and DM. Follow-up periods were 14, 30, 60 and 90 days post-implant. At these times prostheses were macroscopically examined for the presence of infection and/or rejection and the formation of adhesions to abdominal viscera. Specimens were also taken for microscopic analysis (optical and scanning electron) and for immunohistochemical analysis using the rabbit macrophage-specific monoclonal antibody RAM-11. Labelled macrophage counts were performed at each follow-up session. No cases of infection or rejection were found. Loose adhesions between prosthesis and underlying viscera were observed in 2 of the STP, 4 of the MM and 2 of the DM implants. STP and DM implants were progressively encapsulated by organized connective tissue on both peritoneal and subcutaneous surfaces. Cellular colonization was observed on both STP surfaces and on the porous surface of the DM although no more than a third of the biomaterial was penetrated by cells in either case. Colonization was very slight at prosthesis anchorage points. MM implants differed only in the formation of connective tissue bridges in perforated areas, and cellular infiltration in interlaminar spaces. Macrophage response was similar in the 3 prostheses with a reduction in RAM-11 labelled cells ($p<0.05$) between 14 and 90 days post-implant. We conclude: a) the 3 types of PTFE prosthesis induced low incidence of adhesion formation between biomaterial and viscera; b) integration mechanisms of the 3 prostheses were similar and culminated with the encapsulation of the PTFE by the neoformed tissue; c) the macrophage response induced by the 3 prostheses was similar to that of any reparative process in the absence of biomaterial.

Key words: Polytetrafluoroethylene, PTFE prostheses, Abdominal wall, Macrophages, Rabbits

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Introduction

Expanded polytetrafluoroethylene (ePTFE) is one of the most widely used prosthetic materials for the repair of abdominal wall defects (mainly hernial type) (Berliner, 1993). Previous experimental studies have shown that the behavior of a biomaterial depends largely on its structure and, in particular, its porosity (Jenkins et al., 1983; Pans and Pierard, 1992; Bellón et al., 1994). Currently the ePTFE prosthesis most used in clinical practice is the Soft Tissue Patch® which is laminar in structure and of reduced porosity (30-60μm). This prosthesis shows optimal behavior at the prosthesis/visceral-peritoneum interface although its integration with neoformed tissue is incomplete (Bellón et al., 1995). For this reason new types of ePTFE prostheses have been developed which differ in structure to the Soft Tissue Patch. These include Mycro Mesh® which is a multilaminar PTFE prosthesis with 2mm-diameter perforations and Dual Mesh®, a prosthesis with one non-porous surface and one of similar porosity to the Soft Tissue Patch. Moreover, one of the sides of Mycro Mesh and the porous side of Dual Mesh have a rough surface.

The aim of the study was to determine the degree to which the structure of ePTFE conditions the reparative process with respect to integration with the receptor organism.

Materials and methods

Thirty-six male, white, New Zealand rabbits weighing between 1800 and 2000g were employed. The animals were caged and maintained under constant light and temperature conditions throughout the study (EEC norms 28871-22A9). Abdominal wall defects (7x5cm) were created following a sterile surgical technique previously described (Bellón et al., 1994). Anesthesia was achieved with a mixture of ketamine hydrochloride (70 mg/kg), diazepam (1.5 mg/kg) and chlorpromazine (1.5 mg/kg) i.m. Animals were implanted with one of 3 types of prosthesis; the Soft Tissue Patch®, Mycro Mesh® or Dual Mesh® (Gore Tex, Flagstaff, Arizona, USA). Follow-up periods of 14, 30, 60 and 90 days post-implant were established. At each follow-up time the presence of infection and/or rejection was determined as was the formation of adhesions to abdominal viscera. Specimens were taken from the prosthesis/subcutaneous tissue, prosthesis/peritoneum and prosthesis/receptor tissue interfaces and subjected to conventional light microscopy techniques (hematoxylin-eosin and Masson's trichrome stains), scanning electron microscopy and immunohistochemical analysis using a monoclonal antibody specific for rabbit macrophages (RAM-11) (Dako M-633). Labelled-macrophage counts were performed in 20 microscopic fields (x16) at each follow-up time for each type of prosthesis. Mean counts obtained independently for each type of prosthesis were statistically compared using the Student-Newman-Keuls test.

Results

No infection or rejection was observed in any of the experimental animals. Loose, easily removable adhesions between prosthesis and abdominal viscera were observed in 2 of the STP, 4 of the MM and 2 of the DM implants. These adhesions were found in the prosthesis-to-abdominal wall suture areas and, at times, in perforated areas of the MM implants.

Microscopic examination of the STP implants revealed the progressive encapsulation of the biomaterial by connective tissue on both surfaces. Neoformed tissue was of an orderly disposition with fibres running parallel to the prosthetic surface giving rise to a peritoneal interface of smooth appearance. These implants induced a moderate foreign-body reaction shown by discrete accumulation of monocytes/macrophages and lymphocytes along the edges of the prosthesis (Fig. 1). This accumulation decreased over the follow-up period. Fibroblasts were the most abundant type of cell at 90 days post-implant. At this time the fibrous capsule was highly vascularized with small and medium calibre vessels visible in areas adjacent to the biomaterial (Fig. 2). Cellular colonization was detectable on both

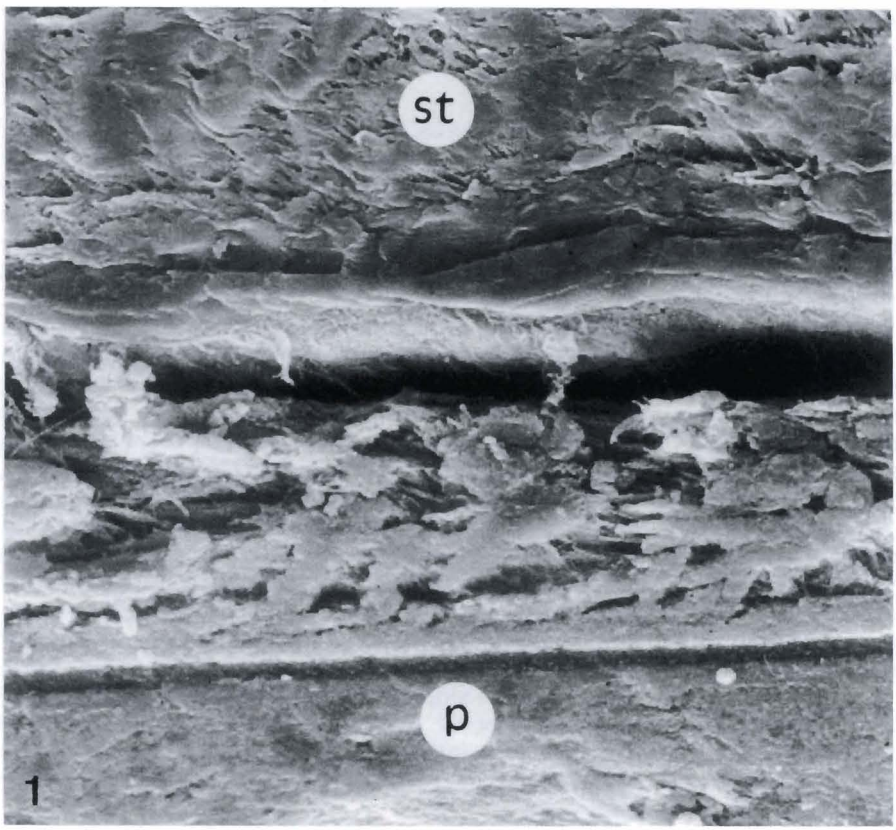

Fig. 1. Accumulation of cells at the edge (prothesis/peritoneum interface) of a Soft Tissue Patch implant. st : Soft Tissue Patch; p: peritoneum. SEM, x 370

prosthetic surfaces and increased between days 14 and 90 although in no case did the cells penetrate more than one third of the prosthesis on any side (Fig. 3). Colonization by fibrous elements was scarce. Only isolated collagen fibres were seen 60 days post-implant. Cellular or fibrous colonization was very scarce at anchorage points to the abdominal wall (Fig. 4).

Microscopic examination of the DM implants showed no major differences with respect to the STP implants. Fibrous capsules were established in both cases. The only differences observed were an absence of fibrous colonization of the non-porous DM surface and more abundant connective tissue on the rough prosthetic surface (in contact with subcutaneous tissue) (Figs. 5, 6).

Mycro Mesh implants showed some differences with respect to the STP and DM. The formation of an orderly

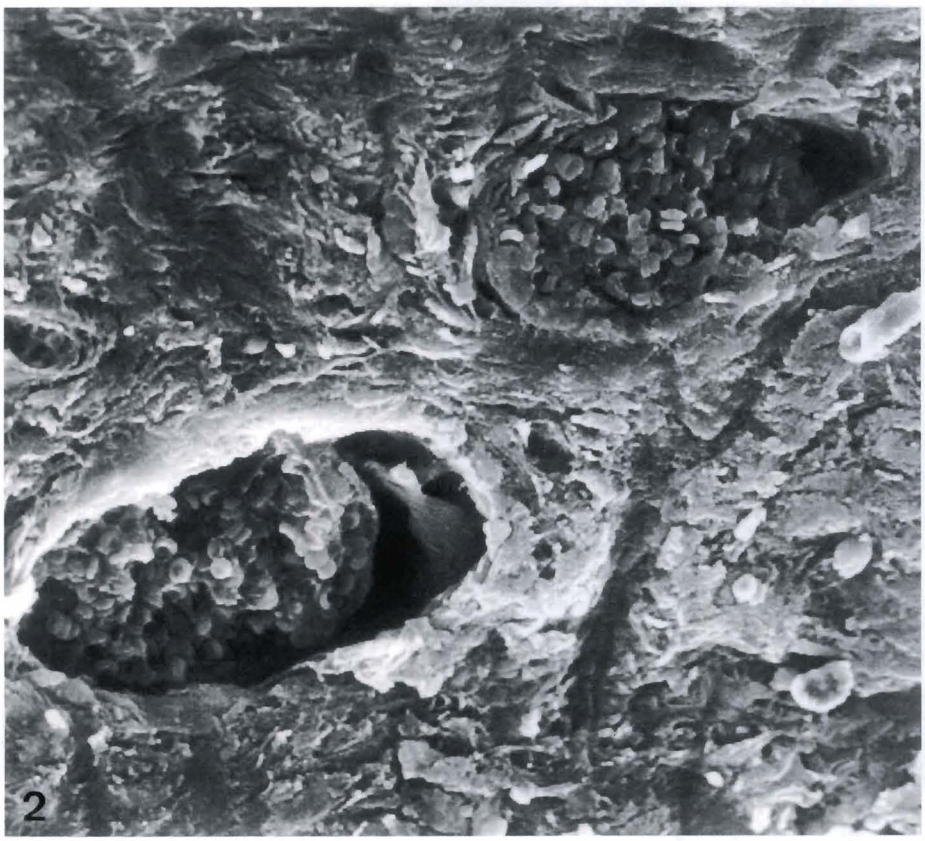

Fig. 2. Neoformed peritoneal blood vessels in a Soft Tissue Patch implant. SEM, x 460

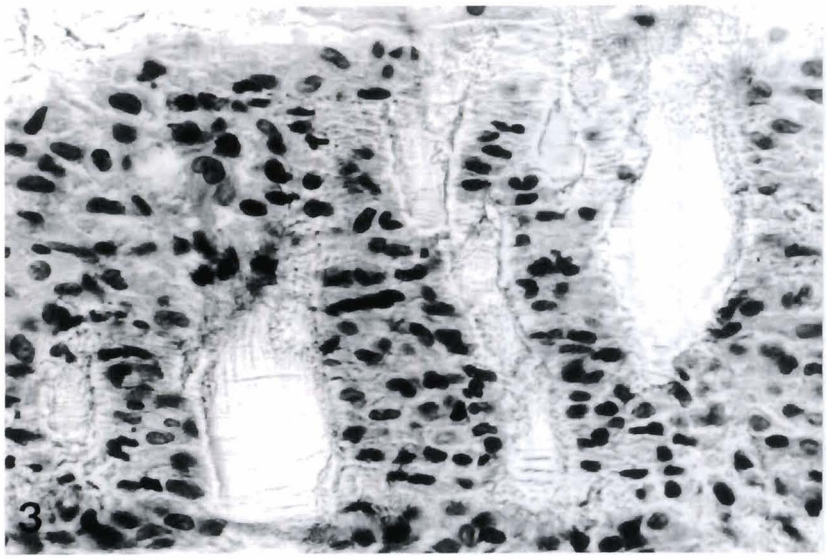

Fig. 3. Cellular colonization in the first third of the Soft Tissue Patch. LM, H-E, x 400

structured fibrous capsule integrating the PTFE on both surfaces was also observed (Fig. 7). However, connective tissue bridges were visible in perforated areas enabling contact between neoformed tissue on both sides of the prosthesis (Fig. 8). These perforations were at first seen to be occupied by typical foreign-body cells which then decreased in number giving way to tissue similar to that of the fibrous capsule. Cellular colonization of the prosthesis was similar to that of the STP with cells penetrating the prosthesis at its external borders. Cellular infiltration was also observed in the multilaminar spaces of the biomaterial. These cells presumably gained access

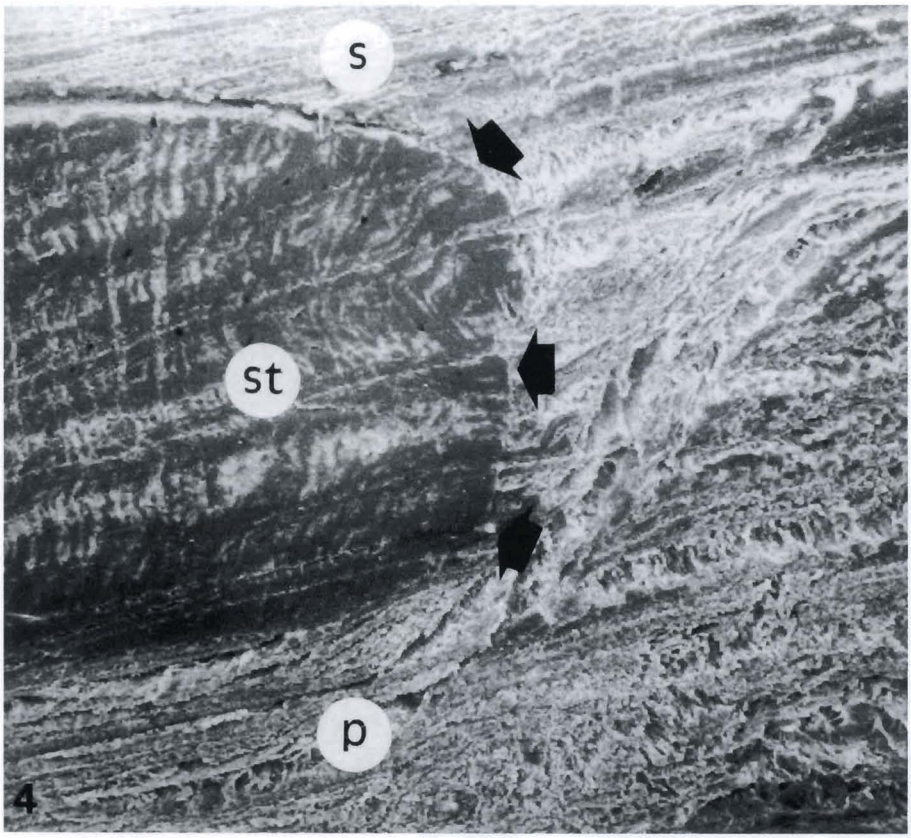

Fig. 4. There were no cellular or fibrilar colonization of the anchorage zone (arrows) in the Soft Tissue Patch implants. st: Soft Tissue Patch; s: subcutaneous; p: peritoneum). SEM, x 50

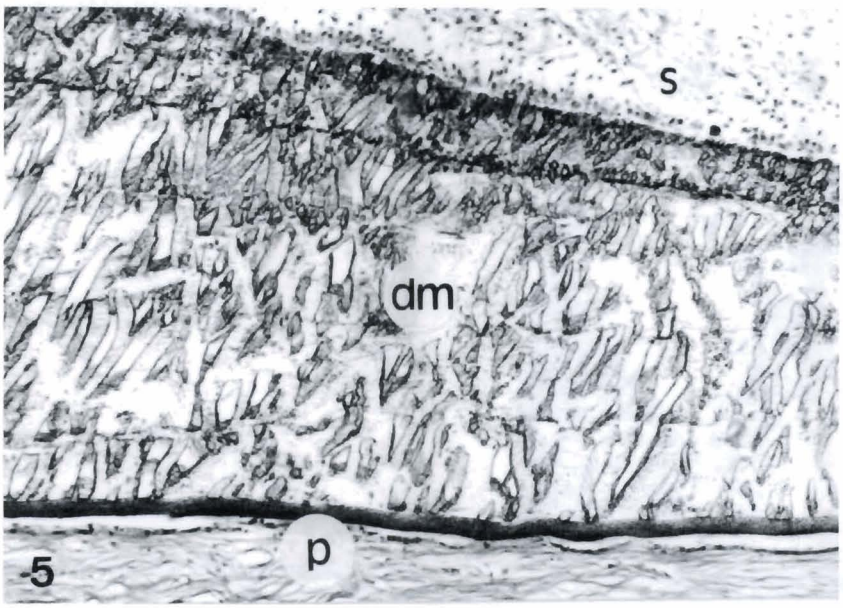

Fig. 5. Panoramic view of a Dual Mesh (dm) implant. It can be noted the neoformed tissues in the prosthesis/subcutaneous interface (s) and in the prosthesis/peritoneal interface (p). LM, H-E, x 63

via the MM perforations (Fig. 9).

The macrophage response induced by the 3 biomaterials was similar with maximum numbers of RAM-11 antibody labelled cells recorded 14 days after implant. These numbers progressively decreased until day 90. This reduction was statistically significant ($p<0.05$) in every case (Fig. 10).

Discussion

The use of a biomaterial is one of the multiple options currently available for the repair of abdominal

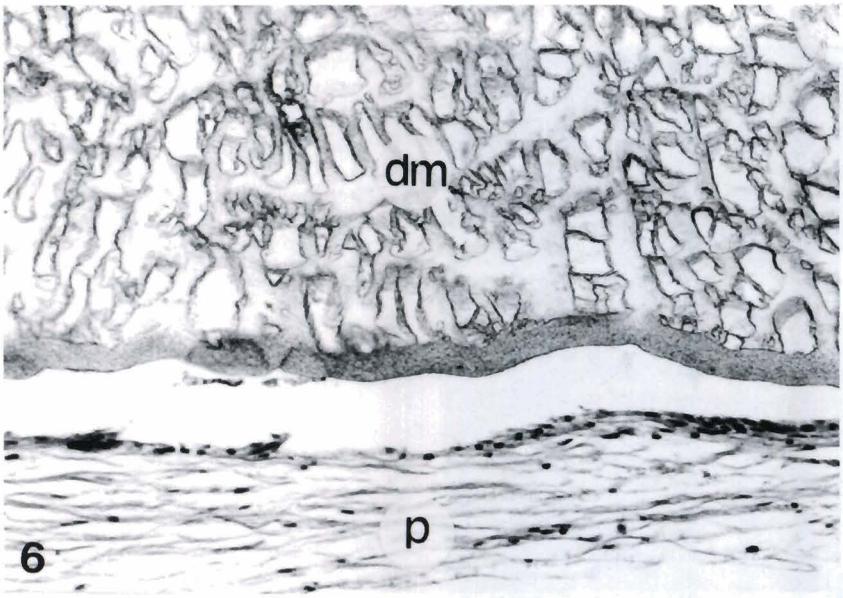

Fig. 6. Neoformed peritoneum in a Dual Mesh (dm) implant. The non-porosity of the Dual Mesh in this side impedes the celullar collonization of the biomaterial. p: peritoneum. LM, H-E, x 160

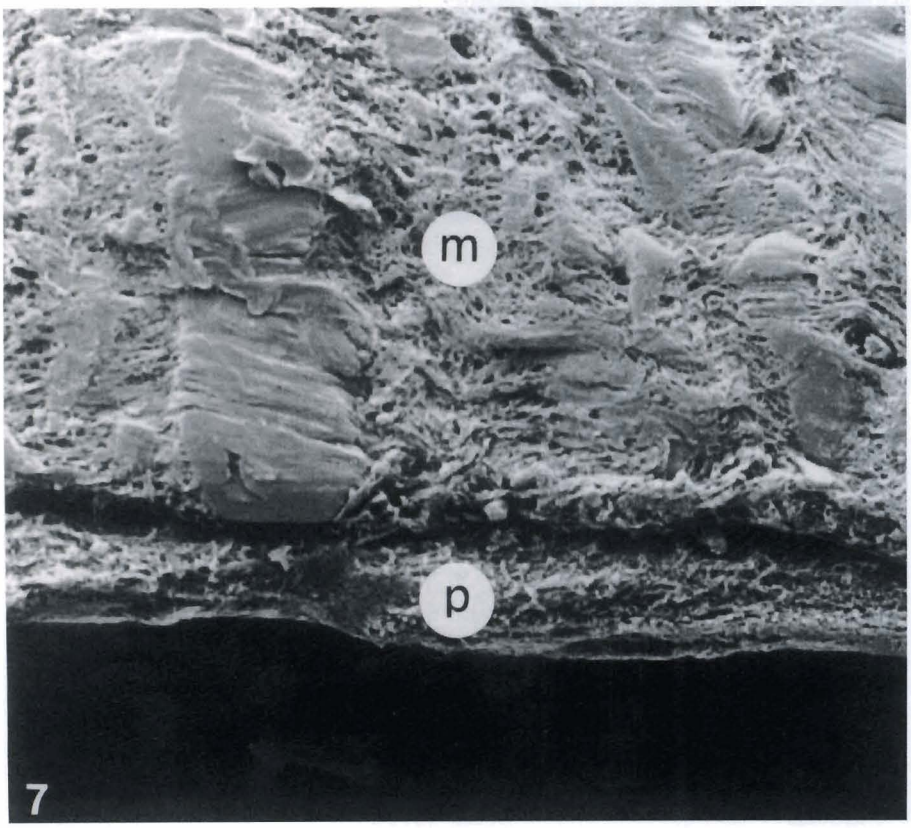

Fig. 7. Detail of the neoperitoneum (p) in a Mycro Mesh (m) implant. SEM, x 450

wall defects. However, previous experimental studies indicate that the behavior of each type of biomaterial is different depending on the structure of the prosthesis (Amid et al., 1994; Bellón et al., 1994, 1996a). It is well known that macroporous prostheses such as those of polypropylene (Marlex and Prolene) are able to achieve complete integration with neoformed tissues giving rise to a disorganized structure which favors the formation of adhesions to abdominal viscera (Murphy et al., 1989; Tyrell et al., 1989; Law, 1990; Dabrowiecki et al., 1991). On the other hand, PTFE in microporous laminar form (Soft Tissue Patch) is encapsulated by organized scar tissue and induces a low incidence of adhesion formation and moderate foreign-body reaction (Law and Ellis, 1991; Bellón et al.,1995). However, this biomaterial has the disadvantage that it achieves poor integration with

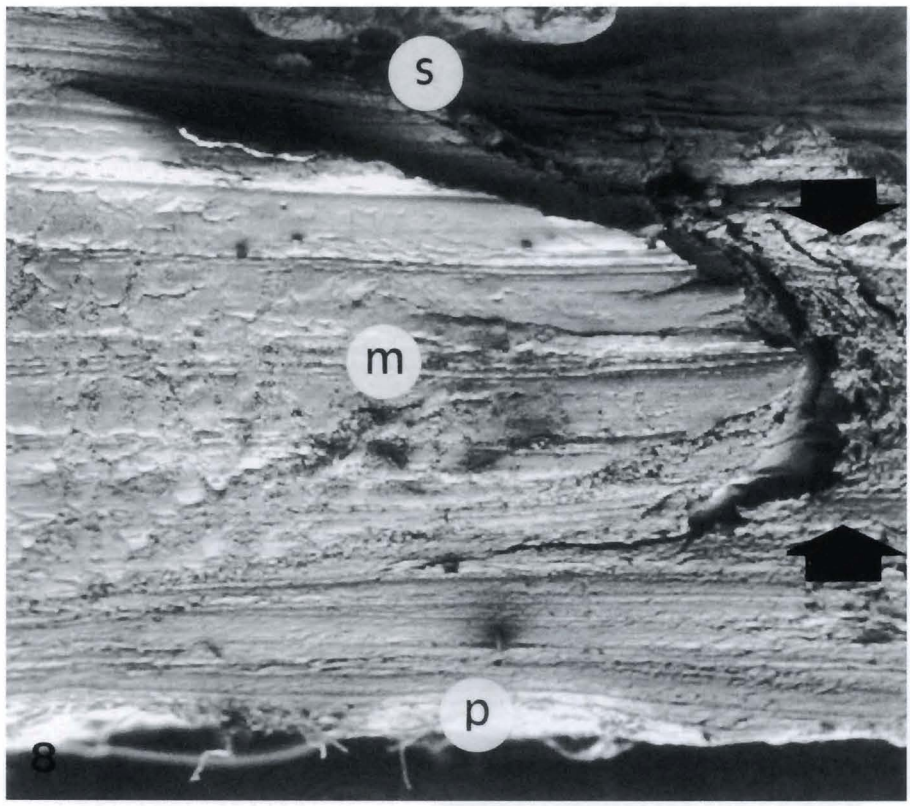

Fig. 8. Tissular bridge (arrows) on a perforation of a Mycro Mesh (m) implant. SEM, x 100

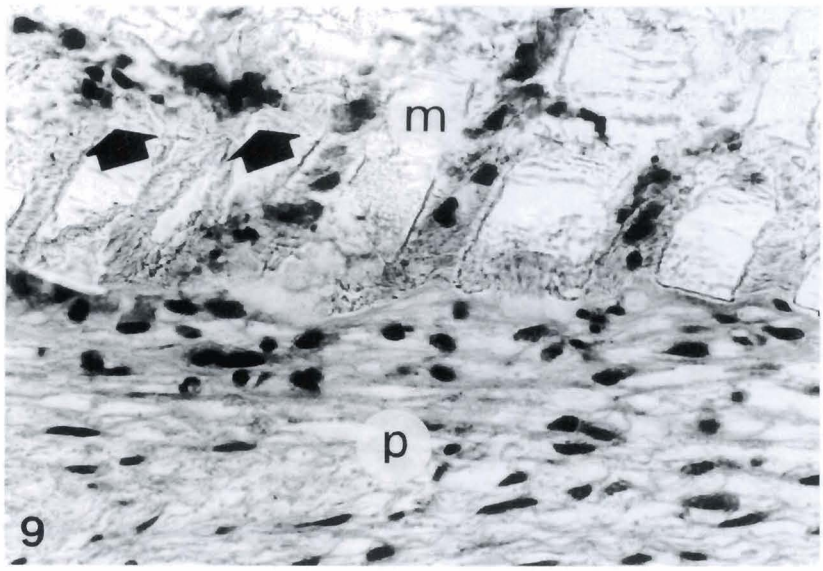

Fig. 9. Cellular colonization of the first third of the peritoneal interface in a Mycro Mesh implant. The cells also colonizate the interlaminar spaces (arrows) of the biomaterial. p: peritoneum). LM, Masson's trichrome, x 400

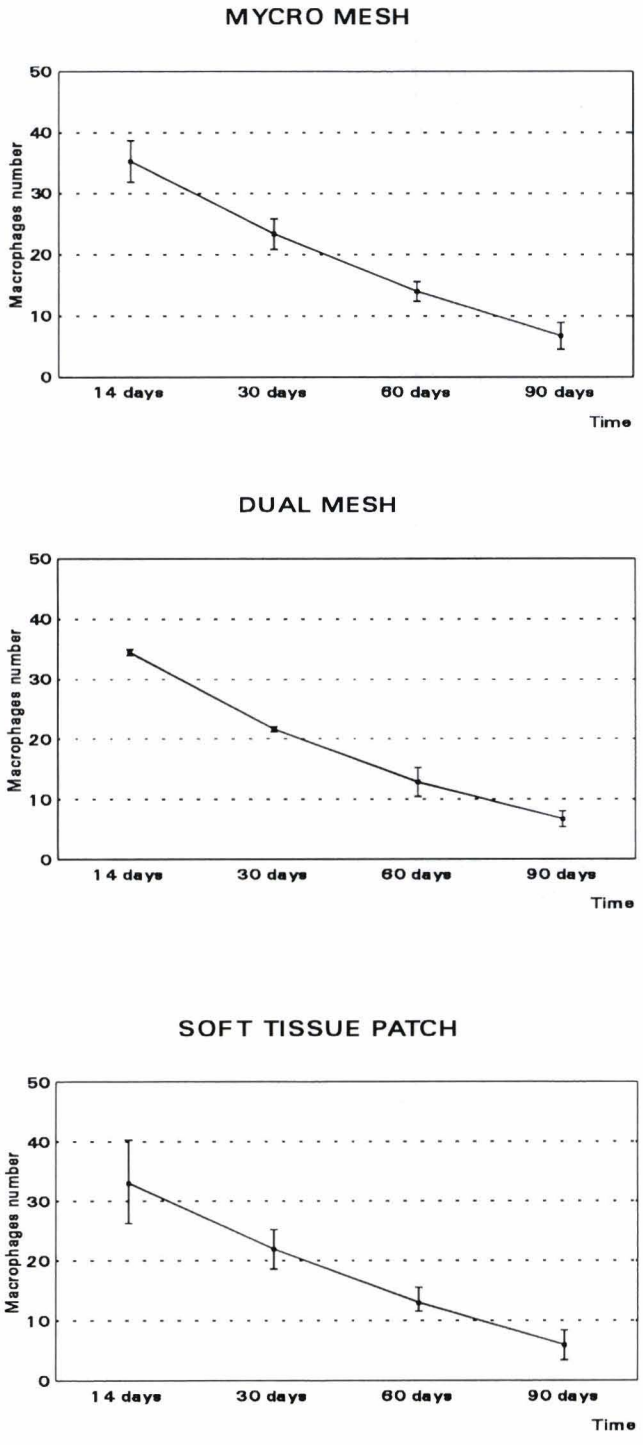

Fig. 10. Evolution of the macrophage response in the three PTFE prostheses employed in the study. The decrease in the number of RAM-11 labelled macrophages was significant (Student-Newman Keuls test $p<0.01$) at each study time with the three biomaterials employed in the study.

neoformed tissue mainly at the anchorage points of the prosthesis to the abdominal wall (Bellón et al., 1996a; Simmermacher et al., 1991). This results in the STP's reduced resistance to traction when compared to Marlex or Prolene (Murphy et al., 1989; Law and Ellis, 1991). Consequently experimental investigations have been performed using combinations of macroporous polypropylene prostheses and laminar PTFE in an attempt to achieve a low incidence of adhesion formation without loss of resistance of the repaired zone (Walker et al., 1993; Amid et al., 1994).

Thus the evaluation of the behavior of prostheses of different structure may contribute to the search for improved prosthetic integration. Perforations found in Micro Mesh permit the establishment of scar tissue bridges which connect neoformed tissue on both sides of the PTFE, affording greater stability to the fibrous capsule. It should be noted that despite its perforations, encapsulating tissue maintains the orderly structure typical of STP implants. Only in the perforated areas is the parallel disposition of conjunctive fibres altered, showing transverse alignment with the prosthetic surface. This causes the appearance of loose adhesions to viscera in these areas. For this reason, and in view of the size of adhesions found in macroporous polypropylene implants (Bellón et al., 1996b; Murphy et al., 1989) it is considered that pore size may condition the degree of adhesion formation.

Dual Mesh behaved similarly to the STP and was encapsulated by an orderly fibrous structure 90 days after implant. The lack of cellular or fibrous colonization of the non-porous surface of the prosthesis allowed the establishment of this orderly structured capsule.

The evaluation of macrophage response is of great importance in the search for new prosthetic materials. Besides providing information on the biological tolerance of a prosthesis (Black, 1992), this response permits monitoring of the scarring process. Macrophages play a critical role in this process by secreting substances such as growth factors (Leibovich and Ross, 1975; Leivobich et al., 1987). Moreover, a chronic macrophage response may alter the physico-chemical characteristics of the biomaterial (Bjursten, 1991). In general, the macrophage response reaches its maximum at the start of the normal reparative process and decreases with time. This was observed in the present study in all the PTFE implants. Maximum numbers of labelled monoclonal antibody to rabbit macrophages (RAM-11) were detected 14 days post-implant and progressively decreased until 90 days post-implant.

It may be concluded that the 3 types of PTFE prostheses show optimal behavior with respect to their interface with the visceral peritoneum. Negligible adhesions were detected between biomaterial and viscera. The mechanism of integration of the 3 prostheses studied was similar and resulted in the encapsulation of the biomaterial by neoformed tissue. The macrophage response induced by the PTFE prostheses was similar to that produced in any reparative

process under normal conditions.

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