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Factors influencing wound complications: A clinical and experimental study

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Summary

Burst abdomen, incisional herniation, sinus formation and post-operative wound infection continue to bedevil the surgeon. A prospective study of 1129 laparotomy wounds defined the extent of the problem; 1.7% incidence of dehiscence, 7.4% herniation and 6.7% sinus formation, all significantly associated with wound infection. Mass closure reduced the dehiscence rate from 3.8% to 0.76%.

Infection reduced wound strength in a rat laparotomy model due to a decrease in fibroblast concentration and activity.

A monofilament non-absorbable suture was shown experimentally to be the most suitable suture for closing infected abdominal wounds. Electron microscopy demonstrated bacteria in the interstices of infected multifilament sutures.

A randomised clinical trial comparing polyglycolic acid and monofilament nylon in the closure of abdominal wounds confirmed the experimental findings; polyglycolic acid resulted in a significantly higher wound failure rate with no decrease in sinus formation.

A mass closure technique using monofilament nylon is recommended for laporotomy closure and efforts should continue to reduce wound sepsis.

Introduction

John Hunter, on his return from Portugal in 1763 at the conclusion of the seven years war, brought back many specimens for his collection including a lizard with a regenerated tail (Fig. 1). 'A lizard in which the new tail when nearing its completion was again broken off and regenerated. The tail thus consisted of three parts: the stump of the original tail, the first new growth covered with scales, different in form from those of the stump, and the second new growth without scales, smooth, soft and slender'. *(1)*

When one considers that in the healing wound, cell and tissue production is proceeding at a rate which exceeds that seen in most malignant tumours, it is humiliating to admit how little we know of the mechanisms involved.

The Clinical Problem

There still remain for the general abdominal surgeon three major healing problems after laparotomy. Burst abdomen, in which the whole wound breaks down and bowel appears on the surface. Incisional herniation where the underlying muscle and fascia give way but the skin remains intact, holding the contents inside the abdominal cavity, and sinus formation in which there is a discharging site usually related to infection and suture material.

There are many possible causes of these complications; firstly, they can be due to local factors affecting the wound

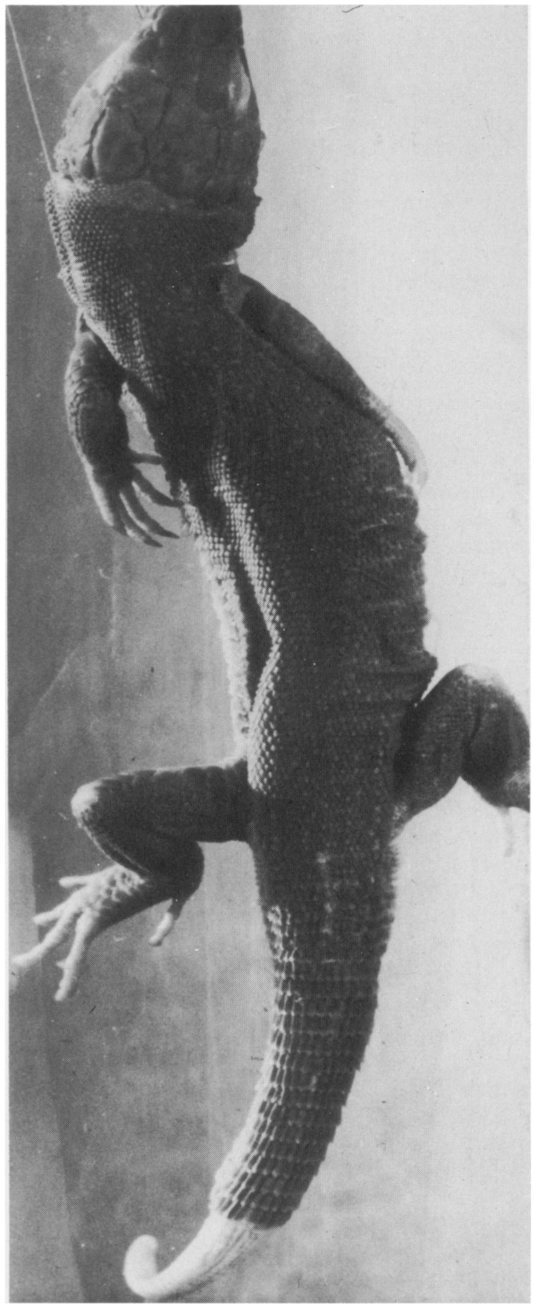

FIG. 1 'Lizard with regenerated tail' published by kind permission of the Curator, Hunterian Collection, Royal College of Surgeons, Lincolns Inn Fields.

Based on a Hunterian Lecture delivered at the Royal College of Surgeons of England on 25th November 1981.

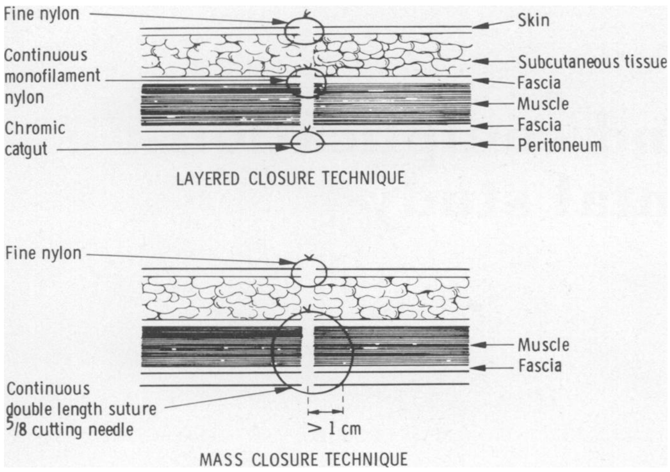

FIG. 2 Techniques of abdominal wound closure.

itself, for example its blood supply, infection and apposition of the wound edges; and secondly, to factors such as jaundice, malignant disease and diabetes, which affect the patient's general state, and may result in poorer healing.

In order to ascertain the extent of the problem in clinical practice and in an attempt to define the factors most influencing these wound complications we have carried out a prospective study.

On the Surgical Unit at Westminster Hospital over the five year period from 1975 to 1980, a total of 1129 major laparotomy wounds were assessed at regular intervals over a 12 month postoperative period. There were 19 burst abdomens (1.68%), 84 incisional hernias (7.44%) and 76 sinuses (6.73%).

In 1977, halfway through the study, the method of wound closure was changed in the light of experience from other centres (*2, 3, 4, 5*). The mass closure technique introduced by Jones (*6*) at the Cleveland Clinic in 1941, but not used routinely in this country until the 1970s, was substituted for the technique of closing the wound in layers (Fig. 2). The mass closure technique consists of picking up all layers of the abdominal wall apart from skin and subcutaneous fat. Care is taken to take wide bites of the rectus sheath at least 1 cm from the edge of the incision (*7*). To achieve this a hand-held 5/8ths cutting needle is used. Deep tension sutures are not employed. Drains are inserted through a separate stab away from the incision and if a colostomy or ileostomy is required it is always fashioned through a separate incision.

Our results compare favourably with those from the other centres. Prior to 1977 341 layer closures were performed and there were 13 bursts (3.81%). However after 1977 using mass closure in 788 patients there were only six burst abdomens (0.76%). Therefore using mass closure the incidence of burst abdomen, with a mortality up to 35% (*8*) should become a rarity with an incidence below 1%.

Abdominal Wound Infection

Whereas with the introduction of mass closure, the freedom from dehiscence is encouraging, the incidence of late herniation remains high. The aetiology of incisional herniation in our study was found to be multifactorial, significantly associated with old age, male sex, obesity, bowel surgery, chest infection, abdominal distension, and most significantly wound infection with 48% of hernias arising from infected wounds.

We therefore went to the laboratory to look specifically at infection and its relationship to wound strength and healing, using an experimental rat model. Midline vertical laparotomy wounds were made and closed in a standard manner and then infected with a 10^8 organisms/ml concentration of different organisms. There were three infection groups based on the organisms used: *Staphylococcus* aureus, *Pseudomonas* aeroginosa and a combination group of *Escherichia* coli and *Proteus* mirabilis.

The ingenious method of testing the wound strength was devised by De Haan (*9*) in our laboratory. It consisted of inserting a rubber balloon into the peritoneal cavity through a defect made in the apex of the vagina. The balloon was connected to a cylinder of oxygen and slowly inflated at a constant rate. The bursting pressure was measured on a manometer at the time of disruption. This mimicked the clinical situation of abdominal distension and gave a definite end point.

Forty infected and forty control wounds were tested for strength on postoperative day 5 and on postoperative day 14. There were 20 rats in each group. The bursting pressure of the non-infected wounds was significantly greater than any of the infected wounds both at day 5 and day 14 (*10*). The cause of this decreased strength had not previously been shown.

The mechanism of wound healing is a dual process consisting of cellular and vascular elements. There is an initial vaso-constriction as a result of wounding which is then followed by the process of repair, with angiogenesis and fibroblast proliferation laying down collagen thus forming granulation tissue. John Hunter knew that granulation tissue resulted in healing. In his notes of a specimen of a healing leg ulcer (Fig. 3) he drew special attention to the 'healthy granulations' (*1*).

We looked at several different aspects of the healing process in the rat model. Histologically the non-infected healing wounds displayed an organised process of repair, with capillary budding and the formation of granulation tissue (Fig. 4). Infected wounds however were much better organised (Fig. 5) with abscess formation and capillary haemorrhage giving the appearance of an acute inflammatory reaction rather than a uniform healing process. Autoradiography using tritiated thymidine labelling identified the fibroblasts responsible for the repair process. These were

FIG. 3 'Healing Ulcer' (granulation tissue arrowed) published by kind permission of the Curator, Hunterian Collection, Royal College of Surgeons, Lincolns Inn Fields.

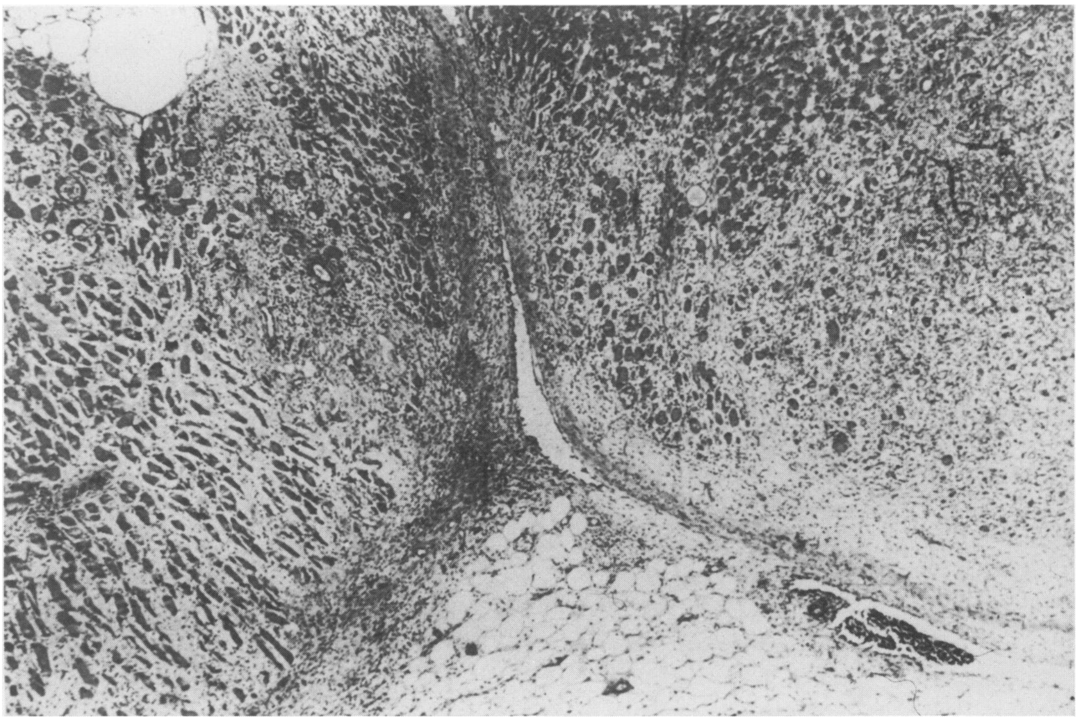

FIG. 4 Healing wound—non-infected at 7 days. H&E ×170.

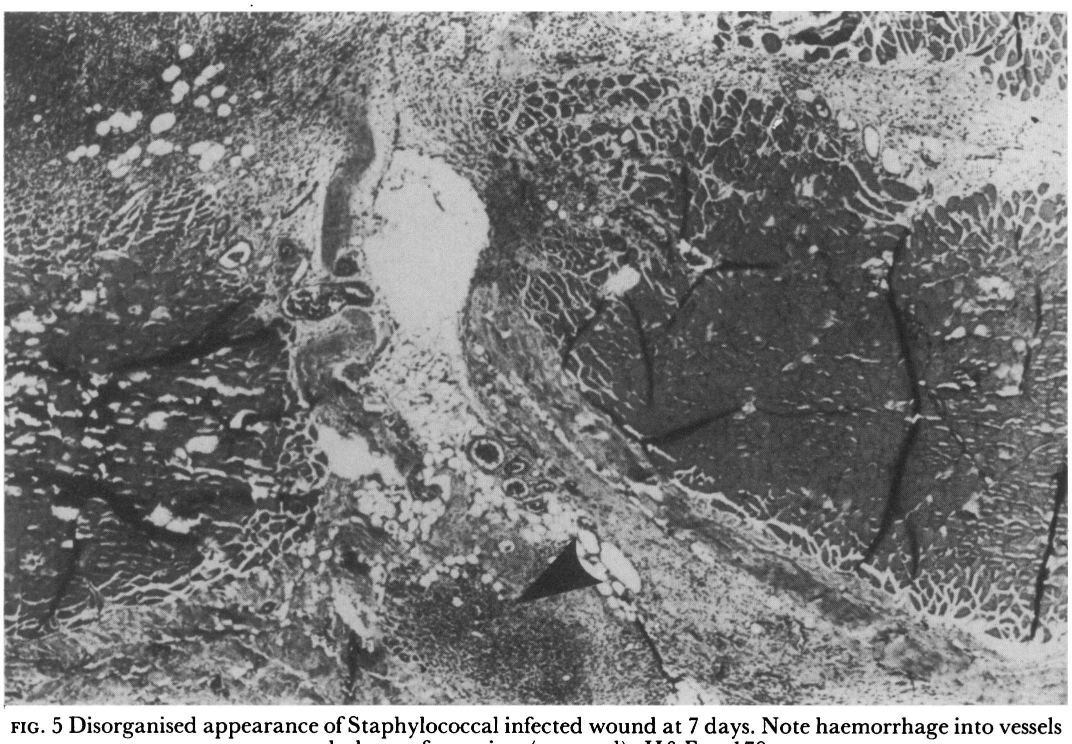

FIG. 5 Disorganised appearance of Staphylococcal infected wound at 7 days. Note haemorrhage into vessels and abscess formation (arrowed). H&E ×170.

seen in abundance in non-infected wounds (Fig. 6) but infection caused a reduction in the number of active fibroblasts, and the collagen produced was disorganised (Fig. 7). By counting all labelled fibroblasts in three fields either side of the incision the percentage of cells labelled, the labelling index (I_L) was calculated. Infected wounds had significantly lower labelling indices. The mean I_L in non-infected wounds was 12.71% compared with a mean I_L in all infected wounds of 3.89%. This was significantly different ($p<0.005$). The mean number of total fibroblasts per field was 212.67 in non-infected wounds compared with a mean of 142.74 for all infected wounds; again this was significantly different ($p<0.005$).

Therefore infected wounds were significantly weaker than controls almost certainly due to decreased fibroblast concentration and activity (*10*). By stimulating fibroblasts in some way it may therefore be possible to encourage healing and Knighton, *et al (11)* have recently had some success by changing the local oxygen concentration in wounds. However infection remains the most significant factor affecting wound healing and efforts must continue to eliminate this serious complication.

FIG. 6 Autoradiograph showing heavily labelled fibroblasts (arrowed) in a non-infected wound at 7 days. H&E ×170.

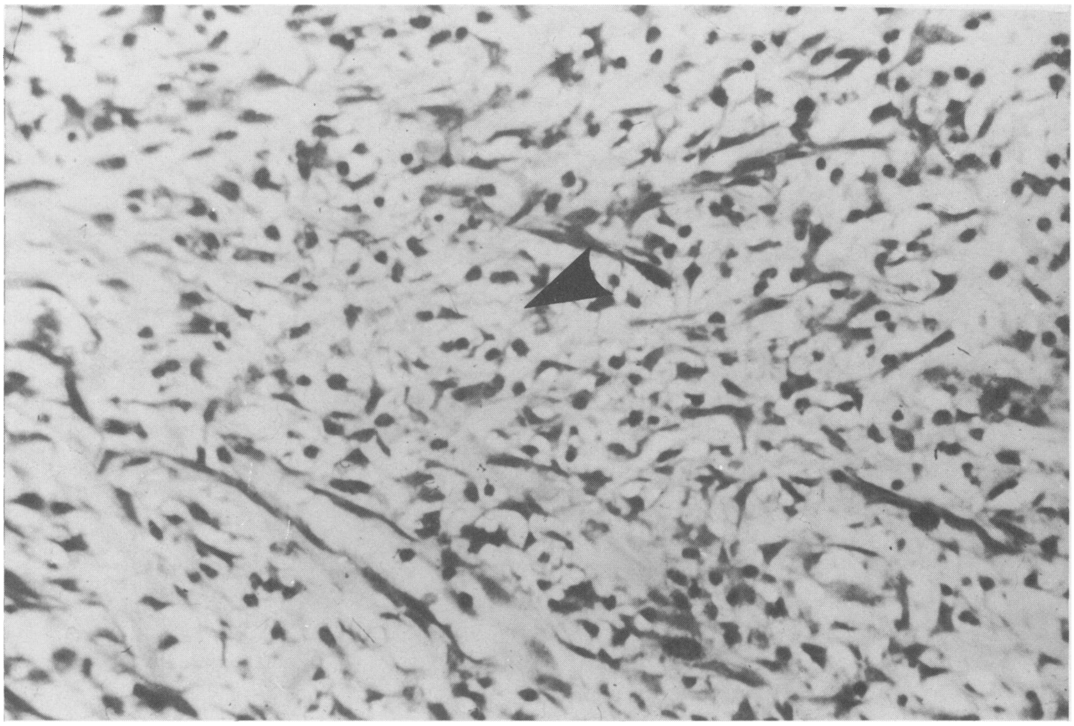

FIG. 7 Autoradiograph showing scanty labelling of fibroblasts and whorls of collagen (arrowed). H&E ×170.

The Ideal Suture

Moynihan said: 'Every operation in surgery is an experiment in bacteriology' (*12*) and we have confirmed the importance of infection in our clinical study. Furthermore, over 85% of patients developing sinuses had a preceding wound infection, the majority in relation to suture material. It is vital therefore to ensure that the suture we use is the best available for the task, particularly in the presence of infection.

There are a large number of sutures available, broadly classified into absorbable, which degrade in tissues and lose their tensile strength within 60 days, and non-absorbables which remain unchanged. These are further subdivided into monofilament, those formed of one strand, and multifilament formed of several strands usually in a braided fashion. The four sutures chosen for testing are all in everyday use for abdominal wound closure. Polyglycolic acid (Dexon), a braided absorbable suture; silk, an organic braided non-absorbable, and nylon, a synthetic non-absorbable suture, which was tested in both mono and multifilamentous forms.

Catgut was not tested as Goligher in 1976 (*4*) showed that it had insufficient strength for use in abdominal wound closure, being associated with an 11% incidence of dehiscence.

Moynihan (*12*) in 1920 laid down the requirements for an ideal suture. It should be free from infection and be non-irritant to tissue, it should achieve its purpose, in this case be sufficiently strong to hold the abdominal wall together and it should disappear when its work is finished. We therefore designed a series of experiments to test these requirements.

The first experiment was designed to test the ability of sutures to potentiate infection, aiming to give a quantitative value to what several observers had noticed, that different sutures potentiate infection to different degrees (*13, 14, 15*). A standard length of suture material was dipped into a culture broth containing a known number of bacteria (C). The suture was then removed and washed. From bacterial counts in the broth after soaking the suture (A) and in the broth used for washing (B) the number of bacteria picked up and retained by the suture was calculated (Fig. 8). This was then expressed as a ratio (R) of the number picked up by the suture (S) over the number available in culture (C). The mean ratios obtained were silk—0.46, polyglycolic acid—0.32, multifilament nylon—0.42, and monofilament nylon—0.13. The suture with the lowest ratio is the least contaminated, in this case monofilament nylon.

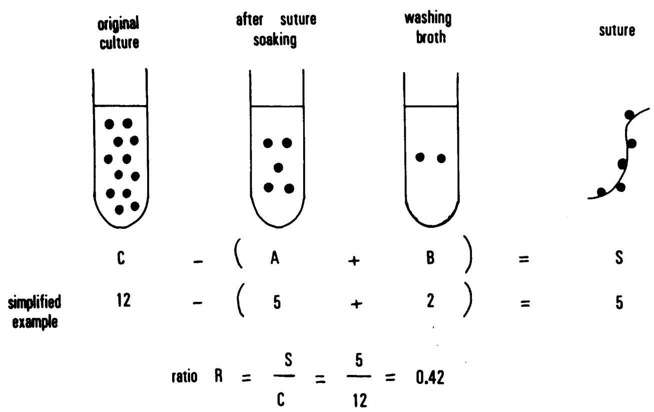

FIG. 8 Suture infectivity calculations with a simplified example.

The effect of washing the suture was demonstrated by placing a 'prewash' and a 'postwash' suture length onto a culture plate and incubating overnight. With monofilament nylon the washing had almost cleaned the suture. However with all the multifilament sutures washing made very little difference. This led us to believe that bacteria may be lodged between the braid of multifilamentous material.

The second experiment tested the inertness, or non-irritability, of sutures by looking at their tissue reactions histologically. Silk, an organic material, was very reactive particularly when infected, with large abscesses dotted along its length. Nylon and polyglycolic acid were inert when non-infected but infection resulted in greatly increased reaction with abscess formation in the braided sutures. Monofilament nylon remained inert, thus confirming the findings of other workers (*16, 17, 18*).

Synthetic materials are therefore less reactive than organic materials but the physical characteristic of braiding induces reactivity and abscesses when used in infected wounds.

We next tested the durability of sutures. Sutures were implanted into the dorsum of rats previously infected by local injection of *Staphylococcus* aureus, or saline if acting as non-infected controls. The sutures were removed at 10, 30 and 70 day intervals and their strength measured on an Instrom tensiometer (*19*). Nylon in both monofilament and braided forms retained its strength during the complete test period. Silk sutures lost up to 83% of their original strength after 70 days. The loss was slowed by infection. Polyglycolic acid rapidly lost strength after implantation and although infection slowed its absorption by 30 days only 4% of the original strength remained. As it takes at least 70 days for an abdominal wound to heal the results for polyglycolic acid are disturbing.

Electron microscopy was used to test the hypothesis that bacteria can hide within the braid of multifilamentous material. Sutures prepared in the same way as for the durability studies were examined using a Cambridge S600 Scanning Electron Microscope. Bacteria were found lodging in the interstices of all infected multifilamentous material particularly silk (Fig. 9) and nylon (Fig. 10), where a

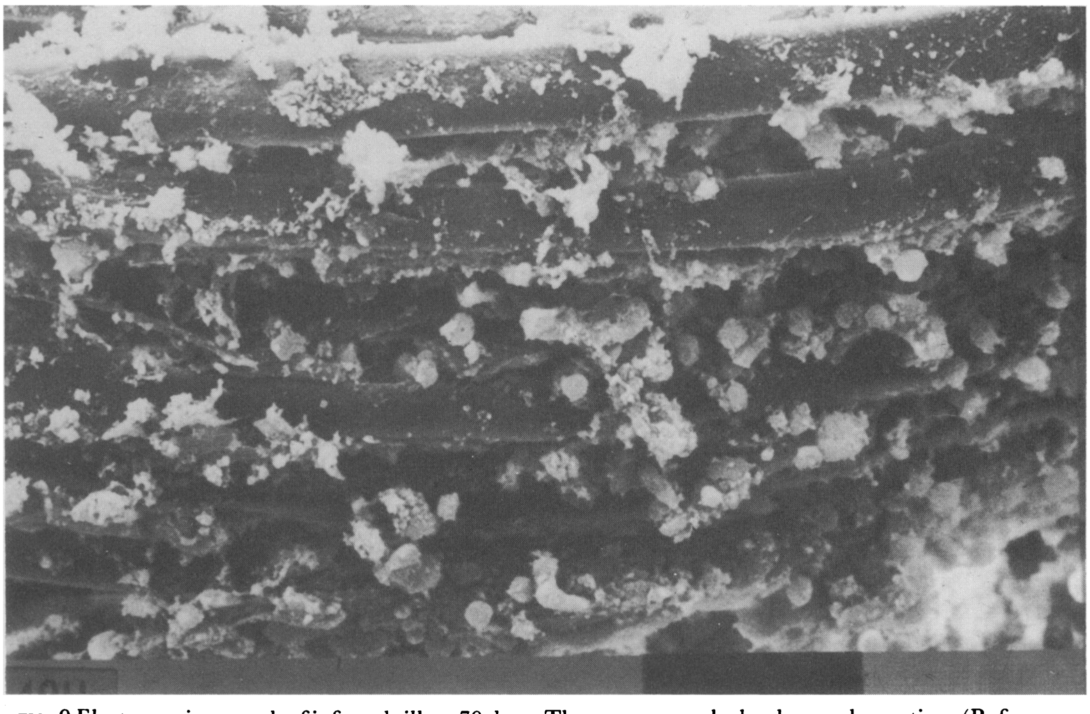

FIG. 9 Electron micrograph of infected silk at 70 days. There was a marked polymorph reaction. (Reference scale 40 μ).

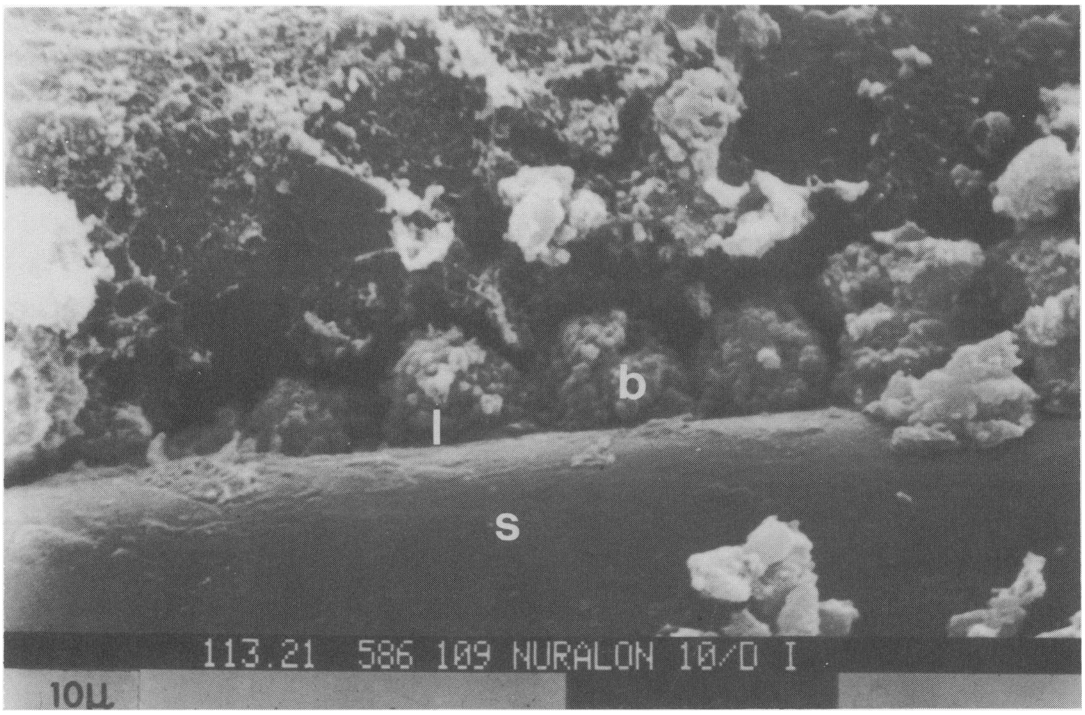

FIG. 10 Electron micrograph of infected multifilament nylon (Nuralon) at 10 days showing leucocytes (l), surrounded with bacteria (b) between suture strands (s). (Reference scale 10 µ.)

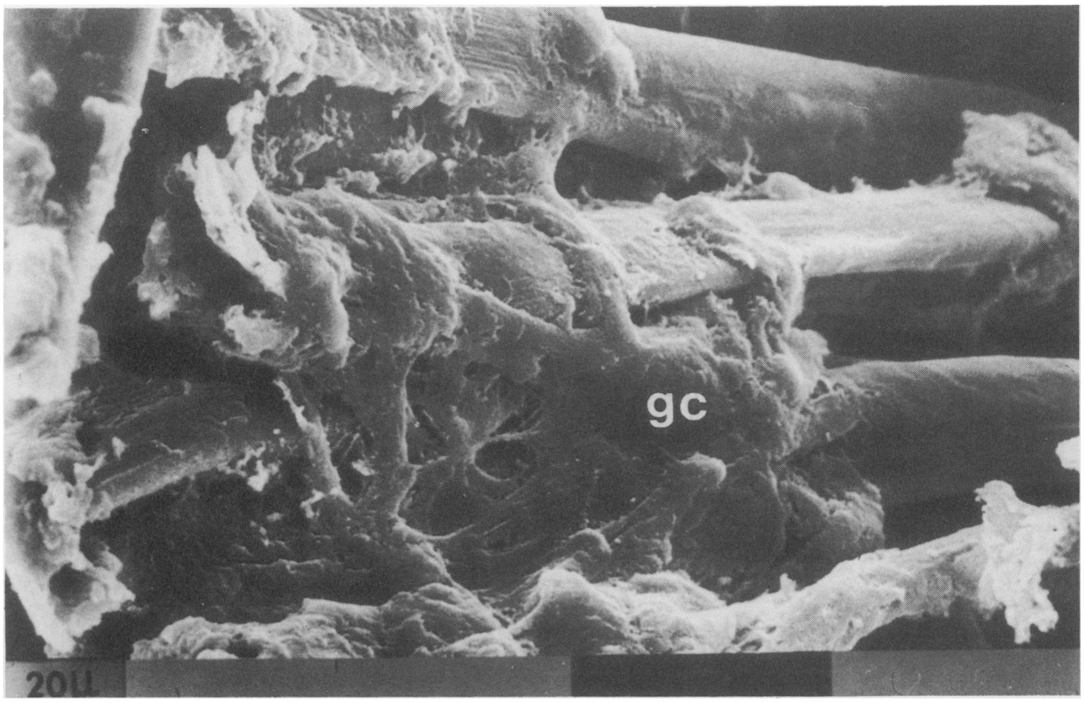

FIG. 11 Non-infected silk at 70 days. Strands have been almost completely engulfed by giant cells (g.c.) (Reference scale 20 µ).

vigorous polymorphonuclear cell reaction between the strands continued to 70 days. In the non-infected sutures fibroblasts and giant cells (Fig. 11) appeared earlier, probably as there were no polymorphs preventing their ingress. Suture strands remained tightly bound in the non-infected state in contrast to the infected sutures where pus was seen between the strands. Polyglycolic acid showed little cellular reaction in the non-infected state until giant cells invaded and quickly absorbed the suture. The giant cell invasion was slowed by infection and consequently strands of polyglycolic acid remained at 70 days. These strands act as foreign bodies but do not retain any strength, as was demonstrated with the durability study. The reaction around monofilament nylon was minimal and a fibrous capsule appeared at 10 days (Fig. 12) even in the presence of infection. There was nowhere for bacteria to hide with the monofilament suture unless the suture was knotted. The knots then provided spaces in which bacteria may lodge.

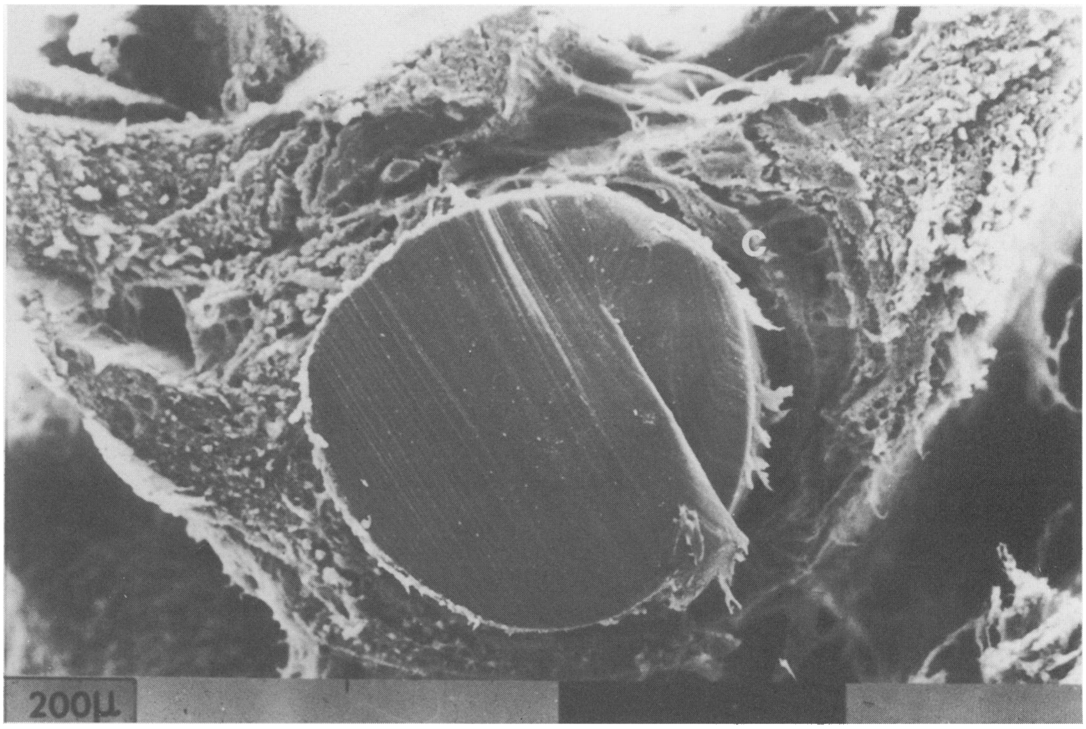

FIG. 12 Infected monofilament nylon at 10 days. Slightly increased cellular components when compared with the non-infected suture, but still only a very small reaction zone. A fibrous capsule (c) has developed. (Reference scale 200 µ).

The closest to the ideal is therefore a monofilament non-absorbable suture, in this case nylon. It provides no hiding place for cells and bacteria, in contrast to the braided sutures. As well as this being desirable in not potentiating wound infections, it is important in reducing sinus formation. The strength should be sufficient to hold abdominal fascia together even if healing were delayed by infection.

This was confirmed in a randomized clinical trial in which we compared monofilament nylon with polyglycolic acid in the closure of abdominal wounds using the mass closure technique (*20*). There was a 12.5% wound failure rate with polyglycolic acid but only 4.7% using nylon ($p = 0.04$). The strength of polyglycolic acid was therefore not sufficiently longlasting to ensure satisfactory healing. Also the expected advantage with the absorbable polyglycolic acid suture in terms of a zero sinus formation rate was not seen (11.5% with polyglycolic acid, 9.5% with nylon), presumably due to infection delaying the complete absorption of the suture, allowing it to act as a foreign body.

Conclusion

We have confirmed what John Hunter wrote in 1790 (*21*) 'A wound will not heal while there is slough to separate' and have shown the importance of using a monofilament non-absorbable suture in this instance.

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