THE MENISCUS—CAN IT BE REPAIRED?

AN EXPERIMENTAL INVESTIGATION IN RABBITS

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In rabbits, repair of incisions in the central part of the meniscus has been demonstrated after surgical excision of the peripheral rim. Healing took place via a highly cellular but relatively avascular fibrous tissue stroma which proliferated from the synovial margin and invaded along the cut edge of the meniscus. Suturing facilitated this healing process by providing stability and possibly by supplying bridges for synovial cells to migrate onto the meniscus. Transformation of fibrous tissue into fibrocartilage has also been observed.

The scientific basis for surgery of meniscal lesions was established by King (1936) in a series of simple experiments on the menisci of dogs. He drew three conclusions. First, a tear in the substance of the meniscus probably never heals; secondly, a tear through the peripheral synovial attachments does heal; and thirdly, a cut in the substance of the meniscus which extends peripherally into the synovium may heal. His first conclusion vindicated the operation of meniscectomy. His second led eventually to the surgical reattachment of menisci which had been avulsed from their synovial attachments in association with major ligamentous injuries. No surgical procedures have been based on his third observation. This is probably because King himself found that synovial cells could invade for only a short distance along a cut which extended from the synovium into the substance of the meniscus. This healing process might be more reliable if the distance the cells had to

travel was reduced by excising the peripheral rim of the meniscus and if instability of the meniscus could be overcome.

MATERIAL, METHODS AND RESULTS

The menisci of young adult New Zealand white rabbits weighing at least 2.5 kilograms were exposed using a parapatellar incision and dislocating the patella either medially or laterally. After operating on the meniscus, the patella was repositioned, the wound closed in layers, and the knee splinted.

Experiment 1. A longitudinal incision was made in the anterior part of the medial meniscus (Fig. 1). The peripheral part of the meniscus between the incision and the synovium was excised. The resulting gap was closed with a single Dexon suture placed between the synovium and the central portion of the meniscus (the two points

Fig. 1

Fig. 2

Figure 1—In this, as in all the subsequent illustrations, the right knee is seen from above, the anterior portion uppermost. This diagram is of Experiment 1, in which a section has been excised from the anterior horn of the medial meniscus and the resulting defect closed with a Dexon suture. Figure 2—At six weeks the meniscus has healed.

Fig. 3

Fig. 4

Fig. 5

Experiment 2. Figure 3—The procedure was the same as in Experiment 1, except that no suture was used. At six weeks the defect has been reduced to a linear gap. Figure 4—A section along A-A' (in Fig. 3) shows that the shape of the meniscus has been restored but the bridge of fibrous tissue across the residual gap is tenuous. (Haematoxylin and eosin, $\times 10$). Figure 5—In this enlarged view ($\times 27$) of the anterior horn, the newly formed fibrous tissue appears avascular and can easily be distinguished from the original meniscus.

marked X, X). Six weeks after operation the animal was killed and the knee examined. Figure 2 shows that the meniscus is soundly healed and has regained its normal shape.

Experiment 2. The procedure here was the same as in Experiment 1, except that on this occasion the meniscus was not sutured. By six weeks the defect was reduced in size to a thin line (Fig. 3). A microscopic section from A to A' showed that the defect was bridged for most of its length, but there was still a small gap in the posterior part. Even where a gap remained the cut meniscal edge was covered with newly formed fibrous tissue (Figs 4 and 5).

Experiment 3. A larger piece of the medial meniscus was excised from the anterior horn attachment back to the level of the medial ligament (Fig. 6). A single catgut suture was placed anteriorly between the two points marked X, X. At six weeks the meniscus was soundly

healed in its anterior part (Fig. 7), but in its posterior part, near the medial ligament, a gap still seemed to be present (Fig. 7). Microscopically, even this area had a fragile bridge of synovial tissue. There was a considerable area of cell death in that part of the meniscus compressed by the suture.

Experiment 4. Again the periphery of the medial meniscus was excised as in the previous experiment; but the length excised was greater, extending from the anterior horn to behind the medial ligament. The defect was not sutured. Six weeks later an arthrotomy was performed; this revealed a large gap through which a probe could easily be passed onto the tibial plateau. At 12 weeks from the beginning of the experiment a necropsy was performed; this showed (Fig. 8) that there was still a large gap, but the meniscal edge was now lined by translucent fibrous tissue and there had been some attempt to close the gap from both ends.

Fig. 6

Fig. 7

Experiment 3. Figure 6—The area of the anterior horn excised extended back to the medial ligament. A catgut suture was placed anteriorly. Figure 7—A small defect is still present near the medial ligament. Anteriorly, in the region of the suture, healing is sound.

Fig. 8

Fig. 9

Fig. 10

Experiment 4. Figure 8—Twelve weeks after operation a large defect still remains but the meniscal edge is covered by translucent fibrous tissue. Figure 9—Section across the anterior horn in the plane A-A' (in Fig. 8). The tissue filling the surgical defect is more vascular than in the previous experiments. (Haematoxylin and eosin, $\times 20$). Figure 10—Section across the meniscus in the line B-B' (in Fig. 8). A large gap is present between the meniscus and the synovium. The cut edge of the meniscus is covered by fibrous tissue of varying maturity. The free border is penetrated by capillaries but the more mature fibrous tissue is largely avascular. (Van Gieson, $\times 8$). Figure 11—High-power view of the edge of the meniscus showing the fibrous tissue "cap". (Van Gieson, $\times 65$).

Fig. 11

Histological examination confirmed that the anterior horn had become "reattached" (Fig. 9). The unhealed peripheral border of the meniscus was coated throughout the length of the surgical incision by a fibrous tissue covering (Figs 10 and 11); this shows two distinct zones suggestive of two episodes of attempted healing, the second possibly stimulated by the arthrotomy. Despite considerable variation between the

various serial sections, it was clear that the fibrous tissue was, in general, more vascular than in the previous experiments.

Experiment 5. A "bucket handle" tear was simulated by making a long incision extending from the anterior to the posterior horns (Fig. 12). The peripheral part of the meniscus was excised and the remaining central portion secured to the synovium with three catgut sutures. At six

Fig. 12

Fig. 13

Experiment 5. Figure 12—The periphery of the meniscus was excised from anterior to posterior horns. Three catgut sutures (X, X) secured the remaining central part of the meniscus to the synovium. Figure 13—Macroscopic appearance at six weeks. Sound healing has occurred but the shape of the meniscus is distorted.

weeks apparently sound healing had occurred but there was some distortion in the shape of the meniscus (Fig. 13).

An attempt to repeat this experiment was less successful. There was healing at the anterior and posterior areas but centrally the catgut suture had not held and a defect had persisted. As in previous experiments, where there was a residual gap histological examination showed the incised edge to be covered by a cellular "cap".

The effect of delay

A series of experiments was next performed, similar to those previously described but with an interval of six weeks between making the incision in the meniscus and excising the peripheral meniscal rim. These experiments were undertaken to see if delay affected the ability of synovially derived cells to adhere to the cut meniscal edge.

Experiment 6. An incision was made in the anterior part of the medial meniscus but no material was excised. Six weeks later the peripheral segment of the meniscus, lying between the central incision and the synovium, was excised. The resulting defect was not closed with a suture. After a further six weeks the animal was killed and the knee examined. The defect left by excising the periphery of the meniscus had filled in with dense white scar tissue. In the centre of this was a depression, suggesting that healing had occurred circumferentially following the spread of synovial cells along the cut edge

Fig. 14

Experiment 6. Transverse section across the meniscus. The central depression which could be observed macroscopically appears as the cleft at X. There is dense newly formed fibrous tissue on both sides and some fine fibrils passing across the central zone. The defect is healing circumferentially. The fibrous tissue on the side of the meniscus is relatively avascular. (Haematoxylin and eosin, $\times 20$).

of the meniscus. This depression corresponds to the cleft seen in Figure 14. It seemed that delay in excising the periphery made no difference to the junction between fibrous tissue and fibrocartilage.

Experiment 7. The procedure described in Experiment 6 was repeated, but with one difference; on this occasion a catgut suture was used to close the defect left when the periphery of the meniscus was excised at the second arthrotomy. Six weeks after this second procedure the animal was killed and the knee examined. Sound healing had occurred and the scar tissue was much less extensive than in the previous experiment.

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Experiment 8. Figure 15—A larger initial incision was made in the meniscus and subsequently a large part of the peripheral rim was excised. Figure 16—Six weeks later the central part of the meniscus has ruptured. There is proliferation of new fibrous tissue along the cut edges of the meniscus. Figure 17—A section along the line A-A' (in Fig. 16) shows: 1, parrot beak, meniscal fibrocartilage; 2, new fibrous tissue; 3, cartilage arranged in radial rows; and 4, central calcified zone. (Haematoxylin and eosin, $\times 20$). Figure 18—Columns of fibrocartilage cells are aligned perpendicular to the surface and run down into the calcified deeper zone. (Haematoxylin and eosin, $\times 200$).

Experiment 8. In this experiment a much larger incision in the medial meniscus was made, extending as far as the medial ligament (Fig. 15). Again nothing was removed until a second arthrotomy six weeks later when the periphery of the meniscus was excised. No suture was used to close the defect left by this peripheral excision. Six weeks after this second arthrotomy the knee was examined at necropsy. The remaining central part of the meniscus was found to have ruptured and the peripheral defect was only partially obliterated (Fig. 16). There was, however, clear evidence of the spread of synovial cells along the cut edge of the meniscus. Figures 17 and 18 show the microscopic appearance through the "parrot beak". There is transformation of fibrous tissue to fibrocartilage which in turn is becoming calcified.

DISCUSSION

A great variety of experiments, similar to those described in this article, is clearly possible, varying the amount of meniscus excised, the time interval between making the meniscal incision and excising the peripheral rim, and the type of material used to stabilise the meniscus. Many experiments, other than those described, were in fact performed. These particular ones were selected as exemplifying the considerable potential for repair in damaged menisci. We also repeated in rabbits the experiments described by King in dogs. Our results were essentially the same as his, but with one difference. He found that the dog's meniscus was unresponsive to an incision, whereas in the rabbit it is common to find clustering of chondrocytes near the margin of the incision.

An essential prelude to meniscal healing is invasion by synovial cells. King found that extending a central incision in the meniscus as far as the synovium did not necessarily result in healing along the entire length of the incision. In rabbits, we found that healing was likely to follow when a small incision in the anterior horn was extended as far as the synovium; whereas a large incision which reached back to the medial ligament was less likely to heal.

Similarly with excision; when the amount of meniscus excised from the anterior horn is small, then healing is reliable. As might be expected, it occurs more quickly and with less scarring when sutures are used. When large peripheral defects are created it seems essential to use sutures in order to provide stability and to reduce the size of the gap. The sutures also appear to act as bridges for the passage of synovial cells to the meniscus. The disadvantage of sutures is that they cause further areas of fibrocartilage cell death in the meniscus.

It is interesting that even in the "failed cases" a layer of synovial cells was always found lining the cut edge of the meniscus. Healing seems to occur circumferentially; initially the cells proliferate at the synovial margin, then they migrate along the cut meniscal edge, gradually closing the defect from both sides. Very few

blood vessels are found in the newly formed fibrous tissue and large areas seem completely avascular. King implied that avascularity was the reason for the absence of healing in meniscal fibrocartilage, but he did not comment on the vascularity of the invading connective tissue pannus. In the only photomicrograph which he published showing this scar tissue in the dog, there are very few blood vessels and the appearance is similar to that observed in the rabbit. Of our experiments, Figure 9 shows the one with the most marked vascularity; even in this section large avascular areas of fibrous tissue are visible. Presumably the invading cells derive their nutrition largely from the synovial fluid. Whether healing occurs seems to depend, not on the presence of a vascular supply, but on the actual type of cell invading the damaged area. Synovial cells proliferate readily while cartilage cells have only limited ability to undergo mitosis. The proliferating synovial cells form fibrous tissue which initially is very cellular, but later becomes more fibrous and may occasionally be transformed into fibrocartilage. This transformation, which may result from compression, is seen in Figures 17 and 18; the zone of fibrocartilage was attached to the "parrot beak". The sequence of events resembles that seen in the embryological development of the meniscus, where the cellular blastema is converted into an organised highly cellular fibrous tissue, with final transformation into cartilage cells. (Kaplan 1955). The pathway in adults may be similar provided the cellular response, potentially present in the periphery, is able to invade the site of injury.

In 1889, Thomas Annandale sutured the torn meniscus of a Newcastle miner. This outstanding technical achievement remains the only case of its kind in the orthopaedic literature. Whether Annandale merely provided stability or whether he actually achieved healing is, of course, unknown, but his patient was fit enough to be working again as a miner six months later. In spite of the remarkable technical expertise which Annandale displayed in suturing a torn meniscus, Sir Robert Jones (1909), writing 20 years later, was clearly unimpressed, for he concluded that "stitching of the cartilage should be an obsolete operation".

However, the meniscus is an important functional component of the knee (Seedhom, Dowson and Wright 1974) and its excision in Man is associated with the development of osteoarthritis some years later (Johnson *et al.* 1974). The experiments reported in this paper demonstrate that cells derived from synovium are capable of healing an incision in the substance of the rabbit's meniscus provided they can penetrate into it. It is possible that a similar healing mechanism might be present in Man; indeed, cases of natural healing of transverse tears have been reported (Smillie 1946). Operations designed to allow an ingrowth of synovial cells and to achieve initial stability could provide a more constructive answer for some longitudinal meniscal tears.

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