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Ultrastructure of normal and torn menisci of the human knee joint

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INTRODUCTION

As yet no transmission electron microscopic study describing the overall morphological features of normal and torn menisci from the human knee joint has been published. However, a few publications dealing with certain ultrastructural features seen in these fibrocartilages are available. These include: (1) a study on surgically removed torn menisci showing that the nuclei of cells near the tear have a thicker fibrous lamina than those well away from the tear (Ghadially, Dick & Lalonde, 1980*a*); (2) a study on surgically removed torn menisci demonstrating the occurrence of myofibroblasts and intracytoplasmic collagen in injured portions of menisci (Ghadially, Lalonde & Yong, 1980*b*); and (3) a report on the occurrence of intramatrical lipidic debris and calcified bodies in surgically removed torn menisci (Ghadially & Lalonde, 1981).

In this paper we record the general ultrastructural morphological features of normal human menisci as seen in autopsy material and the ultrastructural morphological features of surgically removed torn menisci (same cases as in our previous studies) near the site of the tear and the normal-looking portions well away from the site of the injury.

MATERIALS AND METHODS

Surgical specimens

Nine surgically removed torn menisci (Cases 1–9 in Table 1) were used in this study. Immediately after surgical removal the menisci were bathed in 2 % glutaraldehyde in 0·1 M cacodylate buffer (pH 7·4). The gross appearance of the meniscus was rapidly noted and recorded. Small pieces (< 1 mm^3) of tissue were then collected from the relatively normal-looking parts (henceforth referred to as 'uninjured portion') free from any grossly visible roughening or fibrillation. Similarly, small pieces (< 1 mm^3) of the meniscus adjacent to the tear (henceforth referred to as the 'injured portion') were collected. The remaining pieces of meniscal tissue were processed in the conventional manner for light microscopy. Sections were stained with haematoxylin and eosin.

Autopsy specimens

Seven medial menisci obtained from the right knee at autopsy (Cases 10–16 in Table 1) were used in this study. These menisci came from uninjured normal-looking joints with no evidence of articular disease. The menisci showed no fibrillation or

Table 1. *Details of surgical cases (nos. 1–9) and autopsy cases (nos. 10–16)*

Case no.	Age in years	Sex	Interval between injury and surgery (S) or death and autopsy (A)	Meniscus	Size of tear	Cause of injury or death
1	15	M	13 days (S)	Left lateral	0·6 cm	Fighting
2	16	F	18 months (S)	Right medial	3 cm	Struck by car
3	17	M	6 months (S)	Left medial	Multiple small tears	Running
4	18	M	3 months (S)	Left medial	1·5 cm	Pushing wheelbarrow
5	21	M	8 years (S)	Left medial	3 cm	Vaulting
6	28	M	2 years (S)	Right medial	2·5 cm	Playing ball
7	47	M	9 months (S)	Left medial	3 cm	Fell down
8	47	M	2 years (S)	Right lateral	4 cm	Curling
9	60	M	2 years (S)	Left medial	4 cm	Golfing
10	13	M	21 hours (A)	Right medial	No tear	Car accident
11	14	M	14·5 hours (A)	Right medial	No tear	Car accident
12	14	F	17 hours (A)	Right medial	No tear	Car accident
13	15	F	20·5 hours (A)	Right medial	No tear	Car accident
14	20	M	12 hours (A)	Right medial	No tear	Car accident
15	22	M	20 hours (A)	Right medial	No tear	Car accident
16	26	M	21 hours (A)	Right medial	No tear	Motor cycle accident

areas of roughening that could be detected with the naked eye. Immediately after removal the menisci were bathed in 2 % glutaraldehyde in 0·1 M cacodylate buffer (pH 7·4). Their gross appearance was noted and recorded. Small pieces of tissue (< 1 mm^3) were collected from the anterior, middle and posterior portion of each meniscus, and processed as described below. The remaining pieces of meniscal tissue were processed in the conventional manner for light microscopy. Sections were stained with haematoxylin and eosin.

Processing of tissues for electron microscopy

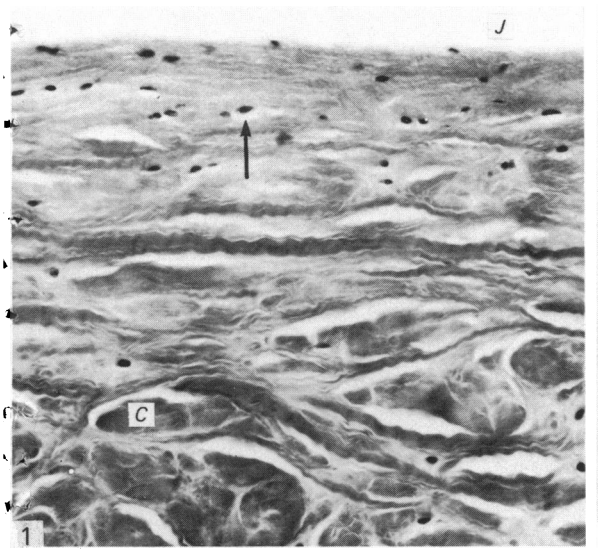
Pieces of menisci obtained as described above were fixed in 2 % glutaraldehyde in 0·1 M cacodylate buffer (pH 7·4) for 1 hour, post-fixed in 2 % osmium in 0·1 M cacodylate buffer (pH 7·4) for 1 hour, rinsed in buffer, dehydrated in increasing concentrations of ethanol, cleared in propylene oxide, embedded in Epon and cut with diamond knives in Reichert microtomes. Semithin sections from all blocks were stained with toluidine blue and examined with the light microscope.

Ultrathin sections from selected blocks were mounted on copper grids, stained with uranyl acetate and lead citrate and examined with a Zeiss EM-9S electron microscope.

RESULTS

Gross examination

Naked eye and ×7 magnifying glass inspection of normal menisci obtained at autopsy showed the surface to be smooth save for the presence of an occasional fine ridge or furrow near the outer margin. Only a small area of surface roughening was detected in one specimen. However, some slight fraying of the inner edge was common. The surface of the injured portion of torn menisci was roughened and at



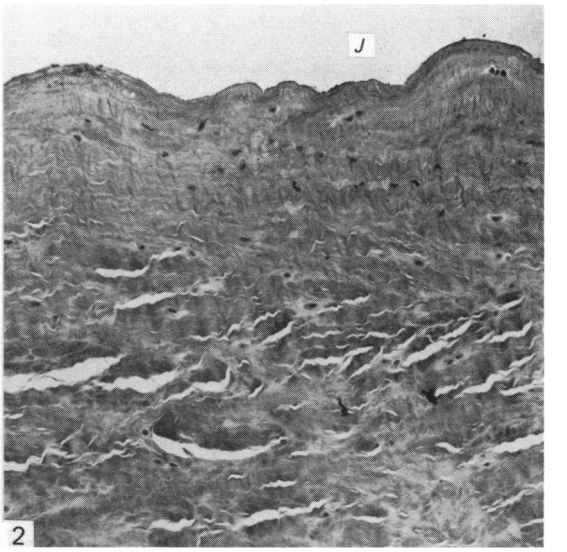
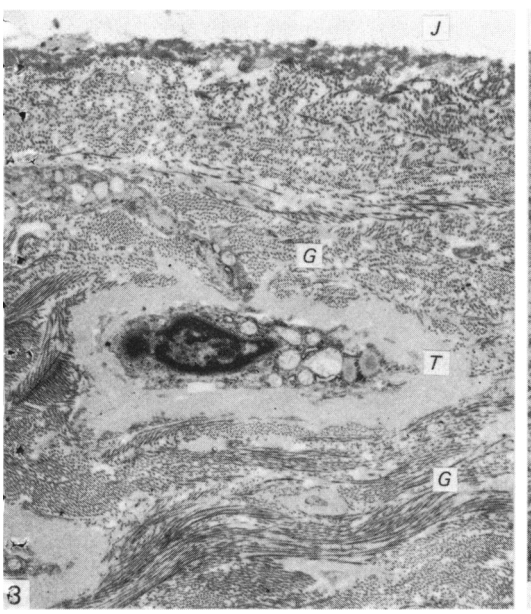


Fig. 1. In this haematoxylin and eosin-stained section from an uninjured portion of a torn meniscus, the shrunken cells appear to lie in clear lacunae (arrow). The superficial zone with its oval and elongated cells is easily distinguished from the middle zone containing transversely or obliquely cut collagen fibres (*C*) and fibre bundles. The surface is slightly wavy but otherwise quite smooth. *J*, Joint space. ×225.

Fig. 2. In this haematoxylin and eosin-stained section from an uninjured portion of a torn meniscus, the surface adjacent to the joint space (*J*) shows irregular undulations. ×120.



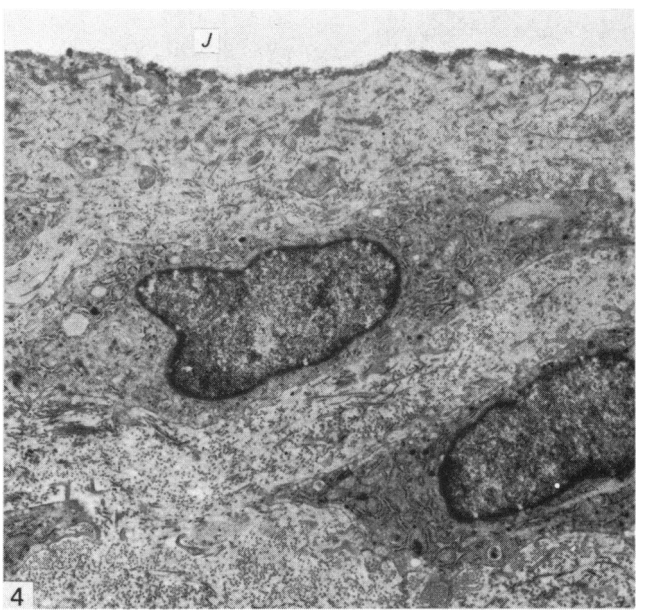
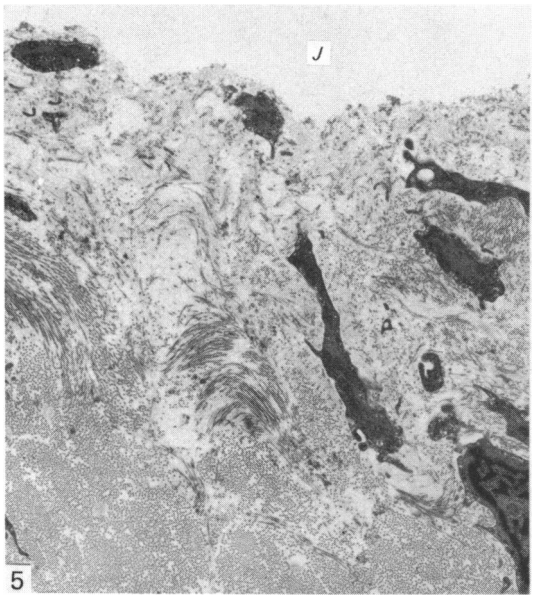


Fig. 3. From the uninjured portion of a torn meniscus. A small part of a convex portion of a gently undulating surface is seen adjacent to the joint space (*J*). The surface is fairly smooth and covered by an electron-dense surface coat. The fine-textured territorial matrix (*T*) surrounding the chondrocyte is easily distinguished from the coarse general matrix (*G*) containing collagen fibrils. ×5400.

Fig. 4. From the uninjured portion of a torn meniscus. The surface adjacent to the joint space (*J*) appears somewhat rough. The cells are difficult to classify as either chondrocytes or fibroblasts; they are of an intermediate form. A clear cut territorial matrix is not seen around these cells. ×6500.



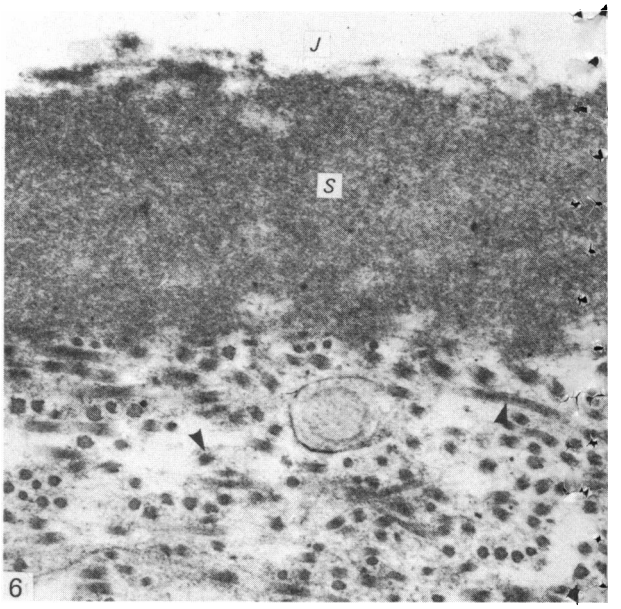


Fig. 5. From the injured portion of a torn meniscus. The surface is markedly disrupted adjacent to the joint space (*J*). The cells appear shrivelled and electron-dense. × 5000.

Fig. 6. From the uninjured portion of a torn meniscus. Near the joint space (*J*) is seen the surface of the meniscus. It is composed of collagen fibrils (arrowheads) surmounted by the electron-dense surface coat (*S*). × 41000.

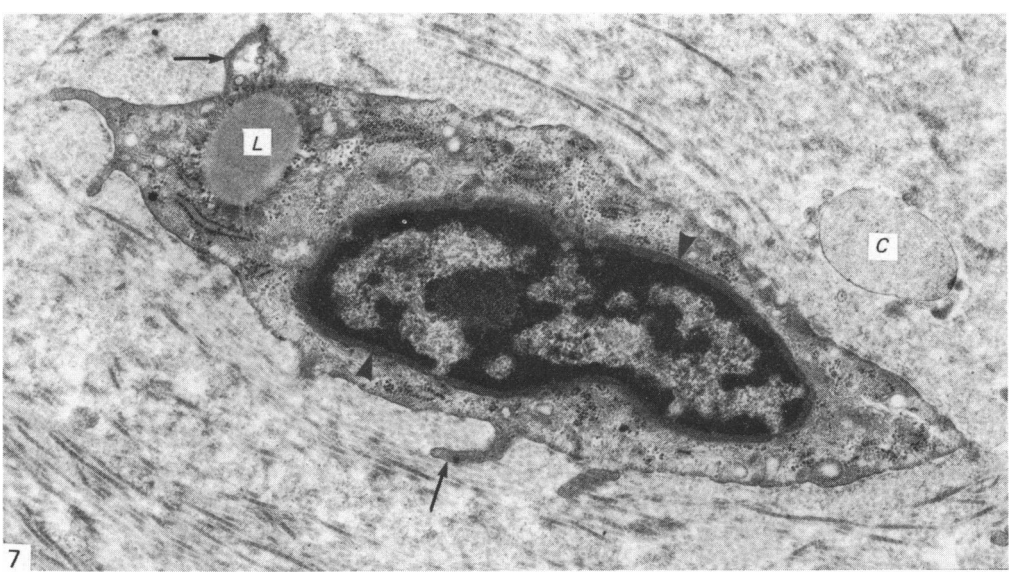


Fig. 7. From the superficial zone of an uninjured portion of a torn meniscus showing a chondrocyte with short cell processes (arrows), a lipid droplet (*L*) in its cytoplasm and a fibrous lamina (arrowheads) in its nucleus. There is a membrane-bound cyst-like structure (*C*) in the general matrix. × 16000.

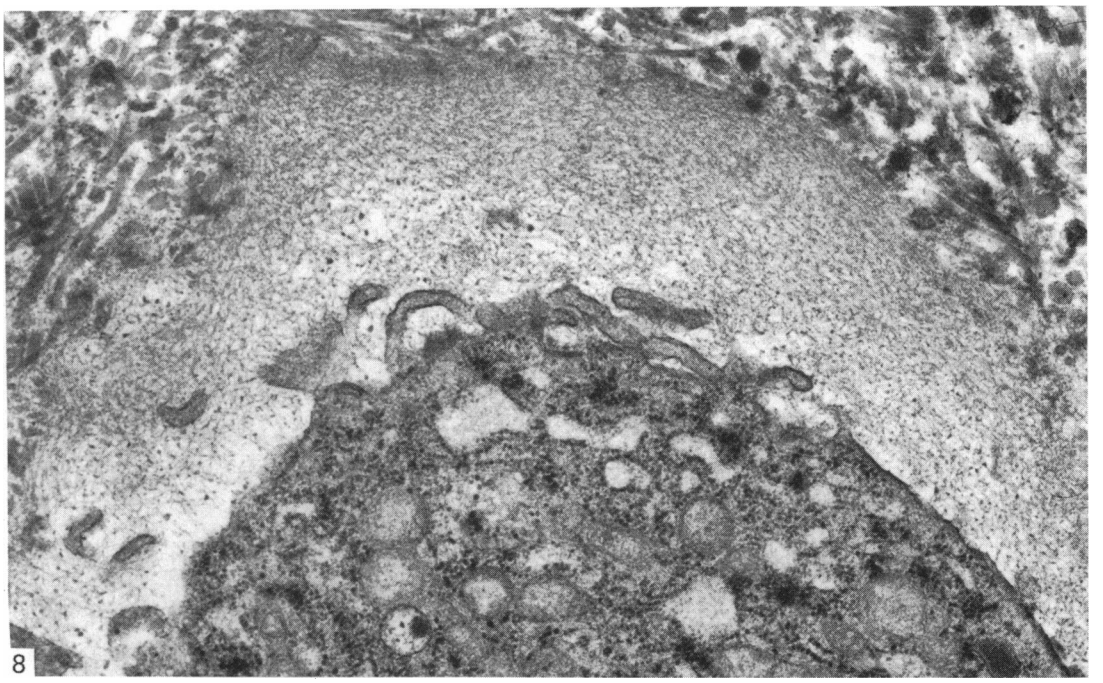


Fig. 8. From the middle zone of an uninjured portion of a torn meniscus. A small part of a solitary chondrocyte is set in an abundant territorial matrix in which proteoglycan particles and filaments are just discernible. The collagen fibrils of the general matrix may be compared with those in Figure 7: the fibrils in the middle zone of the meniscus are much thicker than those in the superficial zone even when the higher magnification of Figure 8 is accounted for. ×24000.

times obviously fibrillated. Areas of roughening and fibrillation were rare in the uninjured portions. Fraying of the inner margin was almost invariably present.

Light microscopy

In sectioned material, the surface of normal menisci and uninjured portions of menisci did not appear smooth (as had been seen in the fresh specimen with the naked eye) but slightly irregular, wavy or markedly undulating, depending on the site and plane of sectioning (Figs. 1, 2). However, marked roughening and disruption of the surface were frequently seen adjacent to a tear.

In haematoxylin and eosin-stained sections, the cells were seen to lie in lacunae (Fig. 1). That such an appearance is largely an artefact due to cell shrinkage is evidenced by the fact that in plastic-embedded material this feature could hardly be discerned. However, in some instances a specialised area of fine textured metachromatic matrix surrounded the cell. This could be designated as the pericellular or territorial matrix. Collagen fibres and bundles of such fibres of the general or interterritorial matrix were more easily visualised in paraffin than in plastic-embedded material (Fig. 1).

Our studies have confirmed two well known facts: namely, (1) that synovial membrane overlaps the peripheral part of the meniscus; and (2) that the peripheral part of the meniscus has a blood supply, but the major part is avascular.

Calcification was not detected in any specimen studied. Chondrocyte clusters as seen in experimentally injured cartilage or fibrillated osteoarthrotic cartilage were not found in injured menisci.

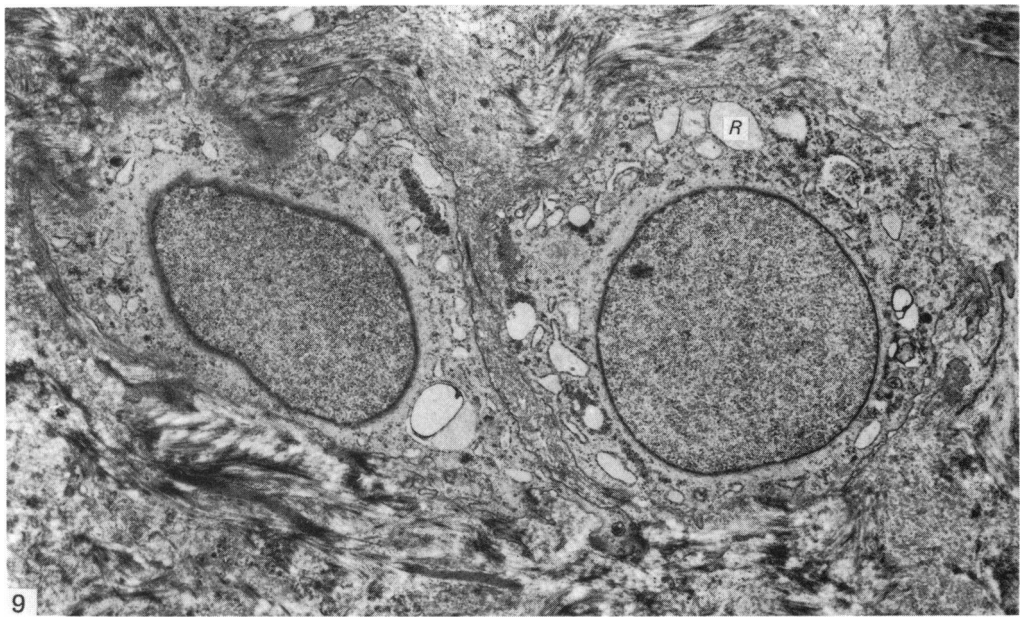


Fig. 9. From an autopsy specimen (Case 11). A chondrocyte pair from the middle zone of the meniscus. Little or no territorial matrix is present. The collagen fibrils of the general matrix abut the cell membranes of the chondrocytes. Dilated and vesiculated rough endoplasmic reticulum (R) is present. × 7500.

Electron microscopy

General observations

The sections obtained from the three regions (anterior, middle and posterior) of the menisci collected at autopsy showed no constant regional ultrastructural differences worthy of note. However, morphological differences were found between the surface layers (superior and inferior) and the deeper or middle parts, in all regions of the meniscus. These will be referred to as the superficial and middle zones of the meniscus. Further division into a superficial zone adjacent to the superior surface and another adjacent to the inferior surface is not warranted on the basis of the present study, for all surfaces encountered showed similar features.

The autopsy specimens resembled the uninjured portions of torn menisci, except that well known anoxic or early autolytic changes (such as dilatation of the rough endoplasmic reticulum and mitochondrial swelling) were more marked and almost invariably present in virtually every cell in the autopsy specimen. Collagen fibrils and proteoglycan particles were well preserved in the autopsy specimens and so were the elastic fibres except that collections of 11 nm electron-dense filaments usually found at the periphery of elastic fibres had deteriorated into irregular electron-dense granules.

Surface

In ultrathin sections, the surface of normal menisci or uninjured portions of torn menisci was usually smooth but gently undulating (Fig. 3). However, at times it was noticeably roughened (Fig. 4). A much rougher disrupted surface was seen (Fig. 5) in the injured portions of menisci and at times cells lay exposed at the articular surface.

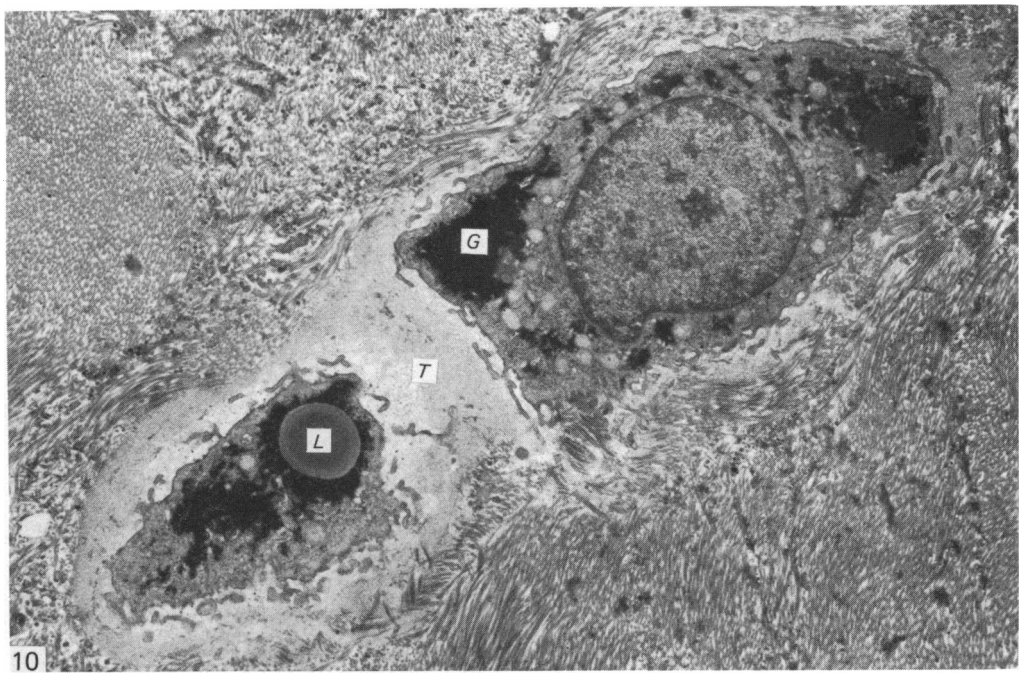


Fig. 10. From the middle zone of an uninjured portion of a torn meniscus. A chondrocyte pair lying in a pool of territorial matrix (*T*) contain lipid droplets (*L*) and glycogen deposits (*G*) in the chondrocytes. × 6500.

As in the case of articular cartilage (Ghadially, Yong & Lalonde, 1982) the surface of menisci was composed of collagen fibrils deployed in various planes and covered by a filamentous and particulate electron-dense surface (Figs. 3, 4, 6). The surface coat showed considerable variations in thickness and was sometimes absent in places.

Cells

Several types of cells were identified in menisci. These included: (1) chondrocytes; (2) fibroblasts; (3) cells of intermediate form, difficult to classify as either fibroblasts or chondrocytes; (4) myofibroblasts (only in injured portions of three torn menisci); (5) mast cells (only in outer parts of menisci); and (6) degenerate and necrotic cells.

Chondrocytes

The chondrocytes of the superficial zone of the meniscus resembled the chondrocytes of Zone I of articular cartilage. They usually presented as oval or fusiform profiles with a few short cell processes (Figs. 3, 7), but occasionally a circular cellular profile was also seen. The scant cytoplasm made the nucleus appear rather prominent. Organelles such as mitochondria, rough endoplasmic reticulum and Golgi complex were commonly encountered, but lipid droplets and glycogen particles were only rarely detected.

The chondrocytes of the middle zone of the meniscus resembled the chondrocytes of Zone II and III of articular cartilage because they had a rounded or polygonal profile in sectioned material. However, occasional elongated cellular profiles similar to those seen in the superficial zone were also encountered. Mostly, these cells were

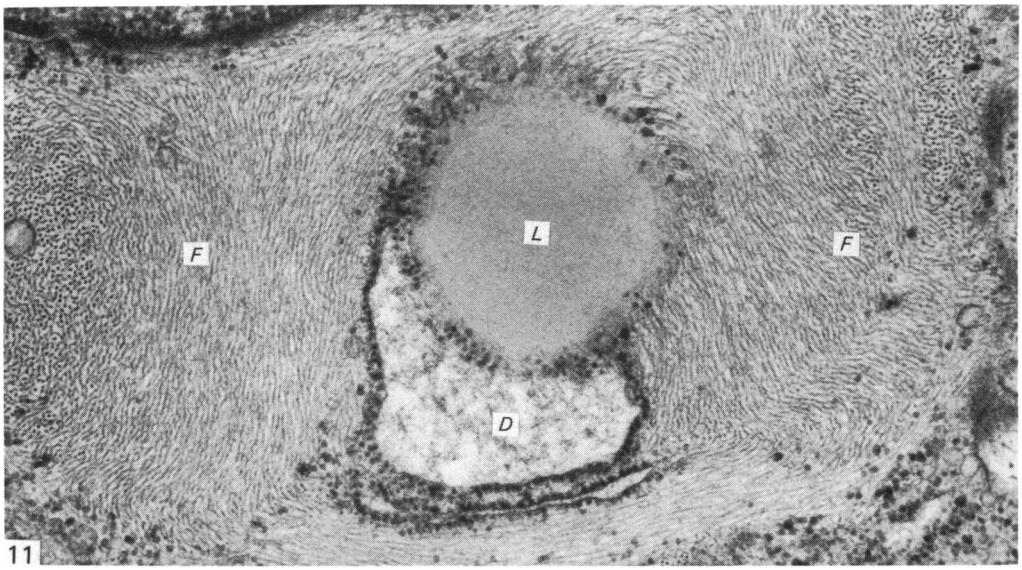


Fig. 11. A chondrocyte from the injured portion of a torn meniscus. Surrounding a lipid droplet (*L*) and a dilated cistern of the rough endoplasmic reticulum (*D*) is a deposit of whorled intermediate filaments (*F*). × 38000.

solitary (Fig. 8) but an occasional pair of cells (Figs. 9, 10) or three cells in a row were seen.

These cells had variable amounts of rough endoplasmic reticulum and Golgi complex.The mitochondria had lamellar cristae and an occasional intramatrical dense granule was seen. Swollen mitochondria were of common occurrence in surgically removed menisci and this change was more marked in autopsy specimens. As in chondrocytes of articular cartilage, occasional lipid droplets (Figs. 10, 11) were found in the chondrocytes in the middle zone of menisci. Glycogen deposits (Figs. 8, 10) and deposits of intracytoplasmic filaments were also common but they were of more frequent occurrence and more prominent in the chondrocytes adjacent to a tear in the meniscus (Fig. 11).

The nuclei of the chondrocytes in menisci (superficial and middle zone) were similar to those found in chondrocytes of articular cartilage. A nuclear fibrous lamina was seen in some instances (Fig. 7). The fibrous lamina in the nuclei of cells in the injured part was significantly thicker than that in the uninjured part of the meniscus as has been reported elsewhere (Ghadially *et al.* 1980*a*).

Fibroblasts and cells of an intermediate morphology

In the fibrofatty region where menisci blend with the joint capsule, fibroblasts were commonly seen, but in the true substance of the menisci typical fibroblasts were rare. They presented as elongated or spindle-shaped cells with abundant cytoplasm containing much rough endoplasmic reticulum (Fig. 12) and in favourable planes of sectioning a fairly well developed Golgi complex was also seen. Dilatation of the rough endoplasmic reticulum was sometimes seen, particularly in fibroblasts from the injured site and invariably in all cells in menisci obtained at autopsy. Numerous small cell processes did not sprout from the surface of fibroblasts as they do on chondrocytes, but elongated cell processes occurred at the poles of fibro-

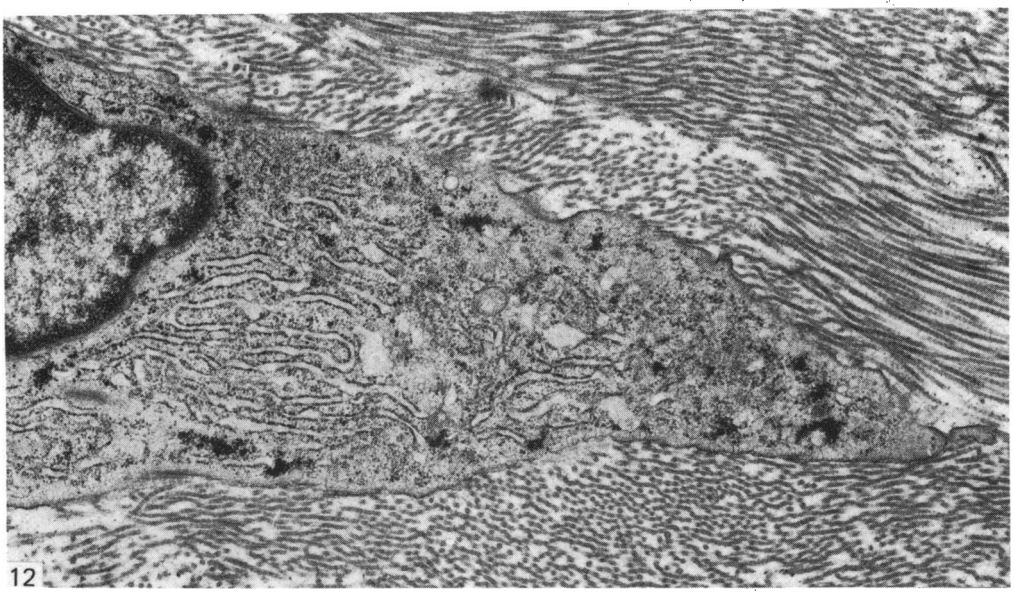


Fig. 12. From the injured portion of a torn meniscus. A fibroblast well endowed with rough endoplasmic reticulum and some glycogen deposits. The collagen fibrils of the general matrix abut the cell membrane in several places. × 14000.

blasts. Further, chondrocytes are usually set in a fine textured pericellular matrix but no such specialised matrix was seen around fibroblasts; the collagen fibrils of the general matrix abutted the cell membrane of the fibroblasts. Using these criteria to distinguish fibroblasts and chondrocytes, we found: (1) a few fibroblasts in normal human menisci (autopsy material) and in normal-looking portions of torn menisci well away from the damaged site; and (2) somewhat more fibroblasts near the injured site in torn menisci. Some of these cells contained intracellular collagen and also, at times, fibrils or filamentous material in the Golgi sacs or vacuoles. This phenomenon has already been reported in detail (Ghadially *et al.* 1980*b*).

Cells of an intermediate form and difficult to classify as chondrocytes or fibroblasts were also at times encountered. These were plump, polygonal cells with a fair amount of rough endoplasmic reticulum. Little or no territorial matrix was discerned around them but an occasional short cell process was seen sprouting from the cell surface. Such cells were found in both the superficial zone (Fig. 4) and middle zone of the meniscus (Fig. 13).

Myofibroblasts

Myofibroblasts were not found in normal menisci or in uninjured parts of torn menisci. However, in three out of nine torn menisci studied by us myofibroblasts were detected near the damaged site (see Figs. 3–6 in Ghadially *et al.* 1980*b*). They presented as long strap-like cells (sometimes branching) with a fair amount of rough endoplasmic reticulum and myofilaments with focal densities along their course. Dense bodies acceptable as lysosomes were rarely seen in these cells, but they often contained lipid droplets and glycogen. Intracellular collagen was frequently seen in these cells. The occurrence of myofibroblasts in menisci has already been dealt with in a previous paper (Ghadially *et al.* 1980*b*) and no further comments will be made here.

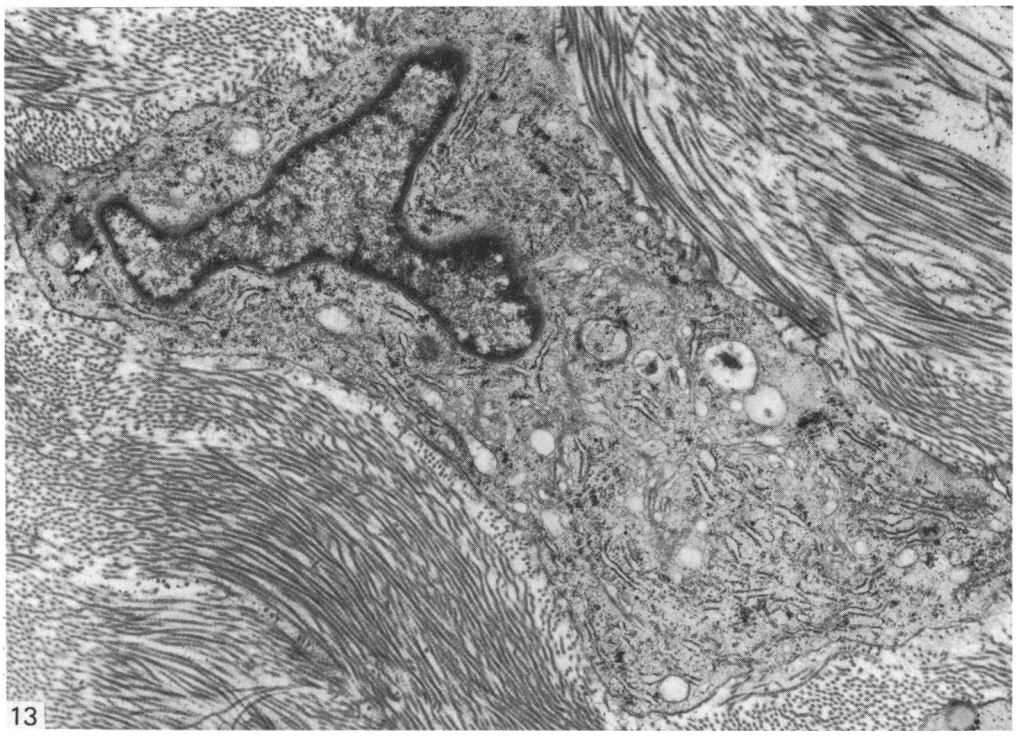


Fig. 13. From the uninjured portion of a torn meniscus. The cell shown is of an intermediate form and is difficult to classify as a fibroblast or a chondrocyte. ×11000.

Mast cells

These cells were present in the outer, peripheral parts of the meniscus (identified by the presence of vessels) but absent in the more medially situated portions. They were readily identified by their characteristic electron-dense granules which frequently showed membranous and scroll-like patterns in their interior. At times, such cells were singularly well endowed with cell processes.

Degenerate and necrotic cells

As in articular cartilage, a few cells which had suffered *in situ* necrosis were found in normal, injured and uninjured portions of menisci (Fig. 14). Stages of cell disintegration leading to the formation of electron-dense membranous and granular lipidic debris which lay either in lacunae or dispersed in the general matrix was also evidenced (for illustration and details see Ghadially & Lalonde, 1981). Foci of the residual territorial matrix, devoid of cells and containing little or no debris, were also encountered. At times three or four such foci were found close together in a single section from the injured portion of a meniscus. These foci have been interpreted as a late stage arrived at by escape of necrotic debris into the general matrix, leaving behind an area of territorial matrix devoid of a cell (Fig. 15). The alternative possibility that these foci are no more than tangential cuts through the territorial matrix of chondrocytes is not attractive because of their large size (up to about 12 μm) and the failure to find cells within such foci in serial sections.

It is difficult to decide whether both chondrocytes and fibroblasts in menisci

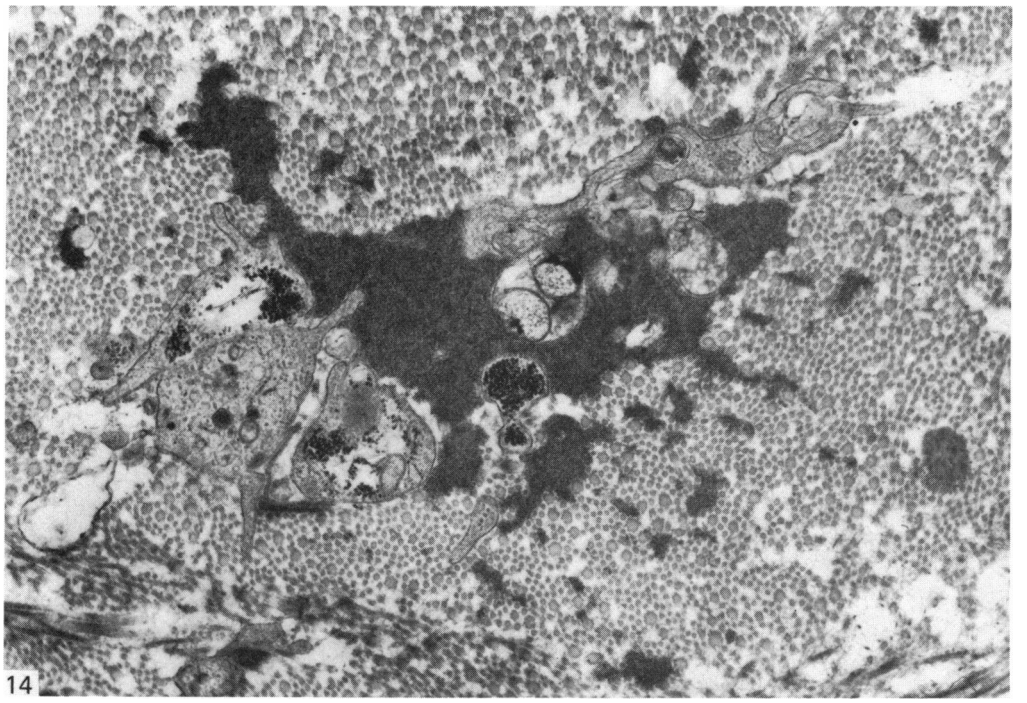


Fig. 14. From the uninjured portion of a torn meniscus. Disintegrating fragments of a cell which suffered *in situ* necrosis are scattered in the general matrix. × 16000.

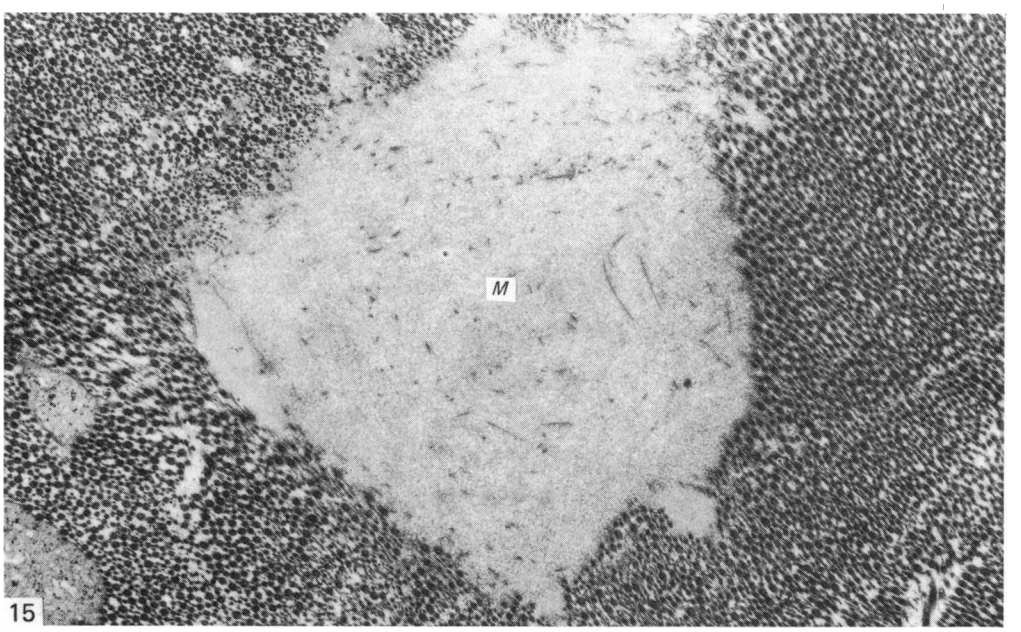
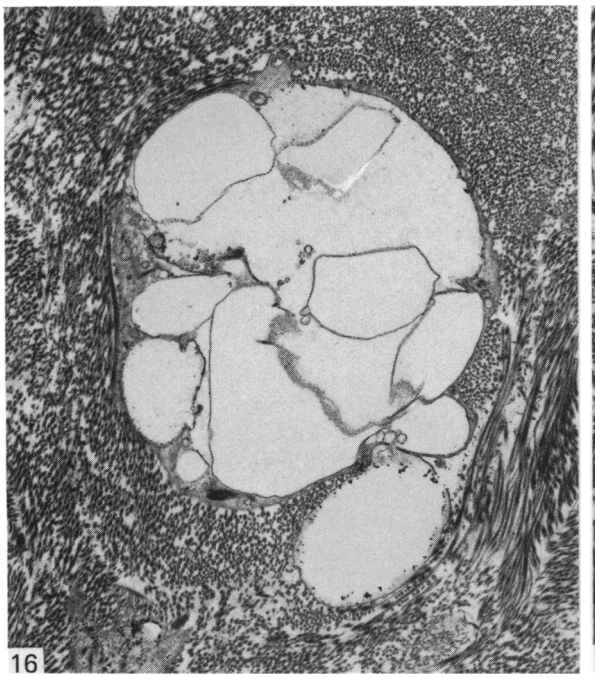


Fig. 15. From the injured portion of a torn meniscus. Seen here is a zone (about 9 μm in diameter) of residual territorial matrix (*M*) which contains neither cell nor cellular debris. × 8500.



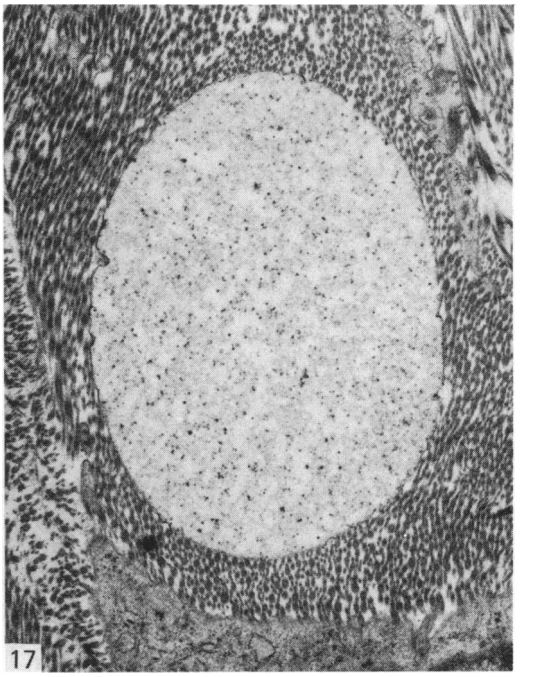


Fig. 16. General matrix from the injured portion of a torn meniscus. A multiloculated cystic structure is seen surrounded by a thin shell of cytoplasm. × 5000.

Fig. 17. From the injured portion of a torn meniscus. In the general matrix lies an egg-shaped membrane-bound structure containing electron-dense particles and some flocculent material. A much smaller cystic structure is depicted in Figure 7. × 9500.

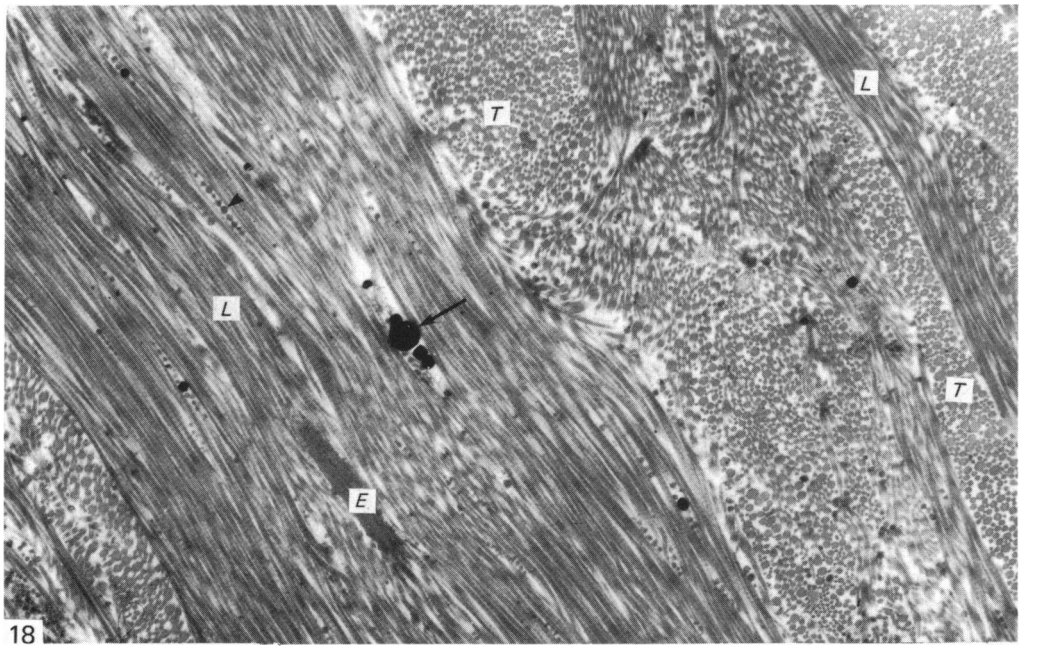


Fig. 18. General matrix from the middle zone of an uninjured part of a torn meniscus. The collagen fibres or lamellae run more or less at right angles to each other, as evidenced by the longitudinally (*L*) cut and transversely (*T*) cut collagen fibrils. An elastic fibre (*E*), calcified bodies (arrow) and lipid debris (arrowhead) are also present. × 11000.

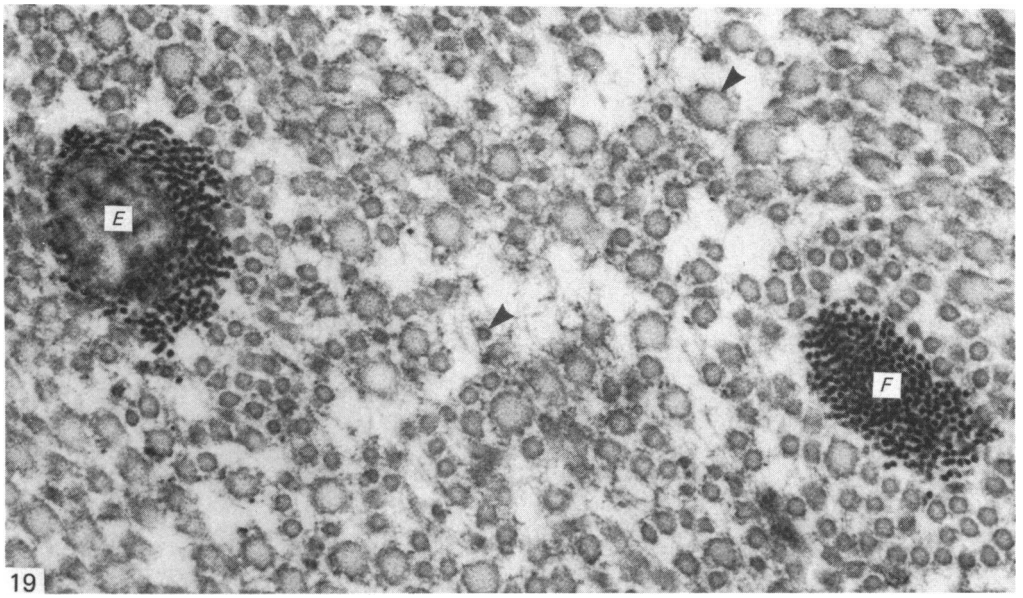


Fig. 19. From the uninjured portion of a torn meniscus. Amongst the collagen fibrils lie a collection of electron-dense filaments (*F*) and a small or immature elastic fibre (*E*). There is marked variation in the diameter of the collagen fibrils (arrowheads). × 51000.

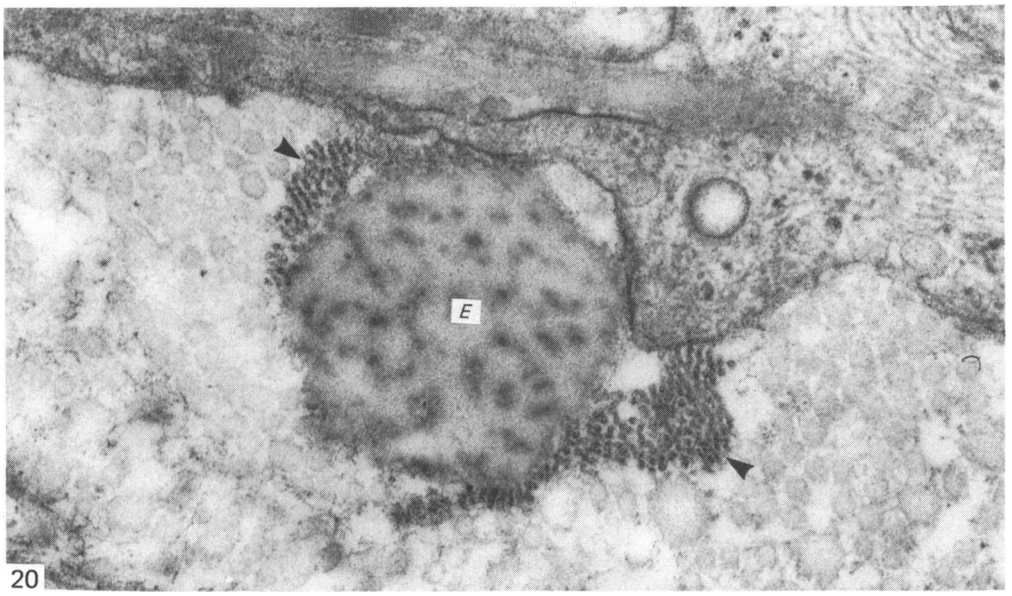


Fig. 20. From the uninjured portion of a torn meniscus. An elastic fibre shows elastin (*E*) mottled with densities (which probably represent altered electron-dense filaments trapped in the elastin) and electron-dense filaments (arrowheads) at the periphery of the fibre. × 64000.

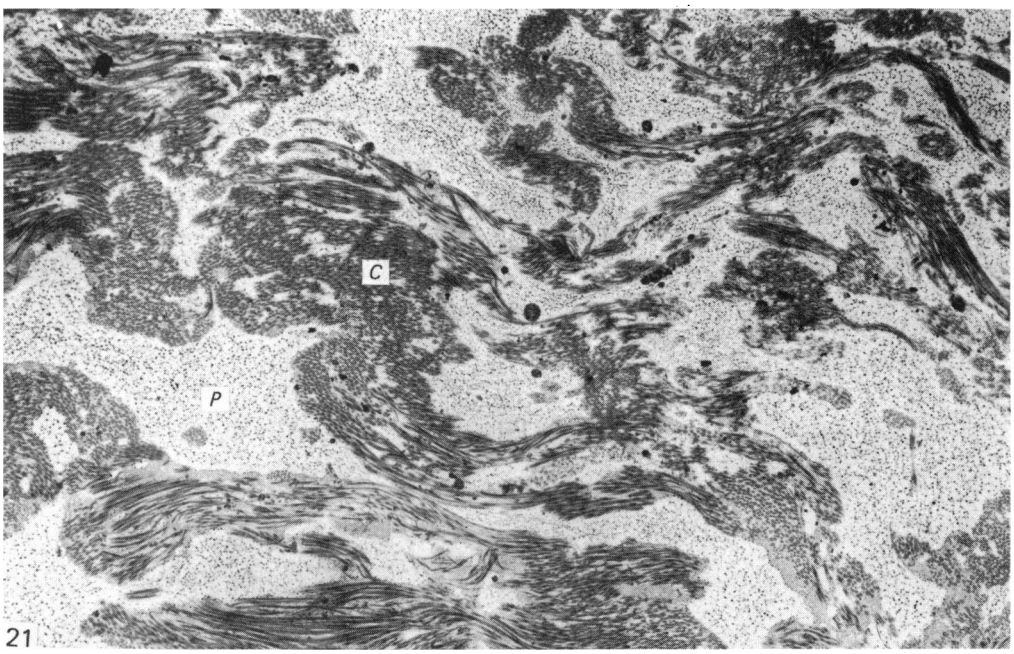


Fig. 21. From the injured portion of a torn meniscus. Pools of proteoglycan particles (*P*) are seen amongst fragmented and parted collagen fibres (*C*). ×4500.

suffer *in situ* necrosis, for the identity of a disintegrating or disintegrated cell can be difficult or impossible to establish. However, necrotic cells and/or debris derived thereof was seen in the territorial matrix (see Fig. 2 in Ghadially & Lalonde, 1981) and also where such matrix was absent (Fig. 14). This suggests that both chondrocytes and fibroblasts can suffer *in situ* necrosis.

A finding encountered once only in the injured part of a meniscus is shown in Figure 16. This could be a degenerate, or a necrotic cell (cells?) distended with numerous cysts, but the interpretation was difficult. Solitary membrane-bound cystic structures (Figs. 7, 17) were also found in the general matrix. The fact that they were membrane-bound indicates a cellular origin but their precise mode of origin remains an enigma.

Matrix

As in articular cartilage, a territorial matrix (i.e. pericellular or, to be more accurate, juxtacellular matrix because the matrix often does not surround the entire cell) and an interterritorial or general matrix could be discerned in menisci. The territorial matrix was seen only in association which chondrocytes, and not with fibroblasts or myofibroblasts.

Territorial matrix

The territorial matrix was more fibrous (i.e. contained more filaments and fibrils) than in hyaline cartilage (Fig. 8). It was usually sparse (and, in rare instances, virtually absent) so that the coarse collagen fibrils of the general matrix abutted almost the entire circumference of the chondrocyte (Figs. 7, 9). More commonly, the territorial matrix was deficient in the sense that it did not completely envelop the chondrocyte, so that banded collagen fibrils were seen apposed to a segment of

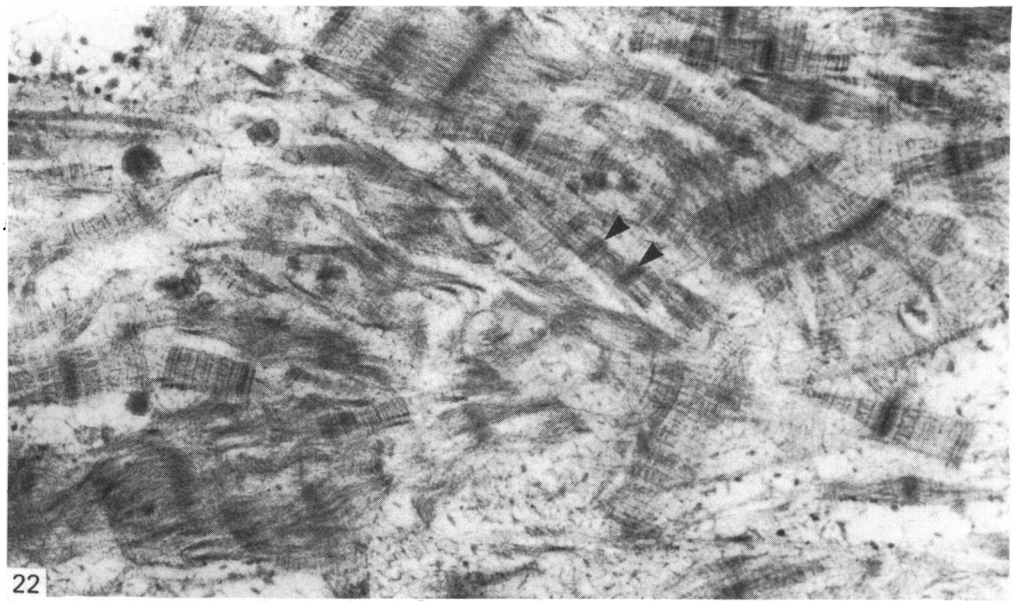


Fig. 22. From the same specimen as Figure 21. Fibrous long-spacing collagen. The width of a period on one of the collagen fibrils is indicated by the arrowheads. The distance between the points of the arrowheads is about 5·5 mm. Hence the calculated width of this period works out at about 112 nm. × 49000.

the cell membrane of the chondrocyte. However, there were also instances where a typical chondrocyte (Fig. 8) or chondrocyte pair (Fig. 10) was surrounded by territorial matrix containing proteoglycan particles and associated short filaments and also unbanded fibrils.

General matrix

The collagen fibrils comprising the major component of this tissue (Fig. 18) were set in a sparse interfibrillary matrix where a few proteoglycan particles and associated filaments were present. In the superficial zone such fibrils were deployed parallel to the surface, but separated from the joint space by the surface coat (Figs. 3, 4, 6). In the middle zone the pattern was more complex and absolute fibre orientation could not be determined from the small blocks of tissue used for transmission electron microscopy. However, a commonly encountered pattern was that of fibres and/or lamellae where the fibrils comprising these structures ran at right angles or almost at right angles to one another (Fig. 18). Collagen fibrils of markedly different thicknesses were mingled together to form these fibres and lamellae (Figs. 14, 18, 19). Collagen fibrils measuring up to about 180 nm in diameter occurred in the human meniscus. The thinnest characteristically banded fibrils measured about 25 nm in diameter and more slender unbanded fibrils were also present.

Dotted amongst the collagen fibrils in the middle zone were a few aggregates of electron-dense filaments (about 11 nm in diameter) (Fig. 19), similar to the pre-elastic filaments or oxytalan filaments described in the skin and other sites. (For a review and references, see Ghadially, 1982.) Numerous small (or immature?) elastic fibres containing a small electron-lucent or medium density core of elastin surrounded by many electron-dense filaments were also present (Fig. 19). Larger, presumably

mature elastic fibres, consisting of a core of elastin with a few peripherally placed electron-dense filaments, were infrequently encountered (Fig. 20).

Membranous and granular debris (often referred to as 'intramatrical lipidic debris') similar to that found in hyaline articular cartilage and thought to be derived by a shedding of cell processes and *in situ* necrosis of chondrocytes was also found in the general matrix (Figs. 8, 14). Calcified bodies were also found in company with such debris (Fig. 18). A detailed account of how this debris is derived and the morphology and atomic composition of the calcified bodies has already been presented (Ghadially & Lalonde, 1981).

Finally, two appearances seen in the general matrix in the injured portions of torn menisci are worthy of note. One of these can best be described as a disruption or fragmentation and parting of collagen fibrils, the spaces so created being filled out with proteoglycan particles (Fig. 21). In such areas fibrous long spacing collagen was also at times detected (Fig. 22).

DISCUSSION

Surface of normal meniscus

Past scanning electron microscopic studies have shown (Refior, 1971; Moshurchak & Ghadially, 1978) that pieces of menisci suffer marked curling and distortion during processing, so that the naturally smooth surface (as seen in the fresh state with a magnifying glass) is altered into one that is covered by prominent ridges and furrows running parallel to the long axis of the meniscus and fine wrinkles which traverse them in various directions. Little wonder then that in sectioned material the surface of normal menisci appears wavy or undulating (Fig. 2). One may surmise that the undulations seen in sectioned material represent cross-cuts through the ridges and furrows which develop during processing of the tissue.

It is interesting to note that a surface coat is seen lying on the collagenous surface of the meniscus (Figs. 3, 4, 6) and that it is similar in form to the surface coat found on articular cartilage (see Fig. 4 in Ghadially *et al.* 1982.) It has been suggested (Ghadially *et al.* 1982) that this coat may be a mixture of extraneous material (e.g. precipitated synovial fluid) and material extruded from articular cartilage (e.g. matrical lipidic debris and degraded metabolites discharged into the joint space). It seems likely that the surface coat on menisci is derived in a similar fashion, for here also the matrical debris has no other route of egress except the surface.

Nature of cells and tissues

There has been some debate in the past as to whether the tissue comprising intra-articular discs and menisci should be regarded as fibrous tissue or fibrocartilage, and whether the cells in the tissue are chondrocytes or fibroblasts (Collins, 1949; Davies, 1969). For example, Davies (1969) stated, "histologically the discs and menisci of man are predominantly composed of closely interweaving white collagenous fibrous bundles with a few cartilage cells and many fibrocytes". A similar dilemma exists at the ultrastructural level for, in a brief abstract, Silva (1970) stated, "ultrastructural studies carried out on the intra-articular menisci of the knee joint and the temporo-mandibular joint of monkeys, cats and guinea pigs revealed that all joints consisted in large part of either dense fibrous tissue or areas of dense fibrous tissue and islands of fibro-cartilage".

In our view, the tissue is fibrocartilage, because, as shown in this paper, most of the cells in human menisci, and perhaps all the cells in rabbit menisci (Ghadially,

Thomas, Yong & Lalonde, 1978), more nearly resemble chondrocytes than fibroblasts, although in human menisci a few typical fibroblasts and cells difficult to classify as fibroblasts or chondrocytes also occur.

The reasons for this belief are as follows: (1) the cells in menisci more resemble chondrocytes than fibroblasts because many of them are rounded and have short cell processes on their surface; (2) the oval and elongated cells seen mainly near the surface (which would probably be regarded as fibroblasts by light microscopists) more resemble Zone I chondrocytes of hyaline articular cartilage than fibroblasts; (3) characteristic proteoglycan particles, as seen in hyaline articular cartilage and epiphyseal cartilage, are found in both the territorial and general matrix; and (4) although the territorial matrix may at times be sparse, it can be demonstrated in most instances. This is in contrast to what is seen in fibrous tissue, where a specialised territorial matrix does not occur around fibroblasts and proteoglycan particles are of rare occurrence and often undetectable (Ghadially, 1982).

Collagen fibres and lamellae

A point of considerable interest is that in the human menisci (this study) and in rabbit menisci (Ghadially *et al.* 1978) collagen fibrils of markedly different thicknesses were found mingled together to form the fibres and lamellae. Silva (1969, 1970) noted a similar situation in discs and menisci, pointing out that such an arrangement makes these structures efficient broad-banded shock absorbers, absorbing energy over a wide range of vibration frequencies.

Past light and scanning electron microscopy studies (Bullough, Munuera, Murphy & Weinstein, 1970; Cameron & MacNab, 1972) have shown that the principal fibre orientation in human knee menisci is circumferential (i.e. along the length of the meniscus) but that radial and oblique fibres are also present. Our light microscopic observations on human and rabbit menisci are essentially similar, for here too most of the fibres were found to be grouped into bundles which have a circumferential orientation. Electron microscopic observations are in keeping with such an idea, but they cannot bear significantly on this point because of the small size of the samples and the random planes of sectioning.

Elastic fibres

The occurrence of elastic fibres in menisci seems not to have been noted by light microscopists, but elastic fibres and their precursors are demonstrated by electron microscopy (Figs. 19, 20). It is now well known that elastic fibres have two components, a central amorphous core of low electron-density in which focal densities are seen and a peripheral zone of electron-dense filaments about 11 nm in diameter. Further, studies on consecutive stages of elastogenesis in various sites have shown that the filamentous component appears first and that the amorphous component (elastin) is deposited amongst the filaments, ultimately forming quite a large lucent or medium-density core.

Collections of electron-dense filaments, acceptable as pre-elastic fibrils, were noted by Silva (1969) in the intra-articular disc of the temporomandibular joint of the guinea-pig, but mature or maturing elastic fibres, with characteristic lucent core indicating the deposition of elastin, were not found. In the rabbit menisci (Ghadially *et al.* 1978), innumerable small fibrils, composed of electron-dense filaments acceptable as pre-elastic fibrils, were present as were a few larger fibrils composed of such filaments. However, fully mature elastic fibres were not found although occa-

sional young elastic fibres with a small lucent core surrounded by numerous electron-dense filaments were present. In human menisci, the situation is somewhat different in that quite a few relatively large mature elastic fibres (i.e. fibres containing more elastin than electron-dense filaments) and many more small elastic fibres are present, but here also a few electron-dense fibrils seem to persist. It is likely that in the menisci (as in the skin), not all such electron-dense fibrils are destined to serve as scaffolding for elastin deposition and conversion into elastic fibres, but more detailed studies of menisci from various age groups are needed before a firm conclusion can be reached.

SUMMARY

Normal human menisci obtained at autopsy (seven cases) and the injured and uninjured portions of torn menisci obtained at surgery (nine cases) were studied with the electron microscope. The surface of menisci is composed of collagen fibrils surmounted by an electron-dense surface coat. Most of the cells in menisci are chondrocytes but a few fibroblasts and cells of an intermediate form difficult to classify as either fibroblasts or chondrocytes also occur. Mast cells are found at the vascularised periphery of the meniscus. Myofibroblasts were found in the injured portions of menisci in three out of the nine cases studied. A territorial matrix containing fibrils and proteoglycan particles with associated filaments is seen around or adjacent to chondrocytes, but sometimes this matrix is sparse or absent. The interterritorial or general matrix comprises collagen fibrils of widely varying diameters (25–180 nm) set in a sparse interfibrillary matrix containing proteoglycan particles. A few mature elastic fibres and several small or immature elastic fibres and collections of electron-dense filaments are seen in the general matrix. Also seen in this region are calcified bodies and matrical lipidic debris derived by the shedding of cell processes and *in situ* necrosis of cells. Other features seen in the matrix of the injured portion of the meniscus include: (1) membrane-bound cystic structures; (2) parting and fraying of collagen fibrils; and (3) pools of proteoglycan particles.

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