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Review

The joint capsule: structure, composition, ageing and disease*

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ABSTRACT

The joint capsule is vital to the function of synovial joints. It seals the joint space, provides passive stability by limiting movements, provides active stability via its proprioceptive nerve endings and may form articular surfaces for the joint. It is a dense fibrous connective tissue that is attached to the bones via specialised attachment zones and forms a sleeve around the joint. It varies in thickness according to the stresses to which it is subject, is locally thickened to form capsular ligaments, and may also incorporate tendons. The capsule is often injured, leading to laxity, constriction and/or adhesion to surrounding structures. It is also important in rheumatic disease, including rheumatoid arthritis and osteoarthritis, crystal deposition disorders, bony spur formation and ankylosing spondylitis. This article concentrates on the specialised structures of the capsule—where capsular tissues attach to bone or form part of the articulation of the joint. It focuses on 2 joints: the rat knee and the proximal interphalangeal (PIP) joint of the human finger. The attachments to bone contain fibrocartilage, derived from the cartilage of the embryonic bone rudiment and rich in type II collagen and glycosaminoglycans. The attachment changes with age, when type II collagen spreads into the capsular ligament or tendon, or pathology—type II collagen is lost from PIP capsular attachments in rheumatoid arthritis. Parts of the capsule that are compressed during movement adapt by becoming fibrocartilaginous. Such regions accumulate cartilage-like glycosaminoglycans and may contain type II collagen, especially in aged material. In capsular tendons, the fibrocartilages develop from a special population of cells on the deep surface. Some capsular tissues may have very large articulations with the joint: in the PIP joint the fibrocartilaginous part of the central slip of the extensor tendon has an articulation with the proximal phalanx comparable to that of the intermediate phalanx. The capsular fibrocartilages are similar in composition to the better known menisci and other intra-articular discs. It is emphasised that the tissues of the joint capsule are dynamic, and that the precise composition of their fibrocartilaginous parts is likely to depend on at least 3 factors: their developmental origins, the loading experienced, and age.

Key words: Fibrocartilage; synovium; extracellular matrix; collagen; glycosaminoglycans.

INTRODUCTION

The joint capsule is of vital importance to the function of a synovial joint. It forms part of the seal that keeps lubricating synovial fluid in position, provides passive stability by limiting joint movements, active stability via its proprioceptive nerve endings and may also form articular surfaces. It is well known that menisci or articular discs provide articular surfaces, but it is often not appreciated that the capsule itself may form part of an articulation. In these regions the capsular tissues are specialised to resist compression, usually as fibrocartilage. Such regions, although functionally of great importance, have been little studied, Here, we briefly review the general structure of the capsule of synovial joints and its importance in function and pathology and then present some recent work on tendons and ligaments that form part of joint capsules, emphasising their function, development, structure and composition and indicate age-related changes

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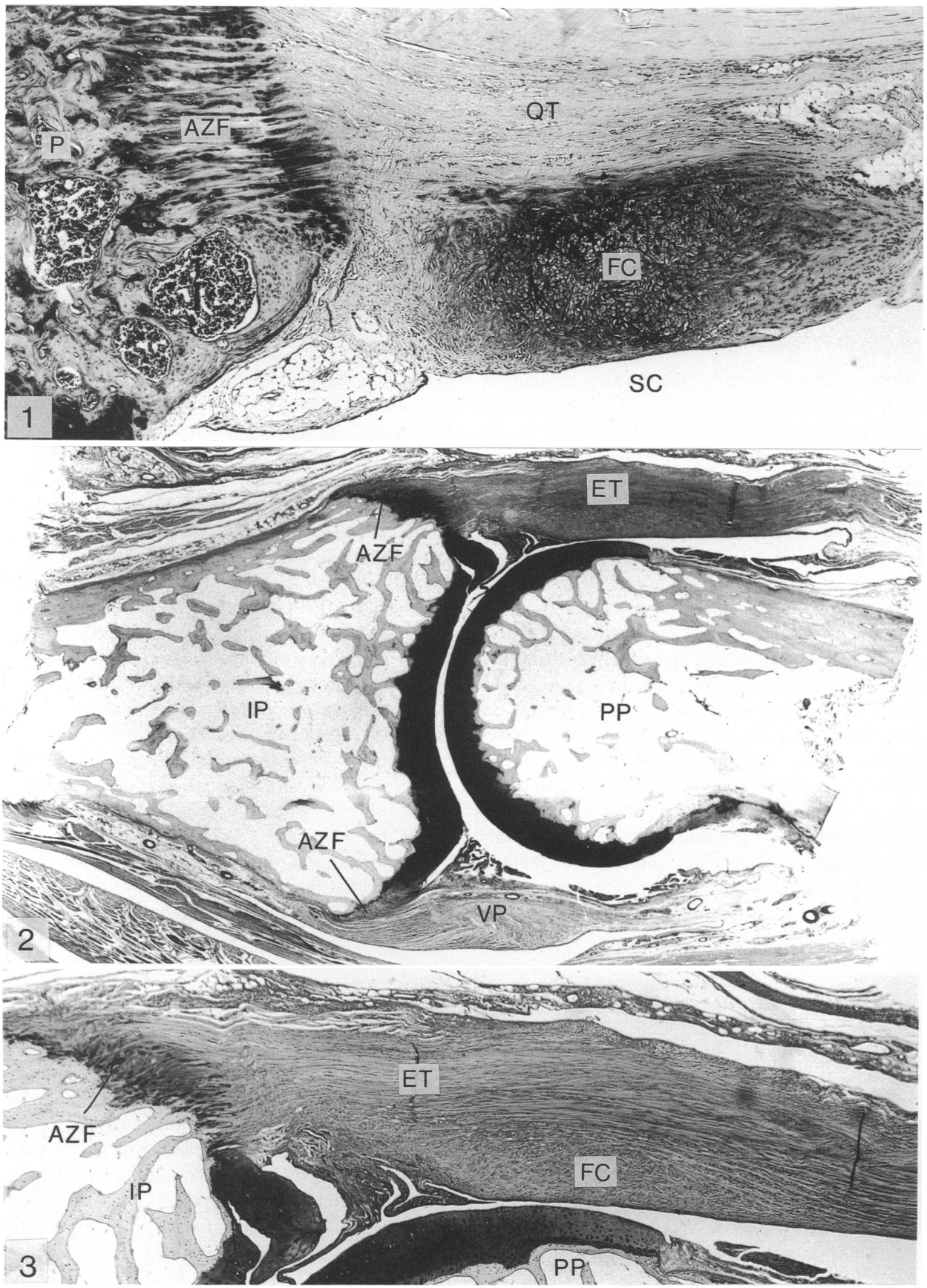

Fig. 1. Fibrocartilages associated with the anterior portion of the capsule (i.e. the quadriceps tendon, QT) in the knee joint of the rat. Attachment-zone fibrocartilage (AZF) is present where the tendon attaches to the patella (P) and there is fibrocartilage (FC) in the compressed region of the capsule adjacent to the synovial cavity (SC). Toluidine blue, ×47.

that could be important in impaired function and pathology.

STRUCTURE AND FUNCTION OF THE SYNOVIAL JOINT CAPSULE

General structure

The typical synovial joint capsule consists of dense fibrous connective tissue, lined with synovium, that forms a sleeve around the articulating bones to which it is attached. It is made of bundles of collagen fibres that adhere firmly to the bones via specialised attachment sites (see below). Nerves and blood vessels pass through the capsule, and there may be gaps through which the synovium may protrude to form a pouch. In general, the thickness and fibre orientation of the capsule depends on the stresses it endures in its different regions. As is well known in the hip joint, for example, the capsule is thicker anteriorly than posteriorly because the centre of gravity passes behind the joint and there is a tendency for the joint to hyperextend. In most joints, there are 2 or more localised thickenings of the capsule, forming ligaments; there are at least 4 distinguishable capsular ligament systems in the human hip (Fuss & Bacher, 1991). Joint capsules may be further supported by accessory ligaments, inside or outside the capsule, which also restrict motion. Protection of the capsule from loading by such ligaments has been shown in the cat knee, where less than 4% of applied load is taken by the posterior joint capsule in full extension (Hoffmann & Grigg, 1989). In many sites, tendons attach to the capsule, and in some cases replace it. For example, the quadriceps and patellar tendons form the anterior part of the knee joint capsule, and the extensor tendons the dorsal part of the capsule of interphalangeal joints (Figs 1, 2). The most complex joint capsule supported in this manner is that of the shoulder joint. It is extremely lax so as to allow the wide range of movement of this joint. The capsule is supported by the tendons of supraspinatus, teres minor, long head of triceps and subscapularis. All but the long head of triceps blend into the fibrous capsule to form the rotator cuff, providing reinforcement and active support for the joint. Despite this, the shoulder is the most commonly dislocated joint, and surgery is often required to tighten the capsule after dislocation.

Innervation

Capsular and synovial tissues are innervated, the capsule usually more than the synovium. The nerves are commonly derived from those supplying muscles acting on the joint. Some nerves have encapsulated endings and are thought to be proprioceptive, whereas others have free nerve endings, especially at the attachments; intense pain generally follows injuries to joint ligaments (Resnick & Niwayama, 1981*a*). Nerve endings include pacinian and ruffinian corpuscles, which also occur in accessory ligaments (e.g. anterior cruciate of the knee; Haus et al. 1992). Characteristic sensory neurotransmitters (calcitonin gene related peptide and substance P) have been detected in capsular tissues (Buma et al. 1992; Marinozzi et al. 1992). The capsular innervation is important in active protection of the capsule and associated ligaments by reflex control of the appropriate musculature. It is interesting that such control can be modified according to the condition of the joint or its ligaments. In the lower limb, tibialis anterior and quadriceps femoris are reflexly activated when the body sways backwards. In patients with torn anterior cruciate ligaments, the reflex also includes the hamstring muscles (Di Fabio et al. 1992), contributing to the active stabilisation of the damaged joint.

Capsular involvement in joint pathology

Apart from obvious involvement in injuries such as dislocations and fracture dislocations, abnormalities of the capsule itself may affect the functioning of the joint and predispose to other joint diseases. Laxity of the capsule is a common cause of shoulder dislocations and congenital dislocation of the hip. It may be that in the latter the laxity of the capsule affects the proper development and geometry of the femoral head (Carr et al. 1993). Laxity may have to be surgically treated by stapling folds of the capsule to adjacent bony

Fig. 2. Sagittal section of the proximal interphalangeal joint from a human finger. Dorsally, the capsule is formed by a fibrocartilaginous portion of the central slip of the extensor tendon (ET) and ventrally by the fibrocartilage of the volar plate (VP). Both the extensor tendon and the volar plate have attachment-zone fibrocartilage (AZF) where they meet the intermediate phalanx (IP). Note how the central slip articulates with the proximal phalanx (PP). The extent of articulation increases dramatically when the finger is flexed. Toluidine blue, ×7.
Fig. 3. High-power view of the central slip of the extensor tendon (ET) shown in Figure 2. Note the attachment-zone fibrocartilage (AZF) where the tendon inserts onto the intermediate phalanx (IP) and fibrocartilage (FC) on the deep surface of the tendon, next to the proximal phalanx (PP). Toluidine blue, ×15.5.

structures in order to restrict motion, especially in the shoulder (e.g. Landsiedl, 1992). The reverse can also occur: contraction of tissues of the capsule, particularly following trauma and immobilisation of a limb, results in thickening and shortening of the capsule with consequent reduction in joint mobility. In affected elbow joints the capacity of the joint capsule to receive injected fluid (a measure of its size and elasticity) may be reduced from 14 to 6 ml, the joint having a greatly reduced arc of motion; capsulotomy may have to be performed to improve joint mobility (Nowicki & Shall, 1992; Gallay et al. 1993). The mobility of a joint can be affected by adhesive capsulitis, which may occur after trauma and/or immobilisation. The capsule becomes thickened and adherent to adjacent structures, preventing normal motion. This is typical of conditions such as 'frozen shoulder' (Resnick, 1981*a*), but is also common in other joints as a complication after injury, such as adhesive capsulitis of the ankle, hip and wrist (Resnick, 1981*a*; Hanson et al. 1988).

The capsule may also be involved in systemic rheumatic disease. Bony spurs may develop, growing from the bone into the attachment of the capsule or its ligaments or tendons, for example in diffuse idiopathic skeletal hyperostosis (DISH). In ankylosing spondylitis bone formation extends through capsular ligaments, immobilising joints, particularly in the spine. Deposition of mineral crystals can occur in capsular tissues as well as in articular surfaces, for example calcium pyrophosphate dihydrate crystal deposition disease in menisci, intra-articular discs and capsules (Resnick & Niwayama, 1981*b*), and calcium hydroxyapatite crystal deposition disease, especially in the tendons of the shoulder joint capsule (Resnick, 1981*b*). Rheumatoid arthritis of the fingers can result in severe deformities due to weakening of the capsule (e.g. swan neck deformity; Louis, 1987). Severe osteoarthritis may cause wear damage of capsular tissues because of cartilage loss, and may lead to ruptures (Carr & Burge, 1992).

STRUCTURE AND COMPOSITION OF CAPSULE AT SPECIAL SITES: THE ATTACHMENT TO BONE AND IN REGIONS ACTING AS ARTICULAR SURFACES

In several joints, capsular tissues are involved in the actual articulation of the joint, as well as in controlling its motion. This may occur by interposition of capsular tissues between the joint surfaces, for example in articular discs of the temporomandibular joint (TMJ) or menisci of the knee, where the capsule is modified to form fibrocartilage, or by using part of the joint capsule as a bearing surface, for example in the knee joint and the interphalangeal joints of the fingers or toes.

Attachment to bone

The capsular attachment to bone has a specialised structure. It has most been studied where tendons blend with the capsule and insert as part of it (Ralphs et al. 1991; Rufai et al. 1992; Benjamin et al. 1993; Figs 1–3), although the insertions of capsular ligaments are essentially the same. The attachment zone is important because injuries frequently occur at or near it, although rarely through the specialised insertional tissue itself (Woo et al. 1988). Injuries more commonly occur by avulsion of a bone fragment beneath the attachment zone, or by tearing of the tendon, ligament or capsule above it. Structurally, the attachment zone is fibrocartilaginous, and can be regarded as having 4 zones (Cooper & Misol, 1970): pure fibrous tissue, uncalcified fibrocartilage, calcified fibrocartilage and bone. We have recently shown that attachment zone fibrocartilage associated with the knee joint in the rat and the proximal interphalangeal (PIP) joint of the human finger is rich in type II collagen, characteristic of cartilage (Ralphs et al. 1991; Benjamin et al. 1993), and chondroitin and keratan sulphates. In development, the type II collagen is derived from the cartilage rudiment of the bone to which the tendon attaches and is left behind when the rest of the cartilage is replaced by bone in endochondral ossification (Ralphs et al. 1992; Rufai et al. 1992). It is noteworthy that tissues may regenerate a histologically normal attachment zone after injury or surgery, although the composition of such attachments has not been investigated (Woo et al. 1988). As the tissues age the type II collagen-containing region spreads significantly from the attachment zone into the tendon or ligament itself (Benjamin et al. 1991; Rufai et al. 1992). Changes in composition of attachments have also been observed in disease; in the human PIP joint type II collagen is lost from the attachment zone in rheumatoid arthritis, although not in Dupuytren's contracture, which also immobilises the finger (Benjamin et al. 1993). It seems likely that the formation of abnormal calcifications and bony spurs in a number of disease conditions may be related to changes in the composition of the attachment zone fibrocartilage.

Compressed regions of joint capsule

Parts of the capsule that articulate with the joint itself become fibrocartilaginous and pressure resistant, accumulating glycosaminoglycans and in some cases type II collagen, typical of cartilage. We have examined a fibrocartilage in the quadriceps tendon of the rat (which forms the anterior part of the knee joint capsule; Ralphs et al. 1991). This fibrocartilage, the suprapatella, lies immediately proximal to the patella and forms an extension of the articular surface, articulating with the patellofemoral groove of the femur when the knee is flexed. Its extracellular matrix is rich in chondroitin sulphate, and progressively accumulates type II collagen with age (Benjamin et al. 1991). The cells are interesting because they accumulate large quantities of intermediate filaments, especially vimentin (Benjamin et al. 1991; Ralphs et al. 1991). This may be a cellular response to compressive loading: it also occurs in articular cartilage at certain depths within the tissue and positions in the joint, and in arthritic conditions (e.g. Ghadially, 1983; Paukkonen & Helminen, 1987; Eggli et al. 1988). The fibrocartilage is derived from a population of cells that lie on the deep surface of the quadriceps tendon, and does not begin to develop until after birth when the animals become mobile (Ralphs et al. 1992). Metaplasia of tendon cells, as occurs in some other tendon fibrocartilages (Evanko & Vogel, 1990; Rufai et al. 1993) may also contribute. There is no equivalent fibrocartilage in the human knee, although it is interesting that large fibrocartilaginous extensions of the patella occur proximally in the acromegalic knee (Resnick, 1981*c*). However, in other sites there are functionally similar capsular tendon fibrocartilages. The joint at present under scrutiny in our laboratory is the PIP joint of the finger (see Figs 2, 3). Its capsule comprises dorsally the central slip of the extensor tendon, ventrally a specialised ligament, the volar plate, and laterally the collateral ligaments. The central slip has a very large articulation with the cartilage of the proximal phalanx, wrapping around it to a considerable degree in flexion – the articulation of the proximal phalanx with the tendon is comparable in extent to that with the intermediate phalanx. The deep surface of the tendon contains a large fibrocartilage in its articular region (the dorsal hood of Slattery, 1990). The extracellular matrix of this fibrocartilage has similarities with the fibrocartilage in the rat knee – it contains chondroitin sulphate (both 4 and 6 sulphates), keratan sulphate and dermatan sulphate, and sometimes contains type II collagen (Benjamin et al. 1993; Lewis, Benjamin & Ralphs, unpublished observations). The cells sometimes show evidence of being enriched in vimentin. The volar plate contains the same glycosaminoglycans (although with much weaker labelling intensity), but we have not detected type II collagen. The collateral ligaments are qualitatively simpler in GAG content – they lack chondroitin 4 sulphate (see Table).

Table. *Extracellular matrix components of the capsule of the proximal interphalangeal joint of 11 human fingers*

Collagen type	I	II	III	
Central slip	*	(*)	*	
Volar plate	*	—	*	
Collateral ligament	*	(—)	*	
Attachment zones	*	*	*	
Glycosaminoglycan	**C4S**	**C6S**	**KS**	**DS**
Central slip	*	*	*	*
Volar plate	(*)	(*)	(*)	(*)
Collateral ligaments	—	(*)	*	*
Attachment zones	*	*	*	*

C4S, chondroitin 4 sulphate; C6S, chondroitin 6 sulphate; KS, keratan sulphate; DS, dermatan sulphate.
* = strong immunolabel; (*) = weak immunolabel; (—) = weak immunolabel seen in only 1 specimen; — = no immunolabel.

There are 2 other fibrocartilages associated with joints that are well known. These are the menisci of the knee and the articular disc of the TMJ. They have structural and compositional similarities with the PIP fibrocartilages. Menisci contain types I, II and III collagens. Type II collagen forms about 2% of the total, consistent with the occasional labelling we observe in central slip fibrocartilage. A similar range of GAGs is also present (Arnoczky et al. 1988). TMJ discs also contain types I and II collagens and a similar range of GAGs, arranged into cartilage-like proteoglycans (Fujita & Hoshino, 1989; Nakano & Scott, 1989*a*, *b*; Milam et al. 1991). The composition of the intra-articular disc changes in pathology or experimental manipulation. There is a change in the distribution of the large cartilage-like proteoglycans in pathological changes related to meniscus displacement, where the anterior part of the disc is subject to abnormal loading (Blaustein & Scapino, 1986), and type II collagen appears in the disc in experimental malocclusion in the rat, probably because of the change in loading patterns on the disc (Fujita & Hoshino, 1989).

These various results demonstrate that capsular and related tissues are dynamic in terms of the synthesis and nature of their extracellular matrix, and that the tissues change if the forces acting on them change. The precise composition of their fibro-

cartilaginous parts is likely to depend on at least 3 factors: developmental origin, the nature of the loading experienced, and age. Investigations as to how capsular tissues respond to use, injury, age and disease should be of interest to all involved in the repair or replacement of joints.

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