Morphology

The menisci are two crescent-shaped fibrocartilaginous structures that are found within each knee between the femoral condyles and the tibial plateau (Fig. 1.2.1). For many years, the menisci were considered to be the functionless remains of a leg muscle [31]. Indeed, in his paper in 1942, McMurray [21] stated that “When the knee-joint is opened on the anterior aspect, and the suspected cartilage appears normal, its removal can be undertaken with confidence if the diagnosis of a posterior tear has been arrived at (clinically) prior to operation. A far too common error is shown in the incomplete removal of the injured meniscus”.

Attitudes towards the menisci have changed dramatically, and since King’s pivotal paper in 1936 [17], numerous studies have shown that the menisci do in fact play various important functional roles within the knee (see Chap. 1.4).

The menisci are sometimes referred to as “the semilunar cartilages”, even though they are crescentic when viewed from above, not half-moon shaped. They are wedge-shaped in cross-section and are attached to the joint capsule at their convex peripheral rim, and also to the tibia anteriorly and posteriorly by insertional ligaments. They partially cover the tibio-femoral joint surface.

Fukubayashi and Kurosawa [7] examined intra-articular contact areas using a casting method employing silicone rubber and found that the menisci combined occupied 70% of the total contact area within the joint. Walker and Erkman [34] also used casting techniques and found that under no load, contact occurred primarily on the menisci, but that with loads of 150 kg, the menisci covered between 59 and 71% of the joint contact surface area.

The peripheral rim of each meniscus has a length of approximately 110 mm [18]. Except for a portion of the lateral meniscus (LM) in the region of the popliteus tendon, the menisci are attached at their peripheral rims to the inside of the joint capsule throughout their length. This capsular attachment is often referred to as the coronary ligament. At its mid-point, the medial meniscus also has a firm attachment to the deep portion of the medial collateral ligament. The central border of each meniscus tapers to a free edge.

A congenital variant of the normal morphology of the meniscus is the discoid meniscus. Smillie [29] suggested that this variation in structure is due to a failure of the foetal discoid form of the meniscus to involute. It is difficult to determine the true incidence of discoid menisci, but in a study by Nathan and Cole [22], only 30 out of 1,219 menisci (2.5%) that had been surgically removed were found to have been discoid. Smillie [29] found 185 discoid menisci in 3,000 meniscectomies (6%). Discoid menisci are more common on the lateral side than the medial side, and they are only rarely ever found in both compartments of the knee.
They may cause symptoms of snapping and popping in the knee in children, usually between the ages of 6 and 12 years. A discoid LM is a constant finding in some of the great apes, with substantial meniscofemoral attachments and absent tibial insertions.

In our centre, the various meniscal dimensions were measured as part of a study on meniscal allograft sizing [20]. Examining 88 menisci (medial and lateral) from a total of 22 pairs of dissected cadaveric knees, the dimensions demonstrated in Fig. 1.2.2 were determined using digital Vernier callipers. The results are given in Table 1.2.1. These results are of significant interest, as they demonstrate the very wide range that exists in dimensions between different knees. Table 1.2.2 shows the percentage difference between the largest and smallest values for each dimension.

<table>
<thead>
<tr>
<th>Table 1.2.1</th>
<th>Meniscal dimensions (mm) measured from cadaver knees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Medial meniscal circumference</td>
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</tr>
<tr>
<td>Medial meniscal body width</td>
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<tr>
<td>Medial meniscal length</td>
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<tr>
<td>Medial meniscal width</td>
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</tr>
<tr>
<td>Lateral meniscal circumference</td>
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</tr>
<tr>
<td>Lateral meniscal body width</td>
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<tr>
<td>Lateral meniscal length</td>
<td>35.7</td>
</tr>
<tr>
<td>Lateral meniscal width</td>
<td>29.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 1.2.2</th>
<th>Percentage differences between largest and smallest values for each meniscal dimension (expressed as a percentage of the smallest value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smallest value</td>
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<tr>
<td>Medial meniscal body width</td>
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<tr>
<td>Lateral meniscal body width</td>
<td>8.3</td>
</tr>
<tr>
<td>Medial meniscal length</td>
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<tr>
<td>Lateral meniscal length (LML)</td>
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<td>Medial meniscal width</td>
<td>23.3</td>
</tr>
<tr>
<td>LML</td>
<td>26.3</td>
</tr>
</tbody>
</table>
expressed as a percentage of the smallest values. The relevance of these values lies in the critical importance that exists in accurate meniscal allograft sizing while performing meniscal transplantation using a bony bridge fixation technique [27].

The Tibial Insertional Ligaments

The circumferential collagen fibres of the meniscal body continue into the anterior and posterior insertional ligaments, which attach to the subchondral bone of the tibia. The insertional ligament of the anterior horn of the medial meniscus is fan-shaped and attaches to the tibia in the area of the intercondylar fossa, about 6 or 7 mm anterior to the attachment of the anterior cruciate ligament (Fig. 1.2.3).

In a cadaveric study of 46 donors, it was found that in 64% of cases, posterior or upper fibres from the anterior insertional ligament blended with fibres of the transverse intermeniscal ligament (which connects the anterior horns of the medial and lateral menisci) [18].

The posterior horn of the medial meniscus is attached to the tibial intercondylar fossa between the posterior attachment of the LM and the posterior cruciate ligament (PCL). Kohn and Moreno [18] found that the tibial attachments of the medial meniscus were fixed in areas that could be defined by bony landmarks, and that the anterior insertion covered an area of 139 ± 43 mm$^2$ and the posterior insertion an area of 80 ± 10 mm$^2$. The bony tibial insertions of the LM, however, were found to be less well defined.

The anterior insertional ligament of the LM inserts into the anterior intercondylar fossa of the tibia, lateral to the attachment of the anterior cruciate ligament and just anterior to the lateral intercondylar eminence. The posterior insertional ligament of the LM attaches to the tibia posterior to the lateral intercondylar eminence, but anterior to the posterior attachment of the medial meniscus.

The insertional ligaments have fibrocartilagenous transition zones that make the change in stiffness between ligament and bone tissue at the enthesis less sudden, thereby reducing the stress concentration in this unit and preventing failure. They may also diminish the risk of fatigue failure during motion.

The functional importance of the insertional ligaments was demonstrated in a study in rabbits, where transection of the anterior or posterior insertional ligaments of the meniscus led to osteochondral changes in the knee after 6 and 12 weeks that were similar to those found after total meniscectomy [30].

The Intermeniscal Ligaments

The anterior intermeniscal ligament, also known as the transverse geniculate ligament, connects the anterior fibres of the anterior horns of the medial and lateral menisci (Fig. 1.2.4). An anatomical study by Nelson and LaPrade [23] found that a transverse ligament could be identified in 94% of fifty unpaired cadaveric knees.
dissected. A study of 92 knees, performed by Kohn and Moreno [18], found a ligament in 64% of specimens. The ligament can be visualised as an opacity of soft-tissue density apparent in the posterior part of the Hoffa’s fat pad on 12% of plain lateral knee radiographs and 58% of magnetic resonance imaging (MRI) scans [28]. The functional relevance of this ligament has not been studied, but it may have a role in moving the menisci during tibial internal–external rotation.

Nelson and LaPrade [23] showed that the average length of the transverse ligament was 33 mm and the average midsubstance width was 3.3 mm. They also identified three distinct patterns of attachment of the ligament. In type I (46%) the ligament passed primarily between the anterior horn of the medial meniscus and the anterior margin of the LM (a true anterior intermeniscal ligament). Type II ligaments (26%) passed from the anterior horn of the medial meniscus to the joint capsule, anterior to the LM. For type III ligaments (12%), the main attachments were to the anterior capsule only.

The Meniscofemoral Ligaments

Two ligaments have also been identified joining the posterior horn of the LM to the lateral side of the medial condyle of the femur in the intercondylar notch. These are known as the meniscofemoral ligaments [26]. The anterior meniscofemoral ligament runs anterior to the PCL, and is known as the ligament of Humphrey. The posterior meniscofemoral ligament runs posterior to the PCL, and is known as the ligament of Wrisberg (Fig. 1.2.5). Kohn and Moreno [18] found the ligament of Humphrey to be present in 50% of 92 cadaveric knees dissected, and the Wrisberg ligament to be present in 76%. This is in keeping with other studies such as that by Lee et al. [19], who found that MRI showed either one or both meniscofemoral ligaments to be present in 83% of 138 patients scanned. Heller and Langman [12] found a meniscofemoral ligament in 71% of 140 cadaveric knees. In this study, they noted that the Humphrey ligament was up to 1/3 the diameter of the posterior cruciate and that the Wrisberg ligament could be up to ½ the size of the PCL. It has also been noted that meniscofemoral ligaments can frequently be found in one knee, while being absent from the other knee [35]. A review of the literature by Gupte et al. [9] suggested that at least one meniscofemoral ligament was present in 93% of knees, with a significantly higher prevalence in younger knees than in older ones.

Although they have often been assumed to be only vestigial structures, there has recently been renewed interest in the meniscofemoral ligaments. They have mechanical properties comparable to the posterior bundle of the PCL [10], and it has been found that they might serve a mechanical role in the knee, acting as secondary restraints to tibial posterior drawer [11].

Further ligaments have been identified, connecting the anterior horns of the menisci to the intercondylar area of the femur, although these are far less commonly found. The antero-medial meniscofemoral ligament has been described arising from the anterior horn of the medial meniscus, and the antero-lateral meniscofemoral ligament arises from the anterior horn of the LM. In a cadaveric study of 60 knees by Wan and Felle [35], these ligaments were each found in 30% of knees.

Similarly, there are capsular bands that pass from the patella, on either side of the patellar tendon attachment, to the anterior tibia. These patello-tibial ligaments attach to the anterior horns of the menisci on their superficial aspects. These attachments appear to pull the meniscal horns anteriorly, when the knee extends.

The Composition of Meniscal Tissue

Normal human meniscal tissue has been found to be composed of 72% water, 22% collagen, 0.8%
glycosaminoglycans and 0.12% DNA [13]. On a dry weight basis, normal adult menisci contained 78% collagen, 8% non-collagenous protein and 1% hexosamine [14]. Histologically, the menisci are fibrocartilagenous and are primarily composed of an interlacing network of collagen fibres interposed with cells, with an extracellular matrix of proteoglycans and glycoproteins.

Type I collagen accounts for over 90% of the meniscal collagen, the remainder consisting of types II, III and IV [6]. Cheung [4] found that the proportion of the different collagen types within bovine menisci varies according to location. Except for trace amounts (<1%) of types III and V collagens, the peripheral two-thirds of bovine menisci consist solely of type I collagen, whereas the type II collagen (60%) predominates over type I (40%) in the inner third [4]. The collagen fibres themselves have been shown to be heavily cross-linked by hydroxylpyridinium aldehydes [6].

**The Fine Structure of Menisci**

The orientation of the collagen fibres within the meniscus relates directly to the function of the tissue (Fig. 1.2.6). Bullough et al. [3] found that the principal orientation of the collagen fibres is circumferential, to withstand tension. They also found that other radially orientated collagen fibres were present, predominantly in the mid-zone of the meniscus and also on the exposed surfaces. They stated that these radial fibres might act as “ties” holding the circumferential fibres together to help prevent longitudinal splitting of the menisci.

Beaupre et al. [2] identified two well-differentiated regions within the menisci: the inner two-thirds and the peripheral outermost third. In the inner part, the collagen bundles were primarily radially orientated and were also parallel to the articular surface. In the peripheral part, the bundles were larger and were circumferential. They related these differences to function, and stated that the radial fibres of the inner part were best adapted to transfer of compressive axial load from the femur to the tibia, while the peripheral circumferential fibres resisted tensile forces. The collagen bundles of the surface layer are randomly orientated with a composition similar to articular hyaline cartilage (Fig. 1.2.6).

There are two types of cell found within the meniscus [8]. The superficial zones contain cells that are oval or fusiform, with few processes and scant cytoplasm, resulting in the nucleus appearing disproportionately large. The deep zones of the menisci are populated by rounded or polygonal cells with a large amount of rough endoplasmic reticulum. These cells are usually solitary, but are occasionally found in groups of two or three. They have properties that are found in both fibroblasts and chondrocytes, and in 1985, Webber et al. [36] proposed the term “fibrochondrocytes” to describe them.

**Blood Supply and Innervation**

It has been shown that at birth, the whole meniscus is vascularised [24]. However, an avascular area soon develops in the inner zone of the meniscus, and in the second decade, blood vessels occur only in the outer third. This progressive loss of vascularity may be due to weight-bearing and knee motion.

Anatomical studies [1] have shown that vessels to the menisci arise mainly from the medial and lateral inferior, and the middle geniculate arteries. Branches from these vessels form a perimeniscal capillary plexus that was first identified by Policard [25]. Radial branches from this perimeniscal capillary plexus penetrate the periphery of the meniscus at intervals, with a richer supply to the anterior and posterior horns [5].

The degree of vascularity varies within each meniscus, and the extent of the peripheral vascular zone also varies between individuals, ranging from 10 to 30% of the meniscal width [1]. The extent of the vascular zone has implications for the healing of meniscal tears.
There is an area in the posterolateral region of the LM, adjacent to the popliteus tendon, where the meniscus does not have any capsular attachment. This area is relatively avascular.

Reports on the innervation of the menisci are conflicting. Kennedy et al. [16] found abundant axons, large nerve bundles, free nerve endings, and specialised receptors including complex end bulbs and Golgi-type type III endings in perimeniscal capsular tissue. However, this innervation did not extend into the meniscal body itself. Day et al. [5], however, demonstrated that nerves run with the radially oriented blood vessels in the outer portion of the meniscus. As with the blood supply, there was a greater innervation of the anterior and posterior horns of the menisci, and unlike in the body of the meniscus, here, axons were found in the inner one-third.

Wilson et al. [37] also showed penetration of neural tissue into the outer third of the meniscus. However, they showed that the neural elements were not exclusively paravascular in position, and postulated that the nerves may not be exclusively vasomotor in function, but that they may perform an afferent function. They felt that this was most likely to be “slow” pain.

Zimny et al. [38] also found axons penetrating from the perimeniscal tissue into the outer third of the meniscus, with a heavier concentration at the horns. They comprised all three types of encapsulated end organs (Pacini corpuscles, which are usually involved in continued information of position, and the slowly adapting Ruffini endings and Golgi tendon organs, which respond when extreme stress is applied), and free nerve endings (type IV).

The presence of mechanoreceptors in the menisci suggests that the menisci may play a role in knee-joint afferent nerve transmission. This neural information may be important in joint proprioception. Indeed, it has been shown that proprioception was disturbed in knees with an isolated meniscal lesion, and that it improved after partial meniscal resection [15].

**Meniscal Motion During Knee Flexion**

The menisci are dynamic structures, and to effectively maintain an optimum load-bearing function over a moving, incongruent joint surface, they need to be able to move as the femur and tibia move, to maintain maximum congruency. Thompson et al. [32] were the first to describe meniscal movements through a full flexion-extension arc in the intact knee using MRI of cadaver knees. They showed that from full extension to full flexion, there was posterior excursion of the medial meniscus of 5.1 mm and of the LM of 11.2 mm, with the anterior horns moving more than the posterior horns. However, these observations were made in unloaded cadaver knees, and may, therefore, not be representative of the in vivo weight-bearing situation. Furthermore, Thompson et al. failed to comment on the medio-lateral movement of the meniscal tissue.

More recent technical advances in the field of radiographic imaging have led to the development of the so-called “open” magnetic resonance scanners. These scanners allow a subject to lie, stand, sit or squat within the imaging field, and thus, permit imaging of the intact in vivo knee under load in all positions. Using such a scanner, Vedi et al. [33] described meniscal motion in the normal knee, in both the weight-bearing and non-weight-bearing situation (Fig. 1.2.7). They found that the menisci moved less than was reported by Thompson et al. [32]. However, in common with Thompson et al.’s findings, they observed that the menisci move posteriorly as the knee flexes. The anterior horns were also noted to be more mobile than the posterior horns, and the LM to be more mobile than the medial. The posterior

![Fig. 1.2.7](image-url)
horn of the medial meniscus was found to be the least mobile. Vedi et al. also showed that there was significant movement of the bodies of the menisci peripherally with knee flexion, reflecting the anterior to posterior divergence of the femoral condyles from anterior to posterior.

Vedi et al. [33] compared the meniscal movements observed in the unloaded knee with those found when weight-bearing. They showed that there was significantly greater movement in the anterior horn of the LM when the knee was weight-bearing, but no significant differences were demonstrated between the other meniscal movements.

Summary

The menisci of the knee are highly complex structures, whose form is intricately linked to their various functions. Although far more is now understood about their functional importance in the knee, and even though meniscal preservation is now practised at surgery, where possible, there are still a number of anatomical features of the menisci that at present are all but ignored, from the surgical reconstructive perspective. This includes structures such as the meniscofemoral ligaments and the transverse ligament.

Greater understanding of the relevance of the detailed anatomical features of the menisci is an essential part of developing a deeper knowledge that will hopefully enable more accurate modelling of this tissue, with the aim of some day perhaps being able to manufacture or even grow appropriate artificial scaffolds or tissue-engineered replacement tissue.

References

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