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# INTRODUCTION

Meniscal injuries are among the most common injuries treated by orthopedic practitioners [27]. The loss of meniscal tissue, due to injury, surgery, or from degenerative processes can substantially alter the biomechanical functioning of the knee [1, 21]. While patients requiring complete meniscus replacement following total or subtotal meniscectomy can be sufficiently treated with a meniscal allograft transplantation (MAT), MAT is not an appropriate treatment following partial meniscal resection [34]. While both meniscal scaffolds and MAT offer advantages and disadvantages, the best option for meniscal replacement remains widely controversial. MAT has been shown to provide pain relief, decrease swelling, and improve knee function, though it is technically challenging and appears to be associated with high reoperation and failure rates [5, 6, 38]. Meniscal scaffold implants are advantageous as they provide an option for reconstructive surgery following partial resection with a lack of any clinically relevant inflammatory or immune responses and are more readily available than a size-matched allograft meniscus [27, 35]. Furthermore, the production of new fibrocartilage that is comparable to the original meniscus has been supported by meniscal scaffolds [27]. It has been claimed that replacement using MAT or meniscal scaffolds seems to be the most adequate solution for restoring knee biomechanics and delaying the onset of osteoarthritis [6, 10].

Currently, there are two available scaffolds: Collagen Meniscal Implant (CMI®, Ivy Sports Medicine, Gräfelfing, Germany) and Actifit polyurethane scaffold (Actifit®, Orteq Ltd, London, UK). CMI consists of Type 1 collagen from bovine Achilles tendons. The use of CMI is designed as a regeneration template into which the body's own tissue may grow, and therefore it is most useful when the patient has some meniscal tissue remaining [22, 29]. The use of CMI is intended to reduce pain, restore function, and prevent or decrease the risk of degeneration [39]. The Actifit scaffold degrades slowly over a 5-year period and consists of porous polycaprolactone and urethane segments, and is intended to help with pain relief and restore lost meniscal function by

providing a template for tissue ingrowth [39]. The purpose of this systematic review was to evaluate the current literature in an effort to assess the clinical outcomes following meniscal scaffold implantation.

# AIM OF THE WORK

The purpose of this systematic review is to evaluate the results of using CMI and Actifit as an alternative method for treatment of irreparable partial meniscal tear. Also to summarize and evaluate the clinical outcomes, complications and failure rates.

# MENISCAL ALLOGRAFTS

## 1.1 Introduction

'Keep the meniscus' is the slogan based on the natural history of this disc of soft tissue in the knee joint, erroneously considered by some to be a vestigial soft tissue structure in a 'self-maintaining transmission system'.

These combined sets of asymmetrical components meet the biomechanical need for load transference between the thigh and the leg so well that they have essentially persisted with minimal change for a period of over 300 million years of vertebrate evolution.

The knee thus represents a truly remarkable design of evolutionary biology.

Limbs occur very early in the ontological development of the human embryo, as do menisci in the evolutionary history of the human knee. By the end of the embryological period the menisci have become further defined and by nine to ten weeks they have become completely separated from the articular chondral surfaces of the tibia and femur.

The menisci remain of critical importance to the normal function of the knee joint.

As the menisci are sometimes referred to as 'semilunar cartilages', even though they are crescentic when viewed from above, they are wedge-shaped in crosssection and are attached to the joint capsule at their convex peripheral rim, except for a portion of the lateral meniscus in the region of the popliteus tendon, and also to the tibia anteriorly and posteriorly by insertional ligaments. They thus partially cover the tibiofemoral joint surface.

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 ligaments have fibrocartilaginous transition zones that make the change in stiffness between ligament and bone tissue at the enthesis less sudden, therefore reducing the stress concentration in this unit and preventing failure. In addition, 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. This anatomical finding has been identified in almost 94 % of cases and may have a role in moving the menisci during tibial internalexternal rotation.

Two ligaments joining the posterior horn of the lateral meniscus to the lateral side of the medial femoral condyle in the intercondylar notch, have also been identified. The anterior meniscofemoral ligament runs anterior to the posterior cruciate ligament, and is known as the ligament of Humphrey. The posterior meniscofemoral ligament runs posterior to the posterior cruciate ligament, and is known as the ligament of Wrisberg.

A review of the literature by Gupte et al. 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.

Normal meniscal tissue is composed of 72 % water, 22 % collagen, 0.8 % glycosaminoglycans and 0.12 % DNA.

Histologically, the menisci are fibrocartilaginous structures and are primarily composed of an interlacing network of collagen fibres interposed with cells, with an extracellular matrix of proteoglycans and glycoproteins.

The fine orientation of the collagen fibres within the meniscus is directly related to the function of the meniscus. The principal orientation of the collagen fibres is circumferential, to withstand tension. Radially oriented collagen fibres are predominantly present in the mid-portion of the meniscus and also on the exposed surfaces. These radial fibres might act as ‘ties’ holding the circumferential fibres together.

The entire meniscus is vascularized at birth. An avascular area soon develops in the inner portion of the meniscus, and in the second decade, blood vessels are only present in the outer third. The degree of vascularity varies within each meniscus.

Reports on the innervation of the menisci are conflicting. Wilson et al. also showed penetration of neural tissue into the outer third of the meniscus. The presence of mechanoreceptors in the menisci suggests that the menisci may play a role in knee joint afferent nerve transmission. 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 with movements of the femur and tibia, in order to maintain maximum congruency.

Recent technical advances in the field of radiographic imaging have allowed in vivo studies of the intact knee under load in all positions. Vedi et al. have described meniscal motion in the normal knee in both weight bearing and non-weight bearing conditions.

Biomechanical investigations have looked into material properties of meniscal tissue.

In the literature, attempts have been made to quantify the meniscal response. A discrepancy exists between experimental studies on the variation of the tensile modulus along the circumference of the tissue.

Fewer studies have investigated the compressive properties of meniscal tissue. Menisci appear to be 1000 times stiffer in tension than in compression. These characteristics render the tissue very deformable in compression, which means that it can conform to the variable geometry of the femoral condyles during knee flexion and extension.

It has been well established that the main role of the menisci within the knee joint is transmission of the joint force from the femur to the tibia. This mechanism of loadbearing occurs throughout the whole range of knee-joint flexion precisely because the menisci are mainly attached to the tibia by insertional ligaments at their mobile horns, allowing displacement in all directions. The lateral meniscus is more mobile than the medial meniscus.

The resistance of the menisci to compressive loads by increasing their circumference and developing hoop stresses explains the variable effect and frequency of the various types of meniscal tears.

The shock-absorbing capacity of the menisci has been demonstrated by studies measuring the vibrations in the proximal tibia resulting from gait. Shock absorption has been shown to be approximately 20 % lower in knees without menisci.

Regarding the role of the menisci as secondary stabilizers within the knee, the clinical results of anterior cruciate ligament reconstruction have been shown to be markedly impaired by the presence of concurrent meniscal injury.

The functional importance of the menisci in vivo has been proven unequivocally by clinical studies documenting the long-term results after meniscectomy (**Fairbank et al.**).

Burke et al. demonstrated that pressure distribution patterns within the knee were less affected by partial meniscectomy leaving the peripheral portion of the meniscus intact, than by total meniscectomy.

Many meniscal tears are irreparable, in which case partial or total meniscectomy is inevitable.

Possible solutions to such cases may lie with techniques such as meniscal allograft transplantation after total meniscectomy or partial meniscal replacement with collagen scaffolds after partial meniscectomy.

# THE MENISCUS: BASIC SCIENCE

## 2.1 Introduction

The menisci are semilunar discs of fibrocartilaginous tissue which play critical roles in knee joint biomechanics [1]. Despite, it have been described in the past as nearly useless, with perhaps some minor roles on joint nutrition and stabilization [2]. These complex structures are primarily composed of an interlacing network of collagen fibers (predominantly type I collagen) interposed with cells, and an extracellular matrix (ECM) of proteoglycans and glycoproteins.

Menisci are placed within each knee, between the correspondent lateral and medial femoral condyles and tibial plateaux. It has been now recognized that its removal determines deleterious joint consequences, particularly on the long term [3].

Due to the pivotal role of meniscus in maintaining knee homeostasis and proper joint functioning/stability, novel regenerative treatments have been attempted to develop as an alternative to traditional repair procedures or meniscectomy.

The basic science knowledge concerning human meniscus require re-appreciation given the overturn on therapeutic approach, i.e. from meniscectomy to preservation or substitution; and the nearly universal arthroscopic surgical approach opposing to open surgery.

The biological characterization of this tissue, although not yet completely accomplished, has evolved significantly in the last few years. This is true concerning recognition of different cellular populations, understanding its ultrastructure [4], cells and extracellular matrix segmental distributions, biomechanical properties, biologic interactions and mechanism for triggering the response to injury.

## 2.2 Anatomy and Biomechanics

In early eighties, a biomechanical study stated the importance of medial meniscus on load transfer. Kurosawa et al. showed that total meniscectomy reduces the total contact area by a third to a half in the fully extended knee [5]. Another report stated its major importance in load transfer and the possible consequences of meniscal excision, not only in articular surface, but also on the subchondral bone, proximal tibia’s trabecular bone and cortex [6]. The menisci are not firmly fixed on the tibia and follow knee anteroposterior translation during joint motion. Due to its anatomical features (including stronger attachment to medial

collateral ligament), the medial is less mobile. In the stable knee (functioning central pivot ligaments) the medial meniscus has little participation on anterior tibial displacement constraint. The anterior cruciate ligament stops anterior knee motion prior to significant contact of femoral condyle with posterior horn of medial meniscus and tibial plateau [7].

There are major differences between both femorotibial compartments on knee joint to be considered. Lateral tibial plateau is prone to have a more convex shape, opposing to concave shape on medial compartment [1, 7]. This fact helps to understand that the loss of the lateral meniscus leads to major diminishment on femorotibial congruence. Furthermore, according to Walker et al., the lateral meniscus carries most of load transfer on lateral compartment, while in the medial force transmission is distributed between the exposed cartilage surfaces and respective meniscus [8]. In vitro trials stated about 70 and 50 % of load transmission through the corresponding menisci in the lateral and medial compartment respectively [9].

Regarding gross morphology, medial meniscus resembles a ‘‘C’’, whereas lateral meniscus is more sharply curved (Fig. 2.1). There is a great variability in medial meniscus anterior horn insertion types, but insertions of the lateral meniscus are less

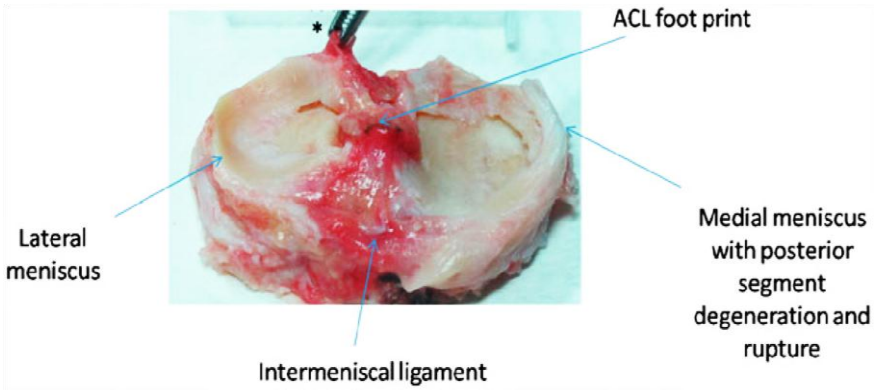



**Figure 1:** Human specimen photo with menisci in place; ligament of Humphrey also present (attached with forceps*) variable and quite closer [10–12]. These variants must be taken into account when performing any kind of meniscus substitution.

The biomechanical response of the menisci to loads acting on tibiofemoral joints result from their macro-geometry, their fine architecture and their insertional ligaments. The collagen bundles of the superficial layer are randomly orientated mimicking articular hyaline

cartilage [13] **(Fig. 2).** This way it lowers friction between menisci, femur and tibia during joint motion.

In the bulk of the meniscal tissue, under these surface layers, two distinct regions of different collagen fibers are present: the inner one-third bundles have a radial pattern, whereas the outer two-thirds are oriented in a circumferential manner.

Accordingly, it has been suggested that the inner third may function in compression and the outer two-thirds function in tension. Furthermore, some radiallyorientated collagen fibers can also be found within the bulk of the meniscal tissue acting as ‘‘tie fibers’’, and resisting longitudinal splitting of the circumferential collagen bundles [14].

Viscoelastic behavior (rubber-like at high loading frequencies; at lower frequencies viscous dissipation occurs) of the meniscus relates with ECM composition (not much dependent of collagen content; higher with increasing glucosaminoglycans (GAGs) content and lower with increasing water content. Accordingly, regional variations can be observed in terms of viscoelastic properties [15]. It has been demonstrated a regional and zonal variation in glycosaminoglycan coverage, size, and cellular density in animal meniscal tissue [16]. Similar studies on human tissue have been required, particularly in the era of Tissue Engineering aiming to replicate menisci in laboratory for clinical application [17]. Pereira et al. have recently presented the first biomechanical segmental characterization of fresh human meniscus [18].

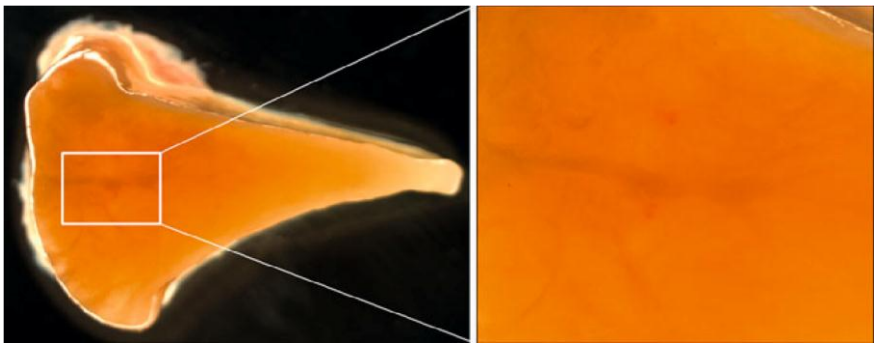


**Figure 2:** Stereomicroscopy images of human meniscus where it is possible to observe the bundles

The anterior intermeniscal ligament (or transverse geniculate) connects the anterior fibers of the anterior horns of medial and lateral menisci. Its prevalence is estimated around 60 % and its functional relevance remains unclear [19].

Two ligaments are known to connect the posterior horn of the lateral meniscus to the lateral side of the medial condyle of the femur-meniscofemoral ligaments.

The ligament of Humphrey runs anterior to the posterior cruciate ligament (PCL), while the ligament of Wrisberg runs posterior to the PCL. Their estimated prevalence is 74 % for Humphrey ligament, 69 % for Wrisberg ligament, and both ligaments found together in around 50 % of knees [20].

The functional relevance of these ligaments has been demonstrated by Gupte et al., who demonstrated that menisco-femoral ligaments contributed 28 % to the total force resisting posterior drawer at 90 of flexion in the intact knee, and 70.1 % in the PCL-deficient knee [21]. Probably this issue will remain a research topic aiming to improve meniscal repair or replacement techniques.

### 2.3 Extracellular Matrix and Cellularity

Considering composition by wet weight, the meniscus has high water content (72 %). The remaining 28 % consists of an organic component, mostly ECM and cells [22]. Collagens comprise the majority (75 %) of the organic matter, followed by GAGs (17 %), DNA (2 %), adhesion glycoproteins (\1 %), and elastin (\1 %) [22, 23]. These proportions vary according to age, injury, or pathological conditions [24].

Collagen is the main fibrillar component of the meniscus. Different collagen types exist in various quantities in each region of meniscus. In the red–red zone, type I collagen is predominant (80 % composition in dry weight), but other collagen variants (e.g., type II, III, IV, VI, and XVIII) are present at less than 1 %. In the white–white zone, collagen makes up to 70 % dry weight, of which 60 % is type II collagen and 40 % is type I collagen [25].

Elastin is another fibrillar component, although its relevance is not completely understood. The combination of mature and immature elastin fibers has been found in very low concentrations (\0.6 %) in the adult meniscus [26, 27].

Proteoglycans are the major component of ECM. These molecules are comprised of a core protein which is decorated with GAGs. The main types of GAGs found in normal human meniscal tissue are chondoitin-6-sulfate (60 %), dermatan sulfate (20–30 %), chondroitin-4-sulfate (10–20 %), and keratin sulfate (15 %) [23]. Aggrecan constitutes the major large

proteoglycan of the meniscus, while biglycan and decorin are the main small proteoglycans [28]. Their main function is to enable the meniscus to absorb water, whose confinement supports the tissue under compression [22]. Regional variation of these molecules has also been observed, with the inner two-thirds containing a relatively higher proportion of proteoglycans than the outer one-third [28].

Adhesionglycoproteinsarealsoimportantcomponentsofthemeniscusmatrix, as they serve as a link between ECM components and cells. The main adhesion glycoproteins present in the human meniscus are fibronectin, thrombospondin, and type VI collagen [29].

Considering shape classification and territorial ECM, chondrocyte-like, fibroblast-like, and intermediate cells were identified in the meniscus [30]. Classification of meniscus cells is controversial and different terms are being used ( i.e. fibrocytes, fibroblasts, meniscus cells, fibrochondrocytes, and chondrocytes) [31].

It is apparent that outer zone cells have an oval, fusiform shape and are similar in appearance and behavior to fibroblasts. Thus, they may be described as fibroblast-like cells [4]. These cells also display long cell extensions, which facilitate communication with other cells and the ECM. The matrix surrounding the cells is mainly comprised of type I collagen, with small percentages of glycoproteins and types III and V collagen [32].

In contrast, cells in the inner portion have rounded appearance and are embedded in an ECM comprising largely type II collagen intermingled with a smaller but significant amount of type I collagen and a higher concentration of GAGs. This relative abundance of type II collagen and aggrecan in the inner region is more reminiscent of hyaline articular cartilage. Therefore, cells in this region are classified as fibrochondrocytes or chondrocyte-like cells [4].

A third cell population has also been recognized in the superficial zone of the meniscus. These cells have somewhat peculiar morphology, i.e. are flattened, fusiform and lack the cell extensions. It has been suggested that these might be specific progenitor cells with more regenerative capacities [33].

Outer meniscus cells seem to migrate quicker and exhibited lower adhesion strengths as compared to inner meniscus cells [34].

Meniscus cells isolated from outer (vascular), inner (avascular), and horn (mixed) can be induced towards chondrogenic, adipogenic and osteogenic lineages. Outer cells are more plastic and can also go to osteogenesis [35]. The distribution of different cells in the meniscus architecture (segments and zones) has recently been focus of research and it is a relevant insight in the ambitious goal of achieving a tissue engineered implant [18].

### 2.4 Vascularization and Innervation

Three classical zones according to vascularization continue to be used as references: red–red; red–white e white–white (Fig. 3) perfectly shows the blood vessels at red–red zone, which arise mainly from medial and lateral inferior and middle geniculate arteries. Radial branches from a perimeniscal plexus enter the meniscus at intervals, with a richer supply to the anterior and posterior horns [36]. Vessels supplying the body are limited to the meniscus periphery with a variable penetration of 10–30 % for medial meniscus and 10–25 % for lateral one, except in the fetus. There is an avascular area adjacent to the popliteus tendon [37].

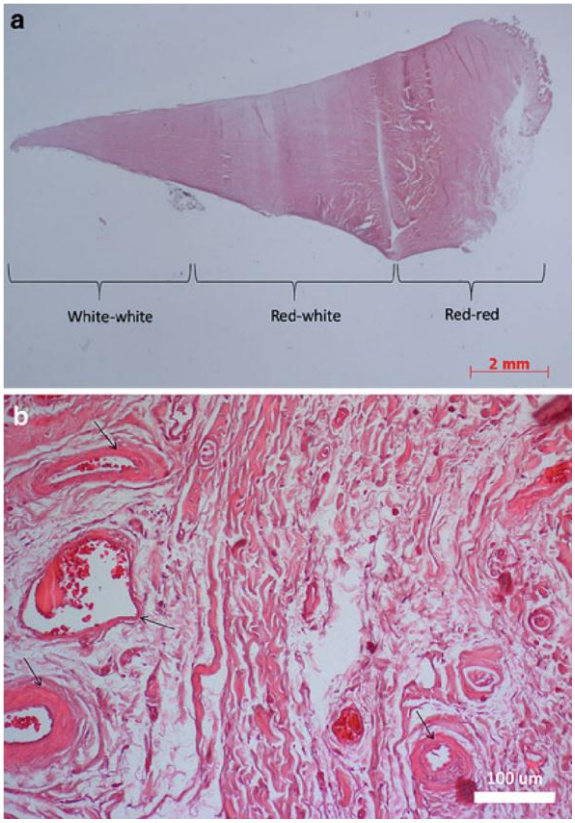



**Figure 3:** Microscopy image of a section of human meniscus stained with haematoxylin and eosin (a) and respective magnification of red–red zone where it is possible to observe the blood vessels (black arrows) (b)

The perimeniscal tissue is richly innervated. Most nerves are associated with vessels. Smaller nerves and axons run radially in convoluted patterns. Single axons course through the perimeniscal tissue, and many nerves are seen in the interstitial tissue of the peripheral zone of the meniscus and in the anterior and posterior horns. The inner menisci core has no nerve fibers [36].

Studies of the vascular and nerve supply of the meniscus in humans have potentially important clinical applications. It has been established that meniscal vasculature is related to the ability of meniscal tissue to heal well, although some healing of meniscal tissue has also been described in avascular portions of the meniscus.

In the fetus, the vascular supply is more extensive, with vessels extending to the inner one-third. There is also a significant nerve supply that is similar in distribution to the vascular supply.

# ORGANISATION: CONSERVATION—REGULATION TYPE OF GRAFTS

## 3.1 Introduction

Joint degeneration following complete meniscus removal has been documented and recognized as a major cause of osteoarthritis [1–5]. The meniscus at the knee has been shown to serve various functions such as load distribution, shock absorption, joint stability, knee proprioception and joint lubrication. A deficient meniscus implies a decrease of surface contact area with a subsequent increase of contact pressure, leading to wear and gradual disappearance of cartilage within a decade [6–9]. The basic principle underlying meniscal transplantation is to restore the joint anatomy and to relocate an implant that will serve and perform in a similar fashion as the original one.

An allograft should delay or better still, prevent osteoarthritis of the knee.

The demand for meniscal allografts has recently increased because of the improvements in graft fixation and the extended indications for meniscus allografting.

Limitations to musculoskeletal tissue donation and donor age contribute to the shortage of available meniscal tissue. Optimal handling and fixation of a meniscus allograft during surgery will avoid tissue wasting and improve the surgical outcome.

### 3.1.1 Tissue Banking Organization

Meniscus transplantation deals with human tissues and, as such, is regulated by the European directive on human tissue, which sets the standards of quality and safety for the donation, procurement, testing, processing, preservation, storage and distribution of human tissues and cells [10–12]. Most large tissue banks are involved throughout the whole process from harvest to graft delivery [13, 14].

### 3.1.2 Donor Selection

#### 3.1.2.1 Consent

The procurement of any human tissue is framed by European directives on human tissue, covering donation, donor selection and tissue safety. In each country, the European directive must be translated into a national law of at least the same level of requirements. Each country has the possibility to reinforce one or more legal aspects. A national authority controls tissue banking activities in each European country.

Menisci are procured from young adult organ donors. Consent for tissue retrieval is obtained according to the national law and European regulations.

In Belgium, the consent is based on donor presumed consent. Tissue harvesting is allowed only if the potential donor is not registered with a national registry. Nevertheless, informed consent from the next of kin will always be sought,

Anonymity between donor and recipient is a key principle, whereas traceability is maintained by a unique donor coding number [12].

**3.1.2.2 Donor Selection**

Donor suitability is determined in compliance with the standards and guidelines developed by European or national authorities, or tissue banking associations such as the American Association of Tissue Banks (AATB) and the European Association of MusculoSkeletal Transplantation (EAMST). Those standards list a series of conditions that might indicate a donor at risk for disease transmission [11, 12, 15–17]. Thorough examination of the medical files and donor physical assessment are imperative.

European standards differ from American ones in two specific points [10, 11, 15, 16]. A past history of cancer is an exclusion criterion in Europe but not necessarily in the United States. In Europe, the donor's body must be refrigerated within six hours for a procurement to occur within 24 h after death, whereas in the United States an interval not exceeding 15 h prior to body cooling can be accepted before procurement.The donor is screened for disease transmission prior to tissue harvesting. If the potential donor has been transfused with a large volume ([2,000 ml) of blood, blood components or plasma volume expanders within 48 h prior to death, a pretransfusion blood sample is required for testing, because dilution of donor plasma carries a risk of false—negative results.

HIV-1 and 2 (two antibodies tests and P24 antigen detection), HTLV-1 (antibodies), hepatitis B (surface antigen HBs and core antibody HBc), hepatitis C (antibodies) and syphilis (antibodies) are systematically screened. Additional safety measures can be taken to screen for potentially false-negative results during the incubation period of a virus, by using nucleic acid testing for hepatitis viruses and HIV (NAT). This type of assay allows significant reduction of the serological window period [17–19]. Furthermore, another safety feedback is

possible for tissues procured from an organ donor as organ recipients can be screened for disease transmission three months after having been grafted [17].

Blood cultures are recommended because they reflect the bacterial quality of the harvested tissue [20, 21].

During and after harvesting, samples of the procured tissues are placed in a thioglycolate broth culture medium in order to exclude bacteriological contamination [14, 22]. They are cultured for aerobic and anaerobic bacteriae and fungi for at least seven days.

### 3.1.2.3 Harvesting

Harvesting from a multiorgan donor is performed under sterile conditions in the operating theatre by a team of three to four trained individuals, one being an orthopaedic surgeon. When selecting viable meniscal or osteochondral allografts, the donor should preferably be under 45 years of age. Close examination at the time of procurement will determine the quality of the surface of the cartilage and of the meniscus. In daily practice, donor age is certainly not the main critical factor: posttraumatic or osteoarthritic changes may be present in younger patients, whereas suitable cartilage or meniscus might sometimes be found in donors above the age limit of 45 years.

At our institution, a 1 cm-thick section of the tibial plateau is removed (Fig. 3.1). Then, the plateau is in its central aspect separated into two parts, taking care not to damage the insertions of the menisci (Fig. 3.2).

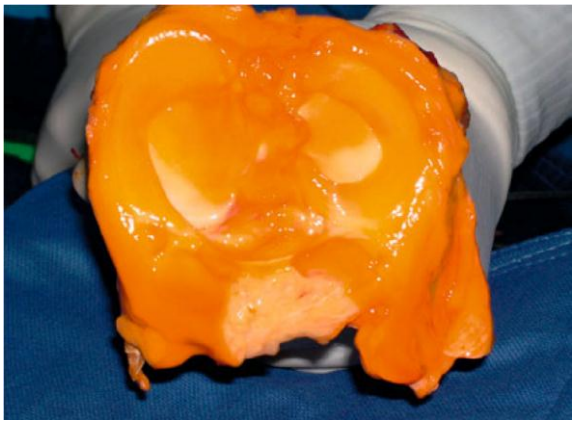


**Figure 4:** Menisci harvested.Aspect prior to bone sawing

### 3.1.2.4 Risks and Recommendations



**Figure 5:** Meniscus harvested with its osseous support

Bone and tissue allografts are capable of transmitting virus and contaminating the recipient [23–28]. The risk of viral disease transmission through tissue is very low, provided that the guidelines for donor selection have been strictly followed and that the donor has been screened by medical history-taking and blood testing. For HIV the theoretical risk of transmission has been evaluated to be less than one in a million, and for HCV one in 200,000 for an unprocessed tissue from a selected and serologically screened donor [29–31].

For a processed tissue such as cancellous bone that has been subjected to thorough saline washing and solvent-detergent exposure with a final irradiation, the theoretical risk is much lower, with an average decrease of two orders of magnitude [26, 30].

The surgeon using the graft must verify the bacteriological and serological results himself and inform the patient of the use of an allograft.

ABO blood group typing is not required prior to a bone or soft-tissue grafting procedure. On the other hand, the Rhesus factor has to be determined if the recipient is a female with a potential of becoming pregnant [32, 33]. It has been shown that 0.5 ml of bone marrow is sufficient to induce Rhesus immunity in a Rhesus-negative patient. Soft tissue such as meniscus does not carry this risk.

### 3.1.3 Graft Sizing

Sizing is usually based on peroperative measurements and standard X-rays.

For peroperative sizing of the graft, the anteroposterior and lateromedial dimensions are measured, as well as the width of the meniscus at its anterior,

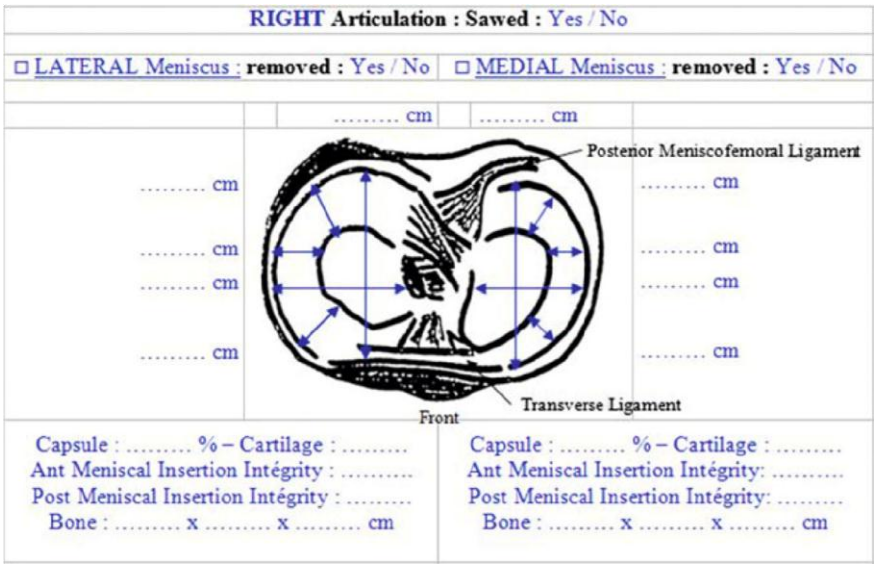



**Figure 6**: Graft sizing. Standard sizing chart used in the operating theatre

medial and posterior parts [34]. All measures are recorded on standardized charts and are catalogued in our tissue bank inventory, providing a wide range of meniscal transplants (Fig. 3.3).

Standard X-rays are difficult to obtain. If true anteroposterior or lateral images are lacking, the inaccuracy of the measurements is significantly increased (Figs. 3.4 and 3.5) [35].

Magnetic resonance imaging (MRI) is not used by bone banks because its superiority has not been clearly demonstrated. Moreover, MRI is not easily applicable in a routine tissue bank protocol or pretransplantation planning [35–37].

A successful transplantation requires precise matching of the size of the donor meniscus and the recipient. The use of digital imaging during procurement might be helpful [38, 39].

### 3.1.4 Types of Grafts

According to the preservation method, four types of allografts are distinguished: fresh menisci, frozen menisci with or without cryoprotectants, and freeze-dried menisci. While fresh and cryopreserved grafts may still contain some viable cells at the time of transplantation, freeze-dried and deep-frozen ones are nonviable and are as such considered to be acellular material [40, 41].

Fresh meniscus is used for viable meniscus allografting. For maximal viability of the meniscus to be preserved, procurement should be within 12 h after death.

Fig. 3.4 Standard AP view of a procured tibia with menisci

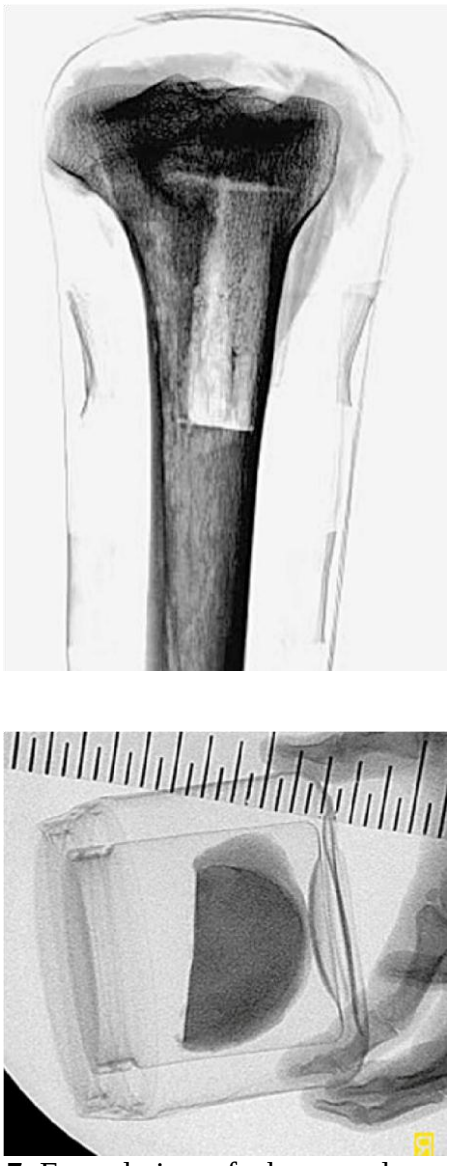


**Figure 7**: Frontal view of a harvested meniscus

After harvesting, the grafts are transported in a sterile saline solution and placed in a culture medium containing 20 % of recipient serum. The graft material is stored at 37 C in a constant controlled environment [41, 42]. Postimplantation viability of fresh grafts has been documented [41, 43]. Because cultured meniscus does produce the components of the extracellular matrix in vitro, it can be expected to perform similarly in vivo. However, the duration of this cellular function in vivo remains unknown. In a goat model, DNA probing showed that cells from fresh and viable meniscus did not survive for more than one month

[44]. However, Verdonk et al. were able to demonstrate some donor cell survival 64 months after transplantation [43].

Recipients of a fresh meniscal allograft do not require immunosuppression, but the importance of the recipient's immune response to the clinical outcome remains unknown [45]. So far, no clear benefit has been shown of a viable meniscal allograft compared to a frozen-preserved one.

Cryopreserved meniscal allografts are tissues that are immerged in a solution containing a cryoprotective agent such as dimethyl sulfoxide (DMSO), a culture medium and an antiseptic agent. After impregnation, the graft is gradually frozen in a controlled fashion to minimize cellular lesions during freezing. Storage temperature is at -196 C. Even if this type of cryopreserved graft may still contain viable cells after thawing, their long- term survival remains questionable [46].

Freshly frozen allografts are soaked in a saline solution containing an antibiotic (rifampicin, 1.2 g/l) after harvesting. Subsequently, they are packaged in a sterile fashion and stored in a mechanical freezer at -80 C. These grafts can be preserved for as long as five years. At surgery, they are again soaked in an antibiotic solution, e.g. rifampicin, which will be gradually released from the implant for at least three weeks after the operation in a similar fashion as demonstrated for bone [30, 47].

Freezing a tissue without other physical treatment such as irradiation does not alter the original mechanical properties, whatever the freezing temperature [48, 49].

The maximal storage period of human deep-frozen tissue is limited to five years in Europe [17].

Freeze-dried allografts: lyophilization or freeze-drying, which consists of drying a tissue under vacuum and freezing conditions, is a suitable method to preserve cellular viability if cryoprotective solutions are used, as for vaccine production. Lyophilization without cryoprotection leaves nonviable dried tissue [30, 50]. Freeze-drying is just a preservation method and as such, not a sterilant.

Freeze-drying is beneficial from a logistical standpoint, because the dried tissue can be stored at ambient room temperature. In addition, from an immunological standpoint,

lyophilization has been demonstrated to be superior to freezing, because freeze-dried tissue does not elicit an immune response, at least not in experimental conditions [51].

Because sterile freeze-drying of tissues is difficult, further irradiation at 25 Kgy is usually associated. In a clinical setting, the dried tissue is also irradiated for final sterilization. This combined process of lyophilization and irradiation appears to be detrimental to the tissue, because it results in a profound alteration of the mechanical properties and the extracellular matrix. From a clinical standpoint, freeze-dried and irradiated meniscal allografts are not suitable for transplantation [52–54].

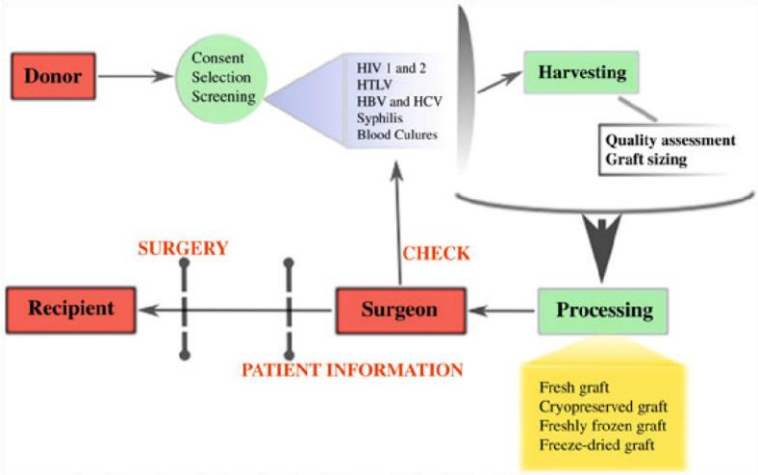



**Figure 8:** algorithm for graft use

### 3.1.5 Data from Our Bank

Our bank has always worked with freshly frozen tissues. Table 3.1 summarizes the path followed by any tissue from donor to recipient. Over the last years, the demand for meniscal allografts has substantially increased, since the year 2000 even 20-fold, with an annual delivery rate of 45 menisci in 2006 and 2007. We advocate the deep-freezing method for several reasons: (1) it does not affect the mechanical properties of the tissue; (2) even if the material is nonviable at surgery, experimental conditions have shown a rapid recolonization of the implant by host cells; (3) it allows storage for five years; (4) it requires minimal tissue handling compared to cultured tissue; and (5) it allows the surgeon to schedule the time of surgery himself. In 2007, we reviewed 69 fresh-frozen meniscal allografts procured by our tissue bank, with a follow-up of two years. Of these 69 grafts, 60 % had been secured by peripheral suturing, 22 % with one bone plug and 18 % with two bone plugs. Using

psychometric scores for knee evaluation, an increase of four points on the Tegner activity scale [55] was achieved, corresponding with a 65 % improvement after allograft surgery. The mean Lysholm score [55] increased from 72 preoperatively to 90 at the last postoperative visit. As for patient satisfaction, we noted 90 % of excellent results and 8 % of intermediate results, while 2 % of patients were disappointed by the surgery. We encountered four complications: three tears and one infection.

Apparently, freshly frozen allografts can be safely and reliably used for meniscal transplantation.

# SURGICAL TECHNIQUES

## 4.1 Open Technique

### 4.1.1 Preoperative Considerations

In contrast to the use of deep-frozen allografts, a strict time schedule from harvest to transplantation is mandatory for viable allografts. The transplantation of viable meniscal allografts implies the availability of viable donor tissues, cultured in vitro immediately following harvest. Sizing of the graft is critical for correct implantation. For deep-frozen allografts the mediolateral and anteroposterior length of the tibial plateau of the receptor are measured on a calibrated X-ray and transferred to the tissue bank. Since viable meniscal allografting is more limited in size-options due to the fact that there is only 1 donor and a limited number of acceptors, the most appropriate acceptor is chosen based on corresponding donor–acceptor height and weight criteria. Once a patient is deemed to be a candidate for this type of procedure, 30–50 ml of autologous serum is prepared and frozen at -21 C. The waiting time for a viable meniscal allograft averages 2 months—ranging from 14 days to 6 months—at our institution. Once an appropriately sized meniscal allograft is harvested, the patient is notified and an operation is planned within the next 14 days.

### 4.1.2 Surgical Technique

#### 4.1.2.1 Introduction

The purpose of this technical chapter is to present medial and lateral meniscal allograft transplantation (1) as an open procedure or (2) as an arthroscopically assisted procedure. Both techniques use primarily soft tissue fixation of the allograft to the native meniscal rim. Additional transosseus fixation of the anterior and posterior horn is used in the arthroscopic technique, while a tag on the anterior horn is used in the open procedure for soft tissue-bone fixation.

#### 4.1.2.2 Anaesthesia and Surgical Preparation

These items are identical for the open and arthroscopic procedure.

The choice of anaesthesia is made in consultation between the surgeon, the anaesthesiologist and the patient and depends on patient’s age, comorbidity and history with regard to previous anaesthesia. General anaesthesia is preferred at our institution.

The patient is then positioned supine on the operating table. A lateral leg-holder is positioned at the height of the tourniquet with the leg positioned in 90 of flexion. A foot holder is used to hold the leg in 90 and 110 of flexion as needed. Previous skin incisions are marked. The limb is exsanguinated and the tourniquet is inflated. The limb is then prepared with chlorhexidine gluconate-alcohol solution (Hibitane, Regent Medical Overseas Limited, Manchester, UK) and draped at the mid-thigh level.

#### 4.1.2.3 Allograft Preparation for the Open Procedure

As previously described elsewhere, the allograft is positioned and fixed on a specially designed cork board with three 25 gauge needles [1]. With a scalpel, the residual synovial tissue is dissected from the allograft meniscus at the meniscosynovial junction level and discarded.

The upper side of the allograft is marked with a methylene blue skin marker. Horizontal 2/0 polydioxanone surgical sutures (PDS II mounted on a double small needle, Ethicon, Somerville, NJ, USA) or 2/0 non-absorbable polypropylene sutures (Prolene mounted on a double small needle, Ethicon, Somerville, NJ, USA) are placed every 3–5 mm through the posterior horn, the body and the anterior horn of the allograft and fixed onto a specially designed suture holder (holder A). The senior surgeon (RV) prefers the use of 2/0 Prolene sutures for the posterior horn since this suture material comes with slightly smaller needles and therefore has easier surgical handling in the more narrow posterior joint space. The sutures are fixed onto the suture holder in sequence from posteriorly to anteriorly. Generally 6–8 sutures are needed to cover the complete allograft.

#### 4.1.2.4 Open Meniscal Allograft Transplantation

A medial or lateral parapatellar incision of approximately 8 cm is made with the knee in 90 of flexion to gain access to the involved compartment of the knee joint. The joint capsule is then opened and the anterior horn of the meniscus remnant is transected.

For the lateral procedure, the iliotibial band is released subperiosteally from its distal attachment. To further open up the lateral compartment, the insertion the lateral collateral ligament (LCL) and popliteus tendon (PT) are detached with a curved osteotomy on the femoral side (Fig. 4.1). The centre of the osteotomy bone block is first predrilled with a 2.7

mm drill. This facilitates subsequent refixation with a screw and washer. The osteotomy is done in a clockwise direction from the 8 o'clock position to the 4 o'clock position and is approximately 1.5 cm deep and conically shaped. The bone block is gently folded out using a bone clamp and then the osteotomy is completed inferiorly from the 4 o'clock to the 8 o'clock position using the osteotome. The lateral joint space can now be opened up easily 1–2 cm by placing the knee in the figure of 4 position in 70–90 of flexion with the index foot positioned across the contralateral limb.

For the medial procedure, the medial collateral ligament is detached on the femoral side with an osteotomy [2]. A flake osteotomy (0.5–1 cm in thickness) is done with a straight osteotome at the level of the medial femoral epicondyle. The soft tissues posterior to the medial collateral ligament are left in continuity. By gently placing the knee in a valgus position, the medial compartment can now be opened up in a controlled fashion.

The meniscus remnant is trimmed preferably to a stable meniscal rim with a scalpel anteriorly and with arthroscopic instruments posteriorly. Most often, the insertion of the

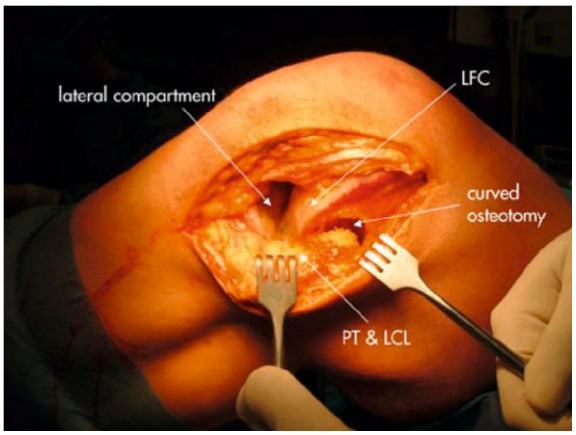



**Figure 9:** Open meniscal allograft transplantation.

posterior horn is still intact and in continuity with the tibial plateau. The insertion of the posterior horn is also trimmed to fit the allograft. The meniscal

To further open the lateral compartment, the LCL and PT are detached with a curved osteotomy on the femoral side rim deserves surgical attention, as it serves as a strong envelope encapsulating the medial or lateral compartment of the knee.

The meniscal remnant level is then marked with a small mosquito clamp anteriorly as landmark for the correct level of subsequent fixation of the allograft. Next, the previously

prepared viable meniscal allograft is introduced into the knee compartment. The sutures are taken from the holder in the correct sequence from posteriorly to anteriorly and driven through the meniscal rim one by one in an allinside fashion from inferiorly to superiorly and transferred to a second suture holder (holder B), again in a sequence from posteriorly to anteriorly. The lateral allograft is also sutured to the popliteus tendon. We have found on follow-up arthroscopies that the popliteal hiatus will recreate itself naturally. The insertion of the anterior horn of the meniscus is not yet sutured at this stage of the operation. Once the sequence of suture transfer from holder A through the meniscal rim (and popliteal tendon) to holder B is completed, the allograft is introduced into the compartment by gently pulling on each suture in a sequence from posteriorly to anteriorly. Generally, this procedure has to be performed progressively to establish a secure fit of the allograft to the meniscal rim. The suture knots are then securely tied and cut. A fine-tipped suture driver and knot pusher are frequently required to securely tighten the posterior sutures. The knee is now positioned again in a normal 90 flexed position. The bone block of the collateral ligament and popliteus tendon is repositioned and fixed using a 35 or 40 mm 2.9 AO cancellous screw with a spiked washer. The anterior horn of the allograft is then fixed to the tibia using an anchor (GII, Depuy Mitek, Raynham, Massachussetts, USA). The Hoffa fat pad and knee capsule are closed using interrupted Vicryl 1/0 (Ethicon, Somerville, NJ, USA) cross stitches after haemostasis.

**4.2 Arthroscopic Technique Without Bone Plugs**

The allograft is positioned and fixed on a specially designed cork board with three 25 gauge needles. With a scalpel, the residual synovial tissue is dissected from the allograft meniscus at the meniscosynovial junction level and discarded.

The upper side of the allograft is marked with a methylene blue skin marker.

Non-resorbable high-strength (Fibre wire, Arthrex, Naples, USA) sutures are placedintheanteriorandposteriorhornofthеallograft.Generally, 3 whip stitchesare placed on the inner and outer rim of the horn of the allograft. An additional vertical non-resorbable suture (Ethibond 2/0, Somerville, NJ, USA) is placed at the posteromedial or posterolateral corner of the medial or lateral allograft, respectively. For the lateral allograft, the

posterolateral suture is positioned just anteriorly to the popliteus tendon hiatus as this will serve as a landmark during arthroscopy (Fig. 10).

Whipstiches (WS) on inner an outer rim of anterior (AH) and posterior horn PH). A vertical nonresorbable suture (NRS) is placed on the posterolateral corner, just anteriorly of the PT hiatus

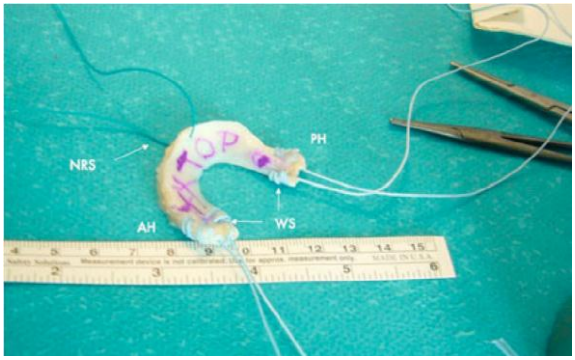


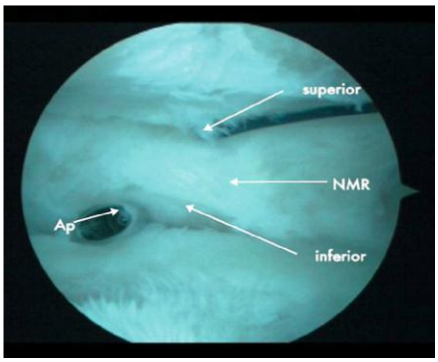

**Figure 10:** Prepared lateral meniscal allograft for arthroscopic meniscal transplantation.

### 4.2.1 Arthroscopically Assisted Lateral Meniscal Allograft Transplantation

The classic anteromedial and anterolateral portals are made. An additional anteromedial portal is positioned very medially to gain easy instrumental access for the debridement and resection of the anterior portion of the native lateral meniscus. Using shaver and punch the remnant meniscus is debrided to the level of the meniscal rim.

A modified ACL aiming device, with a low profile tip, is inserted through the medial portal and positioned at the anatomical posterior horn of the lateral meniscus just posterior to the ACL (Fig. 11).

**Figure 11:** A suture passer (AcupassAp) is introduced twice from outside-in, just anterior to the LCL and the PT, superior and inferior of the native meniscal rim (NMR)



A guide pin is drilled first and subsequently overdrilled by a 4.5 mm cannulated drill. A double loop metal wire is introduced through the tunnel from outside-in and picked up intra-

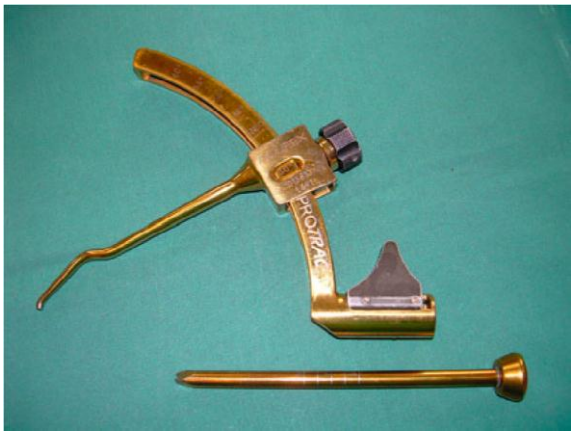


**Figure 12:** Modified ACL aiming device, with low profile tip. This device is positioned at the anatomical posterior horn of the lateral meniscus, just posterior to the ACL

articularly with an arthroscopical grasper and pulled out through the lateral portal. Subsequently, a suture passer (Acupass, Smith and Nephew, Memphis, Tennessee, USA) is introduced twice from outside-in just anterior to the lateral collateral ligament and the popliteus tendon into the joint: one just below and the second above the native meniscal rim (Fig. 12).

The looped wires are picked up and pulled out again through the lateral portal. Next, the posterior horn pull suture and the posterolateral pull suture are pulled through using the double looped metal wire and the double looped suture pass wire. The prepared lateral allograft is subsequently introduced into the lateral compartment throughout an enlarged lateral portal by pulling progressively on the posterolateral pull suture and the posterior horn pull suture. Care should be taken that the graft does not flip upon introduction and that pull wires do not intertwine. Risk for intertwining wires is greatly reduced by using a double loop metal wire for the posterior horn.

The posterior horn is now positioned correctly. Its position can be slightly modified more towards the posterolateral corner or more towards the posterior horn by pulling more on the posterolateral or posterior horn traction wire. One or two all-inside meniscal fixation devices (Fastfix, Smith and Nephew, Memphis, Tennessee, USA) are used to fix the allograft to the meniscal rim. Fixation should be started in the posterolateral corner. Subsequently inside out

horizontal Ethibond 2/0 sutures are used for fixing the body of the allograft. The anterior horn is fixed using outside in PDS or Ethibond 2/0 sutures.

Prior to making the sutures knots, the anterior horn is introduced into the knee joint and the anatomical insertion site is identified and prepared is a same manner as for the posterior tunnel. If necessary, its position can be slightly adapted to the graft position. Similar to the procedure of the posterior horn, the anterior tunnel is prepared and the traction suture is pulled through.

First, the meniscal inside out sutures are knotted. Subsequently, the anterior and posterior horn traction sutures are knotted to each other over a bone bridge on the anteromedial side of the tibia. This procedure reduces the possibly stretched capsule and native meniscal rim tied to the meniscal allograft, by pulling on the anterior and posterior horn by a transosseus suture fixation.

### 4.2.2 Arthroscopically Assisted Medial Meniscal Allograft Transplantation

A similar procedure as for the lateral allograft transplantation is performed for the medial allograft transplantation. However, some steps are different and will be highlighted in this section.

Additional to the classic anteromedial and anterolateral portal, a posteromedial portal should be used to identify the original posterior horn attachments of the native meniscus (Fig. 4.5). Using the same drill guide, the transosseus tunnels can be prepared. These tunnels should be prepared starting on the anterolateral side of the tibia. This direction is more in line with the forces on the traction sutures.

A posteromedial traction suture is used, as in accordance to the lateral allograft. On the medial side, however, we lack a clear anatomical landmark such as the popliteal hiatus on the lateral side.

The anterior horn of the native medial meniscus may in some cases be very anterior on the tibial plateau resulting in a very short transosseus anterior tunnel.

#### 4.2.2.1 Special Note on Soft Tissue Versus Bone Block Fixation [3–7]

Biomechanical cadaver studies have shown the superiority of a bony fixation over a soft tissue fixation technique, although a recent cadaver study showed comparable results. Bony fixation however, has also been shown to be associated with increased risk for cartilage lesions if implanted incorrectly and an increased

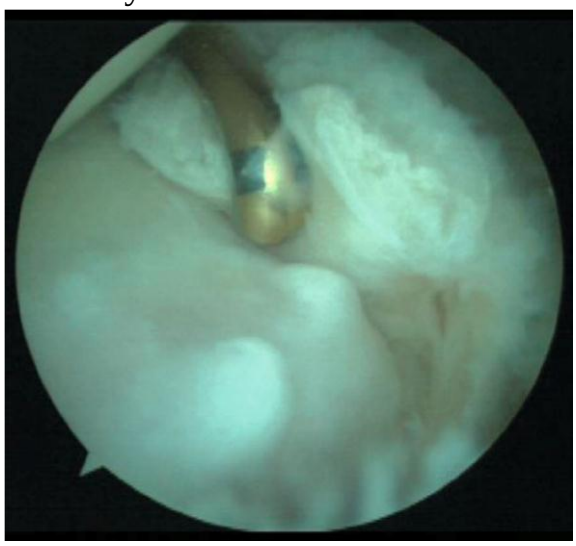


**Figure 13:** Arthroscopical view of the posteromedial portal used in arthroscopically assisted medial meniscal allograft transplantation.

The custum ACL guide in introduced through the intercondylar notch on the anatomical posterior horn insertion of the native medial meniscus immunological potential due to the presence of allogeneic bone. It is the authors experience that perfect allograft size matching is essential if bony fixation is to be used. A malpositioned bone block or plugs can inflict damages to the overlying cartilage. Too small a graft will result in a need to overtension the inside out sutures and possible failure of the soft tissue fixation. Therefore, limited oversizing of the graft is commonly advocated using bone plugs or blocks. Separate bone plugs have the potential advantage that the implantation can be somewhat more variable compared to a single bone block. In addition, on the lateral side a straight bone block sometimes induces the need to sacrifice some posterolateral fibers of the ACL.

Today, clinical and/or radiological differences have not been shown between soft tissue or bone block fixation.

### 4.2.3 Rehabilitation

Rehabilitation is initially focused on providing mobility to the joint without endangering ingrowth and healing of the graft. Therefore, 3 weeks of non-weightbearing are prescribed followed by 3 weeks of partial weight bearing (50 % of body weight). Progression to full weight bearing is allowed from week 6 on to week 10 postoperatively. The use of a knee brace is not strictly necessary and depends on the morphology and profile of the patient. For the same reasons, range of motion is limited during the first 2 weeks from 0 to 30, to increase by 30 each 2 weeks.

Isometric muscle tonification and co-contraction exercises are prescribed from day 1 post-surgery on. Straight leg raise however, is prohibited during the first 3 weeks. Proprioception training is started after week 3.

Swimming is allowed after week 6, biking after week 12 and running is progressively promoted starting at week 20.

## 4.3 Conclusion

In conclusion, ample evidence has been presented to support meniscus allograft transplantation in meniscectomized painful knees, with observance of the proper indications. Significant relief of pain and improvement in function have been achieved in a high percentage of patients. These improvements appear to be longlasting in 70 % of patients. Based on plain radiology and MRI, a subset of patients does not show further cartilage degeneration, indicating a potential chondro-protective effect. The lack of a conservatively treated control group is considered a fundamental flaw in the reported studies, making it difficult to establish the true chondro-protective effect of this type of treatment. Based on the presented results, meniscus allograft transplantation should no longer be considered experimental surgery for the meniscectomized painful knee (Table 4.1).

**Table 1:** International cartilage repair society cartilage lesion evaluation system

| | |
|---|---|
| **Grade 0** | Normal |
| **Grade 1** | Superficial lesions, softening, fissures or cracks |
| **Grade 2** | Lesions, erosion or ulceration of less than 50 % |
| **Grade 3** | Partial-thickness defect of more than 50 %, but less than 100 % |
| **Grade 4** | Ulceration and bone exposure |

### 4.4 Arthroscopic Technique with Bone Plugs

The key objective of the AMT is the alleviation of knee pain and an improvement in knee function for patients that have been submitted to meniscectomy. The correct anatomic positioning and stable fixation of the graft are the main technical targets. Although it may be easier to secure the graft by managing soft tissue alone, cadaver model research indicates superior transmission of load occurs when the meniscal horns of the graft are fixed to the tibia [7].

Bony fixation can be achieved with bone plugs attached to the anterior and posterior horns or simply a bone bridge. The former allows a less invasive technique and might preserve the tibial eminence. There is great variability in medial meniscus anterior horn insertion types and these variants must be respected when replacing the original meniscus [8]. This can be better achieved with bone tunnels but not with the use of a bone bridge. However, it is technically highly demanding due to the fact that minimal misplacement of the tibial tunnels may lead to improper functioning of the meniscal graft [9]. The bone bridge technique better preserves the native distance between horns and eliminates the risk of their incorrect placement. It is particularly useful in lateral meniscus transplantation as the insertions of the lateral meniscus are quite close and there is less variability.

However, it is a more invasive technique because it affects tibial eminence integrity and resects more bone.

While medial meniscus transplantation is more commonly performed with bone plugs, most authors advocate performing AMT in the lateral meniscus with the bone bridge technique. It is more appropriate as the distance between the horns of the lateral meniscus is typically less than 1 cm. Therefore, tibial tunnel collision and a consequent compromised

fixation of the horns might result if a bone-plug technique is used. The medial meniscus can also be transplanted with a bone bridge technique, but this requires careful placement so as not to alter the ACL tibial insertion. Furthermore, interference between bone trough and tibial tunnel may occur if an ACL reconstruction is to be associated at the same time.

The authors advocate the use of bone plugs in the medial meniscus transplantation and bone bridge for the lateral one.

### 4.4.1 Patient Positioning

A thigh tourniquet, inflated after the sterile field is prepared, is recommended. Alternatively, the use of a pump is also a good option as it keeps the joint clean allowing for a good vision without time limitation. Positioning depends mainly of surgeon's experience and comfort. Placing the patient supine was found to be easier for the authors. In the case of a medial AMT, both legs are left hanging free at 908 flexion. The use of a thigh lateral post permits applying valgus stress to open-up the medial compartment.If a lateral AMT is to bedone, the contralateral limb is placed in extension. It allows for the figure-of-four-position without the help of an assistant.

### 4.4.2 Graft Preparation

Medial AMT: After thawing in saline solution with antibiotic at room temperature, the residual synovial tissue from the graft is dissected at the meniscosinovial junction in order to facilitate graft introduction into the joint and suture technique.

A 1.0 mm Kirschner wire is drilled through the centre of the horn attachments prior to bone plug preparation. The hole will be used to pass the traction sutures, and placing first the kirschner wire will facilitate harvesting the plug without the hole collapsing. Bone plugs of 5–6 mm of diameter and 8–10 mm of height, including the anatomic meniscal attachments to the tibia, are then prepared. Both horns are sutured in a whipstitch manner and the suture also includes the bone plugs (through the previously drilled hole) thus making the graft insertion into the joint as well as accommodation of the bone plugs in the prepared bone tunnels easier (Fig. 14 a and b).

The upper side of the meniscus as well as the union between the middle and posterior thirds are marked with a skin marker. This will help in avoiding improper placement of the graft

during insertion. A third traction suture is placed at the junction between the posterior horn and the body of the meniscus where the pencil mark had been made. This will greatly help in placing the posterior horn of the prepared graft into the posterior aspect of the joint.

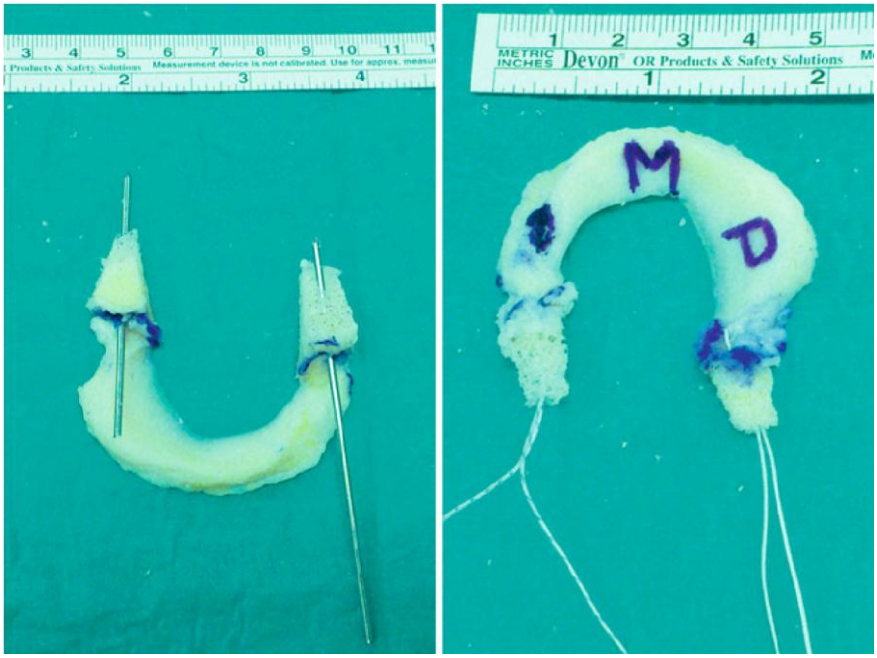



**Figure 14: Medial meniscal graft preparation. Note the k-wires passing through the bone plugs**

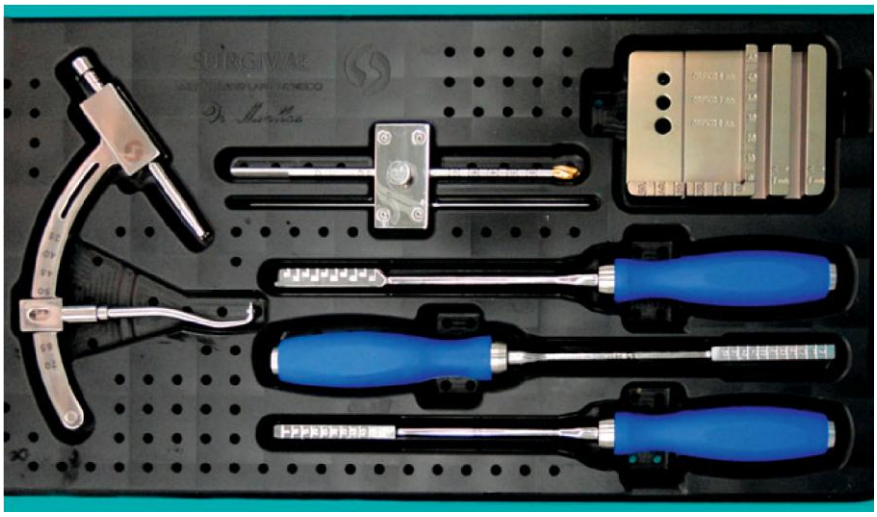


**Figure 15:** Surgical meniscal transplant set of instruments

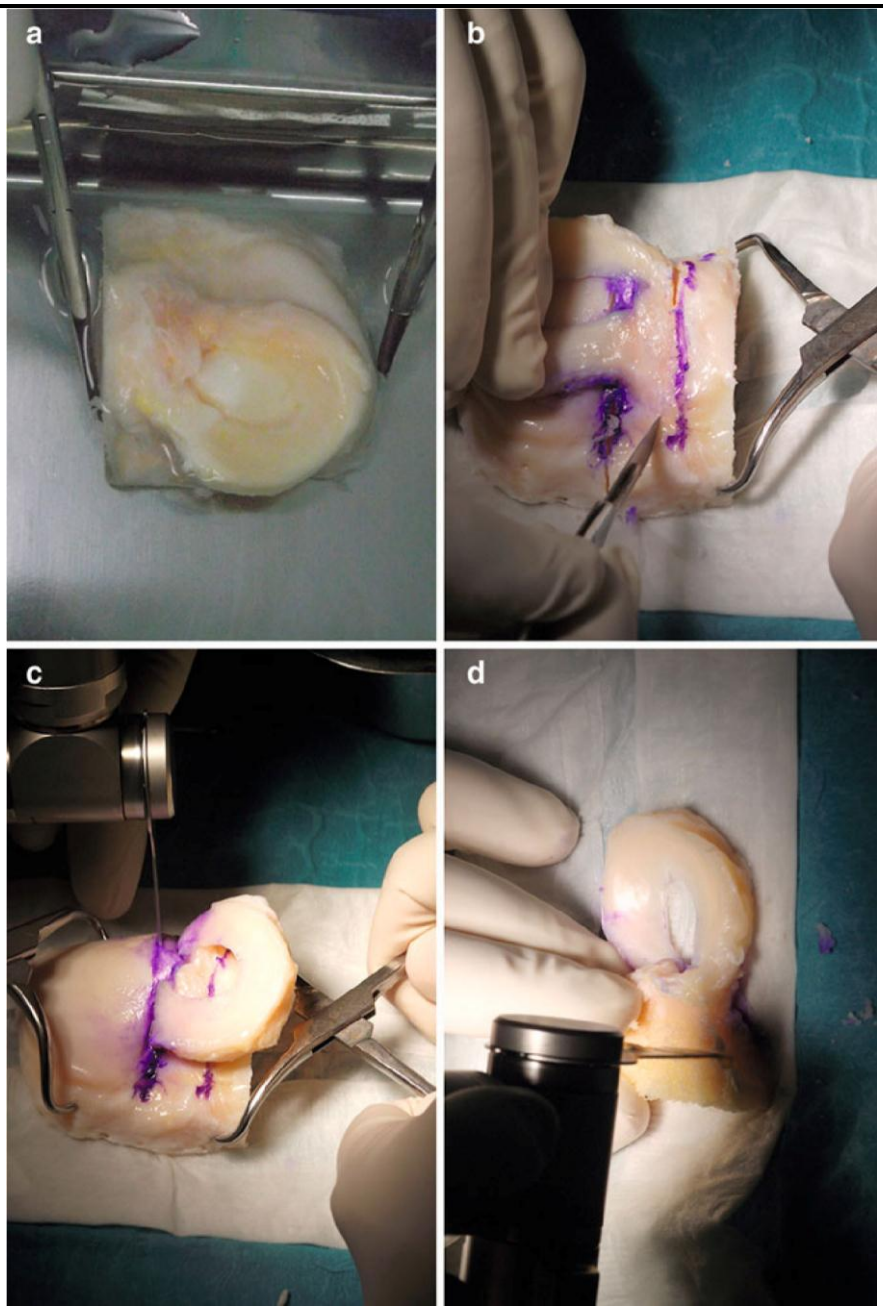



**Figure 16:** the preparation of a lateral meniscus graft for the bridge and slot technique

Once the AMT is harvested, it is wrapped with a wet gauze soak in a saline solution with antibiotic until introduced into the receptor knee.

Lateral AMT: After thawing and dissecting any residual tissue, the hemiplateau with its meniscus on top is brought to the work station (Meniscal Transplantion Set. Surgival. Paterna. Spain) (Fig. 4.7). A bone bridge from anterior to posterior horn of 7–8 mm width and 10 mm high is drawn with a pen and harvested with the aid of a small saw and a chisel (Fig. 4.8a, b, c, d). Since the bone bridge gives optimal stability, no predrilled tibial tunnel or additional traction sutures on the bone block are needed (Fig. 4.9).

A traction suture at the middle and posterior thirds of the graft and upper side marks will be prepared as described for the medial allograft. Once harvested, the graft is also embedded in a gauze soak in saline solution with antibiotic until introduced into the receptor knee.




**Figure 17:** The lateral meniscus graft once prepared and conveniently marked and sized utilizing a metal cutting block

### 4.4.3 Arthroscopic Procedure

A routine diagnostic arthroscopy is done through a standard anterolateral viewing portal. Medial portal and additional accessory portals are established depending on the compartment to be transplanted. The remaining meniscus is debrided to get a stable rim and guarantee a good blood supply. It is important not to eliminate the entire meniscal rim as it may help the suturing and limit later allograft extrusion by maintaining meniscus hoop stress. For that purpose, the authors recommend limiting mechanical debridement by using high frequency or radiofrequency trephination. Radiofrequency creates an area of synovial necrosis adjacent to the graft that is promptly substituted by a newly formed and more vascular synovial

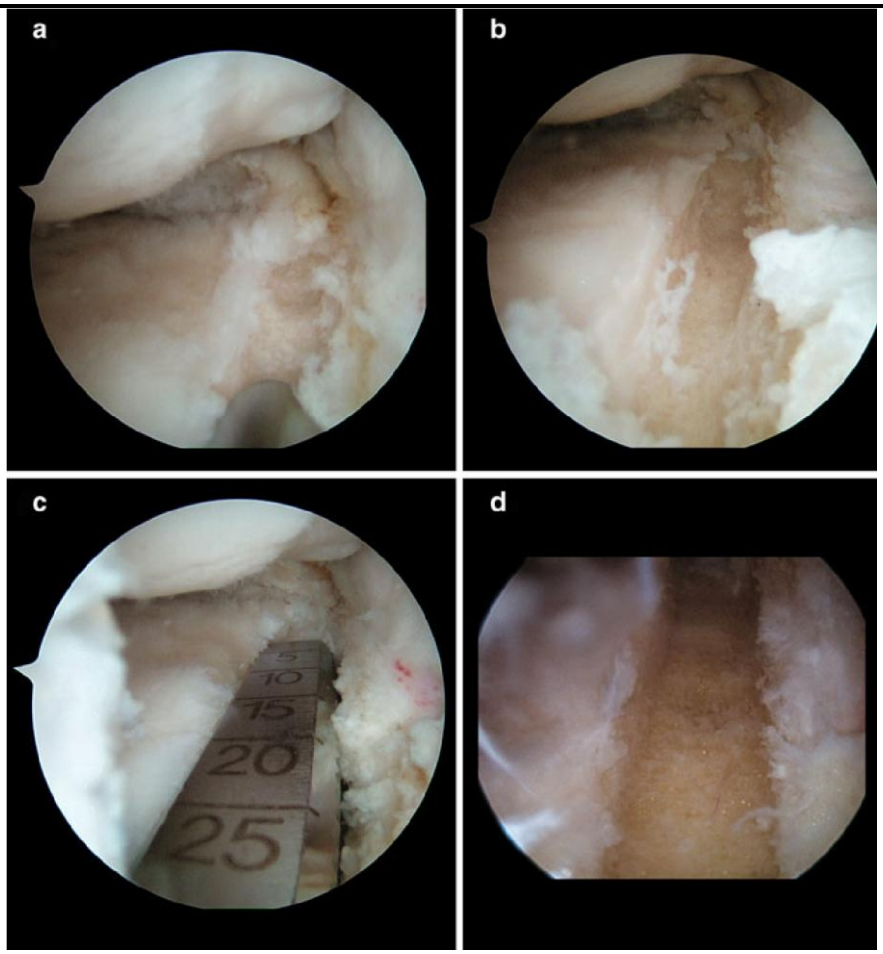



**Figure 18:** Arthroscopic view of the lateral compartment. Using a burr a followed by a drill, b and a set of rasps, c a completely quadrangle trough, d is created

layer that invades the allograft as a wave and retires over time thus creating an appropriate nutritional supply to the graft [10, 11].

A prominent tibial spine might prevent the correct visualization of the medial meniscus posterior horn. Under that circumstance, the tibial spine can be flattened with a burr, thus leaving room enough to introduce the scope or a tibial guide [12].

### 4.4.4 Bone Fixation

If a bone plug technique is to be used, exact positioning of the tibial tunnels for both meniscal horns is mandatory. As well described by Kohn and Moreno, they must be placed at the anatomical insertion sites [13]. The tibial tunnels are drilled with the help of a standard or modified ACL tibial guide. The traction suture is placed at the union of the middle and posterior thirds of the remaining meniscus using an outside-in technique with two 18-gauge spinal needles. This suture is first retrieved from the posteromedial corner and will help with

graft introduction into the joint and the posterior accommodation of its posterior horn. Meniscal horn sutures are passed through the corresponding tibial bone tunnels with the help of a suture passer. Then, the graft must be placed in its bed simply by enlarging the portal (minarthrotomy) and pulling the sutures. These maneuvers are important to making introduction of the graft easier. Traction from both meniscal horns and from the posteromedial traction suture will help to firmly attach the AMT in its



**Figure 19:** The right knee in a figure of four position with a miniarthrotomy and a traction suture placed in the posterolateral corner to facilitate the introduction of the graft

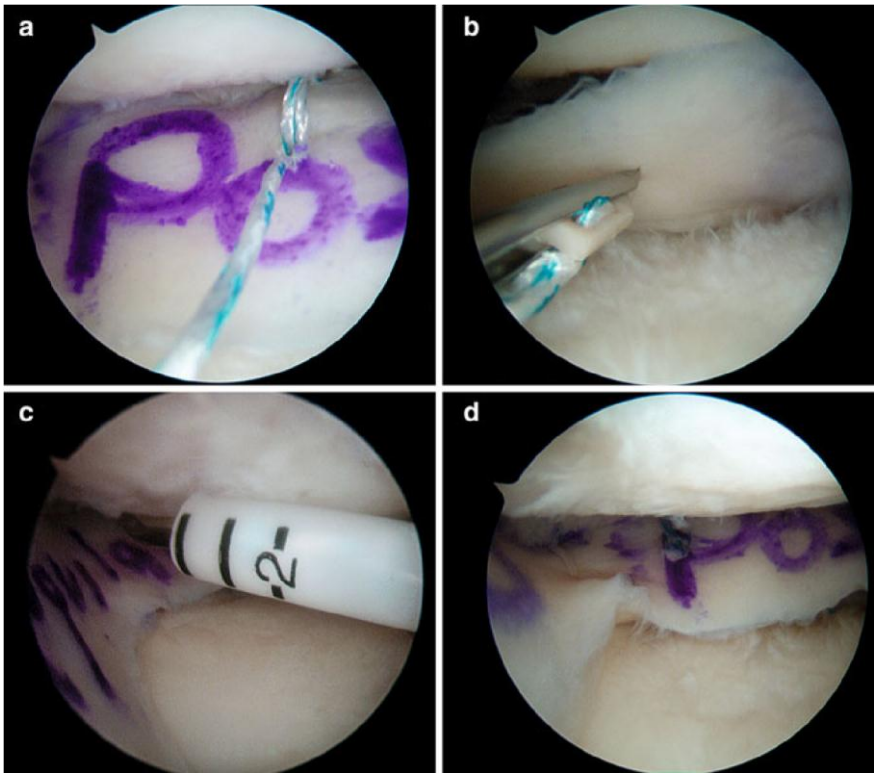



**Figure 20:** All-inside suture combining vertical and horizontal mattress sutures alternatively placed in the upper and lower sides of a lateral meniscus graft

former place. Bone plugs are secured by tying the sutures to each other on the tibial cortex at the end of the procedure.

The bone bridge procedure requires the creation of a trough in the tibial plateau using the bridge-in-slot technique [14]. In this technique, a guide pin connecting the anterior and posterior horns is followed by a drill and finally shaped with a 7 or 8 mm width box cutter to simply create the trough (Fig. 4.10). The same width and length matched size must be obtained with the graft. The authors prefer to create the trough progressively by using a burr followed by a drill and a set of rasps. All these instruments are brought into the joint creating a lateral or medial portal just in line with the desired position of the planned trough. The so-called keyhole technique, which creates the cross-section of the bridge like a keyhole, can optionally be used. The graft must be placed in its bed simply by enlarging the portal some 3–4 cm (minarthrotomy) and sliding the bone block (Fig. 4.11). As already mentioned, the traction suture from the posterolateral corner will help to put the AMT in its place. The bone bar can be fixed with interference screws or left alone, as the authors do, assuming that the bar is kept in place by the joint congruence.

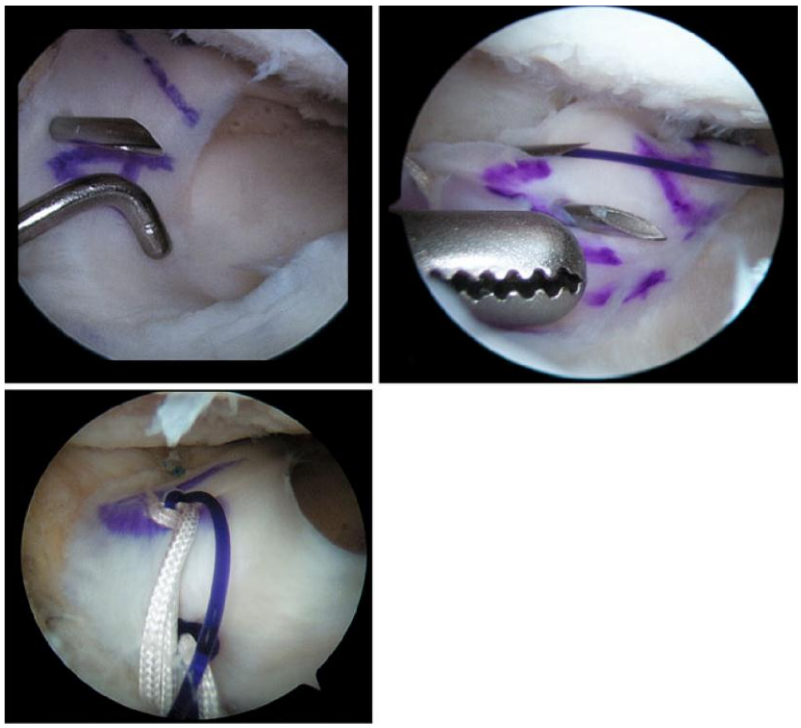


**Figure 21:** Outside-in suturing of the anterior third of the graft

Finally, all-inside (FasT-Fix™ Suture System. Smith & Nephew, Inc., Andover, MA 01810, USA) or inside-out suturing, depending on the preferences of the surgeon, is

performed at the posterior horn and body of the meniscus allograft (Fig. 4.12). If an inside-out suture technique is used, and additional posteromedial or posterolateral portal is necessary to retrieve sutures in a safe manner. The anterior horn can be better fixed with an outside-in technique using a couple of 18gauge spinal needles (Fig. 4.13).

An intra-articular drain can optionally be used. Nevertheless, it is the authors' opinion that some residual blood in the joint might enhance the meniscal healing process. The lower limb is finally placed in an immobilizer with a simple dressing to make it easy to apply an ice-pack in the postoperative period.

# RESULTS AND INDICATIONS

5.1 Indications and Contraindications

### 5.1.1 Indications

According to current recommendations, meniscal allograft transplantation is indicated in three specific clinical settings:

1. Young patients with a history of meniscectomy who have pain localized to the meniscus-deficient compartment, a stable knee joint, no malalignment, and articular cartilage with only minor evidence of osteochondral degenerative changes [no more than grade 3 according to the International Cartilage Repair Society (ICRS) classification system (Table 5.1)], are considered ideal candidates for this procedure. Some studies [1–6] have shown that meniscal allografts can survive in an osteoarthritic joint (Outerbridge grade 3–4), with significant improvement in pain and function. Because of the more rapid deterioration in the lateral compartment [7], a relatively common indication for meniscal transplantation would be a symptomatic, meniscus-deficient, lateral compartment.
2. Anterior cruciate ligament (ACL)-deficient patients who have had previous medial meniscectomy with concomitant ACL reconstruction and who might benefit from the increased stability afforded by a functional medial meniscus. It is the authors' conviction, that an ACL graft is significantly protected by the meniscus allograft as much as the meniscus is protected by an ACL graft.

**Table 2** International cartilage repair society cartilage lesion evaluation system

| | |
|---|---|
| Grade 0 | Normal |
| Grade 1 | Superficial lesions, softening, fissures or cracks |
| Grade 2 | Lesions, erosion or ulceration of less than 50 % |
| Grade 3 | Partial-thickness defect of more than 50 % but less than 100 % |
| Grade 4 | Ulceration and bone exposure |

3. In an effort to avert early joint degeneration, some also consider young, athletic patients who have had total meniscectomy, as candidates for meniscal transplantation prior to symptom onset [8]. However, the results obtained so far still preclude a return to high-impact sports.

### 5.1.2 Contraindications

Advanced chondral degeneration is considered a contraindication to meniscal allograft transplantation, although some studies suggest that cartilage degeneration is not a significant risk factor for failure [9]. In general, greater than grade 3 articular cartilage lesions according to the ICRS classification system should be of limited surface area and localized. Localized chondral defects may be treated concomitantly, as meniscus transplantation and cartilage repair or restoration may benefit each other in terms of healing and outcome [10]. Chondrocyte transplantation or osteochondral grafting procedures should be performed after completion of the meniscal transplantation in order to prevent accidental damage to the patch or graft during meniscal allograft insertion [11]. Radiographic evidence of significant osteophyte formation or femoral condyle flattening is associated with inferior postoperative results because these structural modifications alter the morphology of the femoral condyle [12]. Generally, patients over age 50 have excessive cartilage lesions and are suboptimal candidates.

Axial malalignment tends to exert abnormal pressure on the allograft leading to loosening, degeneration, and failure of the graft [12]. A corrective osteotomy should be considered in patients with more than two degrees of deviation toward the involved compartment, as compared with the mechanical axis of the contralateral limb. Varus or valgus deformity may be managed with either staged or concomitant high tibial or distal femoral osteotomy [11]. However, as in any situation in which procedures are combined, it is unclear which aspect of the procedure is implicated in symptom resolution, such as relief of pain [12].

Other contraindications to meniscal transplantation are obesity, skeletal immaturity, instability of the knee joint (which may be addressed in conjunction with

transplantation), synovial disease, inflammatory arthritis and previous joint infection, and obvious squaring of the femoral condyle.

### 5.2 Results

It is difficult to perform a meta-analysis of all the published results, because of the small populations studied and the differences in indications, contraindications, preservation techniques, preoperative Outerbridge grade, fixation techniques, surgical techniques, concomitant procedures, evaluation tools and rehabilitation protocols.

In this chapter, we will try to present outcome data based on a review of the literature. A total of 39 studies have been included, representing 1,226 meniscus allografts (626 medial vs. 446 lateral, 154 not specified) in 1,145 patients. The mean age at the time of surgery was 34.4 years. The mean follow-up was

5.5 years. Overall, 340 isolated allograft transplantations were analysed, 427 were associated with ACL reconstruction, 107 with a corrective osteotomy and 215 with other procedures. It was not specified whether the remaining 137 allografts were associated with other procedures. Concerning the surgical fixation technique, 631 allografts were fixed using bone blocks and 488 using a soft-tissue fixation technique. For 107 allografts the fixation method was not specified. In the next paragraphs, the outcome is reported independently of the aforementioned parameters.

Methods to evaluate the success or failure of meniscal transplantation range from subjective pain scale measurements and patient perceptions of function to objective measurements such as physical and radiological examinations, magnetic resonance imaging (MRI), and second-look arthroscopy.

#### 5.2.1 Subjective Assessment

All studies showed significant subjective improvement in pain scales and functional activity questionnaires. The data from most studies are summarized in Table 5.3. In general, isolated procedures and combined procedures tended to have similar outcomes. No differences were observed based on tissue preservation technique or fixation method. About 75–90 % of patients experienced fair to excellent results.

**Table 3:** **The difficulty realizing a meta analysis of all the published results, because of the small populations studied and the differences in indications, contraindications, preservation techniques, preoperative outerbridge grade, fixation techniques, surgical techniques, concomitant procedures, evaluation tools and rehabilitation protocolspreoperative outerbridge grade, fixation techniques, surgical techniques, concomitant procedures, evaluation tools**

| Nr | Authors | Year P | Year S | # grafts | M | L | # patients | Age | Time M-TX | Preservation | Rad? | Fix | FUT | Preop cart | # isolated | Concomm. procedures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Cameron and Saha. | 1997 | 1988–1994 | 67 | 37 | 30 | 63 | 41 | 16.7 | DF | Yes | S | 2.5 | 2–4 | 21 | 5ACL, 34OT, 7ACL+OT |
| 2. | Carter et al. | 1999 | NA | 46 | 39 | 7 | 46 | NA | NA | Cryo. | NA | B | 2.8 | NA | NA | 30ACL, 4OT, 1MCL |
| 3. | Garrett et al. | 1993 | NA | 43 | 34 | 8 | 43 | NA | NA | 16DF, 27Cryo. | NA | B | 4.5 | NA | 7 | 24ACL, 13OT, 11OAL |
| 4. | Goble et al. | 1999 | NA | 69 | 48 | 21 | 60 | NA | NA | Cryo. | NA | B | 2 | NA | NA | 28ACL |
| 5. | Groff et al. | 2001 | 1993–1998 | 16 | 0 | 16 | 16 | 27 | 8 | DF | No | B | 3.8 | 1–2 | 16 | None |
| 6. | Wirth et al. | 2002 | 1984–1986 | 22 | 22 | 0 | 22 | 29.6 | NA | 6DF, 16Lyo. | 6No, 16Yes | S | 3/14 | 1, 6 | 0 | 22ACL, 19MCL |
| 7. | Noyes et al. | 1995 | NA | 96 | 79 | 17 | 83 | NA | NA | DF | Yes | B | <2 | NA | 19 | 77ACL |
| 8. | | 2004 | 1995–2000 | 40 | 20 | 20 | 38 | 30 | NA | Cryo. | No | B | 3.3 | 3, 6 | NA | 7ACL, 1PCL, 1ACL+PCL, 1MCL, 16 OAU |
| 9. | Rath et al. | 2001 | 1991–1997 | 22 | 15 | 7 | 18 | 30 | 7.7 | Cryo. + DF | No | 1S, 21B | 4.5 | NA | 3 | 11ACL, 1TTT |
| 10. | Stollsteimer et al. | 2000 | 1991–1995 | 23 | 11 | 12 | 22 | 31 | 3.8 | Cryo. | No | B | 3.3 | COB: 5, 6 | 23 | None |
| 11. | Van Arkel et al. | 2000 | 1994–1995 | 19 | 6 | 13 | 16 | 40 | 16 | Cryo. | No | NA | 2.7 | NA | NA | NA |
| 12. | | 2002 | 1989–1999 | 63 | 23 | 40 | 57 | 39 | 16 | Cryo. | No | S | 5 | NA | 61 | 2ACL |
| 13. | Verdonk et al. | 2004 | NA | 27 | 0 | 27 | 27 | 33,9 | NA | V | No | S | 1 | NA | NA | NA |
| 14. | | 2005 | 1989–2001 | 100 | 39 | 61 | 96 | 35 | NA | V | No | S | 7.2 | 2.5 | 69 | 3ACL, 17OT, 3Mi, 4OPT |
| 15. | | 2006 | 1989–1993 | 39 | NA | NA | 38 | 35.4 | NA | V | No | S | 12.1 | 2.7 | NA | 3ACL, 12OT |

(continued)

### 5.2.2 Objective Clinical Scoring

#### 5.2.2.1 Physical Examination

Almost all studies reported equal or improved physical examination findings at follow-up with regard to range of motion, pain, effusion, stability, function tests or IKDC score. The data from most studies are summarized in Table 4.

**Table 4**: Summary of subjective assessment

| | | | |
|---|---|---|---|
| 1. | Cameron et al. | 1997 | 87 % good to excellent rate. (85 % after 3 years) Fulkerson (=modified Lysholm) functional knee score, Tegner score, Reduction in need of anti-inflammatory medication: SI |
| 2. | Carter et al. | 1999 | IKDC: SI |
| 3. | Goble et al. | 1999 | Quality of life (regarding pain at rest, during recreational activity and functional stability): SI |
| 4. | Greff et al. | 2001 | Lysholm score: 91 % fair to excellent ratio |
| | | | IKDC: 91 % nearly normal to normal |
| | | | All (100 %) were improved, 100 % satisfaction with the condition of their knee as a result of the surgery |
| | | | SF-36: 6 of 8 categories higher scoring than age and sex matched population |
| | | | KOS at FUT: ADLS: 79.3 SAS: 74.5 |
| | | | 41 % had pain with light sports activities |
| 5. | Wirth et al. | 2002 | Lysholm, Tegner (at 3y/ 14y FUT): SI (deep-frozen better than lyophilized, but both deterioration after 14y) (influenced by preoperative cartilage condition and instability) |
| 6. | Noyes et al. | 2004 | Perception of knee condition: 73 % good to normal. 89 % Improvement of knee function |
| | | | 76 % Participation in light low-impact sports |
| | | | Cincinnati score: SI |
| 7. | Heckmann et al. | 2006 | 94 % improvement of knee condition |
| | | | 77 % participation in light low-impact sports |
| 8. | Rath et al. | 2001 | SF-36 for bodily pain, role physical, physical functioning and social functioning: SI |
| | | | Mean IKDC functional score: 54 |
| 9. | Stollsteimer et al. | 2000 | Improvement of preoperative pain in 82 %. Tegner score, IKDC score, Lysholm: SI |
| | | | Articular cartilage changes preoperatively and preoperatively higher IKDC score had significant effect on overall patient outcome score |
| 10. | Van Arkel et al. | 2000 | KASS: 84 % successful result |
| | | | Modified Lysholm: 84 % fair to excellent |
| | | | Tegner: SI |
| 11. | Van Arkel et al. | 2002 | 77 % success |
| | | | Lysholm: SI |
| | | | 91 % improvement of pain |

| | | | |
|---|---|---|---|
| 12. | Verdonk et al. | 2005 | Relieve in pain and improved function at 10 years in 70 % |
| 13. | Verdonk et al. | 2006 | 90 % were satisfied with the operation and would do it again |
| 14. | Cole et al. | 2006 | 75 % completely/mostly satisfied with procedure: 68 % medial, 93 % lateral, 81 % isolated, 74 % "combined with other procedure" subgroup |
| | | | Lysholm, Tegner, Noyes, IKDC, KOOS pain, symptom, ADL and sports, SF-12 PCS score, VAS pain and overall knee condition: SI |
| | | | 86 % would have surgery again: 84 % medial subgroup, 93 % lateral subgroup, 86 % isolated and 84 % in combined subgroup |
| 15. | Rodeo et al. | 1998 | 88 % of bone plugs + 47 % soft tissue fixated transplantations were rated as GOOD OR MODERATE. |
| | | | Lysholm, IKDC, VAS: pain + function: SI |
| 16. | Rodeo et al. | 2000 | 58 % clinical successful |
| 17. | Del Pizzo et al. | 1996 | 89 % were satisfied with procedure |
| | | | 95 % Could perform occasional strenuous activities; none continuous |
| | | | They all returned to their previous activity level |
| | | | Pain was improved in all patients |
| 18. | Yoldas et al. | 2003 | 97 % somewhat to greatly improved |
| | | | IKDC: 97 % nearly normal to normal |
| | | | Lysholm: 68 % good to excellent ratio |
| | | | SF-36: in 7 of 8 categories better than age-and sex matched population |
| 19. | Ryu et al. | | IKDC activity: 68 % nearly normal to normal. VAS, Lysholm II, Tegner score: SI |
| | | | Outerbridge grade had significant impact on outcome. 83 % overall satisfaction |
| 20. | Hommen et al. | | Lysholm, Pain, IKDC, Tegner, SF-12 score: SI. 80 % had improvement |
| 21. | L'Insalata | 1997 | 88 % improvement |
| 22. | Harner | 1993 | 100 % improvement |
| 23. | Felix and Paulos | 2002 | VAS function: SI |
| 24. | Vaquero et al. | 2004 | VAS pain: SI |
| | | | IKDC: 77 % nearly normal to normal |

| | | | |
|---|---|---|---|
| 25. | Sekiya | 2006 | 96 % had improvement of overall function and activity level |
| | | | SF-36: PCS and MCS: higher than age- and sex- matched scores from US population |
| | | | IKDC: 80 % nearly normal to normal |
| 26. | Sekiya | 2003 | IKDC: 86 % nearly normal to normal (patients with primary ACL reconstruction > revision ACL reconstruction) |
| | | | SF-36 PCS and MCS: higher than age- and sex-matched population |
| | | | KOS ADLS: 89.7 at FUT, SAS: 81 at FUT |
| | | | Lysholm: 88.4 at FUT |
| | | | 93 % were somewhat to greatly improved |
| 27. | Stone | 2006 | Pain score: SI of 21 %. Self-reported activity scores: SI of 10 %. Self-reported functioning scores: SI of 19 % |
| | | | IKDC, WOMAC, Tegner: SI |
| 28. | Fukushima | 2004 | 95 % satisfied |
| | | | 95 % had disappearance of joint line pain. 72 % had disappearance of swelling |
| 29. | Rankin | 2006 | Cincinnati Knee Rating System (pain, patient perception, squatting and run): SI |
| 30. | Bhosale et al. | 2007 | 75 % had improvement of function and pain relief at FUT |
| | | | Lysholm score: SI |
| | | | 75 % was satisfied with operation |
| 31. | Graf et al. | 2004 | 10ö % would recommend procedure to a friend |
| | | | 88 % continue to actively participate in recreational sports |
| | | | IKDC: 50 % nearly normal to normal |
| 32. | Rueff et al. | 2006 | Modified Lysholm, IKDC score, VAS pain: SI |
| | | | 94 % considered their surgery to be a success and would undergo the procedure again given the same situation |
| 33. | Von Lewinski et al. | 2007 | KOOS at FUT: mean value of 74 points |
| | | | Lysholm score: mean value of 74 points at FUT |
| 34. | Dienst and Kohn | | Joint function and pain reduction: SI |

*SI* significant improvement from preoperatively to follow-up, *FUT* follow-up time

**Table 5: objective clinical scoring system**

| Nr | Authors | Years | Clinical examination scoring |
|---|---|---|---|
| 1. | Groff et al. | 2001 | 91 % no effusion |
| | | | mean passive flexion: 129°, NS loss of motion |
| | | | side-to side difference in laxity: NS |
| | | | 0 % had joint line tenderness |
| | | | Single leg vertical jump 93 % in comparison to noninvolved limp |
| | | | Hop test: 95 % in comparison to noninvolved limp |
| 2. | Noyes and Barber-Westin | 2004 | 3 % had signs of a meniscal tear |
| | | | 97 % had no tibiofemoral joint-line pain |
| | | | 89 % had a no effusion |
| | | | 95 % normal antero-posterior stability |
| 3. | Heckmann et al. | 2006 | 74 % had disappearance of pain at tibiofemoral compartment |
| 4. | Stollsteimer et al. | 2000 | No patient had loss of motion |
| 5. | Van Arkel et al. | 2000 | 20 % of patients had improvement in stability |
| 6. | | 2002 | 20 % of patients had improvement in stability: SI |
| 7. | Verdonk et al. | 2005 | HSS pain and function: SI |
| 8. | | 2006 | HSS pain score: SI (MMT + HTO group > MMT group) |
| | | | HSS walking score: SI |
| | | | HSS stair climbing ability score: SI |
| 9. | Cole et al. | 2006 | IKDC knee examination: 90 % nearly normal to normal at FUT |
| 10. | Rodeo et al. | 2001 | |
| 11. | Yoldas et al. | 2003 | 81 % no effusion |
| | | | 100 % no joint line tenderness |
| | | | Average flexion at FUT = 129° Average extension at FUT: 2° |
| | | | 97 % had negative to 1 + Lachmann and pivot shift test at FUT |
| | | | vertic jump + hop tests: 85 % compared to contralateral knee |
| | | | KT 1000: average side to side difference of 2 mm translation |
| 12. | Hommen et al. | 2007 | IKDC: 40 % nearly normal to normal |

| Nr | Authors | Years | Clinical examination scoring |
|---|---|---|---|
| 13. | Sekiya et al. | 2006 | IKDC ROM: 31 % nearly normal to normal |
| | | | IKDC ligament examination: 94 % nearly normal to normal |
| | | | Average loss of flexion compared with non-involved knee: 10°; extension: 4° |
| | | | Bony fixation has significant better motion than suture Group |
| | | | Single leg hop and vertical jump: 91 % and 85 % of the non-involved leg |
| 14. | Sekiya et al. | 2003 | IKDC laxity: 92 % nearly normal to normal |
| | | | KT-1000: average increase in AP translation of 1.5 mm to contralateral knee |
| | | | IKDC ROM: 67 % nearly normal to normal |
| | | | Single leg hop and vertical jump: 83 % and 82 % of the non-involved leg |
| 15. | Fukushima et al. | 2004 | Average ROM + 7° at FUT |
| 16. | Graf et al. | 2004 | IKDC ROM: 100 % nearly normal to normal |
| | | | IKDC ligament examination: 75 % nearly normal to normal |
| | | | IKDC compartmental findings: 63 % nearly normal to normal |
| | | | IKDC functional test: 75 % nearly normal to normal |
| | | | Average loss of motion: 2.3°, average loss of flexion: 4.9° |
| 17. | Von Lewinski et al. | 2007 | IKDC overall: 40 % nearly normal to normal |

*FUT* follow-up time, *NS* non-significant

### 5.2.2.2 Radiological Examination

Joint space narrowing indicating cartilage degeneration was observed in a number of patients and tended to increase with a longer duration of follow-up. However, a significant number of patients showed no signs of progression. Based on these limited data, meniscus allograft transplantation is believed to have a chondroprotective effect in 30–40 % of patients. However, the majority of patients are on the ‘slippery slope of osteoarthritis’ and will further deteriorate over time. It is unknown whether allograft transplantation delays the natural course of osteoarthritis after meniscectomy. Future

research is mandatory to determine the chondroprotective power of meniscus allograft transplantation.

#### 5.2.2.3 MRI Analysis

Routine preoperative MRI may be useful for documentation of articular cartilage defects, subchondral bone status, and any remaining meniscus. Potter et al. [13] demonstrated that MRI provides accurate assessment of meniscal position, horn and capsular attachments, meniscal degeneration and adjacent articular cartilage. It correlates well with arthroscopic evaluation of the transplant and is noninvasive. The development of dynamic and weightbearing MRI shows promise for its use in meniscal transplant analysis (Table 5.6).

**Table 6: Radiological evaluation**

| Nr. | Author | Years | FUT (years) | Joint-space narrowing (mean) | Fairbank (average) | IKDC radiological evaluation |
|---|---|---|---|---|---|---|
| 1. | Carter et al. | 1999 | 2.9 | Progression in 4 % | NA | NA |
| 2. | Garrett et al. | 1993 | 2–3.7 | NS | NA | NA |
| 3. | Groff et al. | 2001 | 3.8 | NS | NA | NA |
| 4. | Wirth et al. | 2002 | 3 and 14 | Increased degenerative changes in all patients | Preoperatively: 0.7. At 3 years: 1.4. At 14 years: 2.5 | NA |
| 5. | Noyes et al. | 2004 | 3.3 | Progression in 8 % | NA | NA |
| 6. | Rath et al. | 2001 | 4.5 | NS | NA | NA |
| 7. | Stollsteimer et al. | 2000 | 3.3 | 0.88 mm | NA | NA |
| 8. | Verdonk et al. | 2006 | 12.1 | Progression in 48 % | Stable in 28 % | NA |
| 9. | Yoldas et al. | 2003 | 2.9 | NS increase in joint-space width! | NA | NA |
| 10. | Ryu et al. | 2002 | 2.8 | No change in 63 %, 1–3 mm in 25 %, >3 mm in 12.5 % | NA | NA |
| 11. | Hommen et al. | 2007 | 11.7 | Progression in 67 %. Mean: 1.15 mm | Progression in 80 %. Mean of 0.8 mm of progression from 0.5 to 1.3 | NA |
| 12. | Vaquero et al. | 2003 | >1 | NS | NA | NA |
| 13. | Sekiya et al. | 2003 | 2.8 | NS | NA | 48 % nearly normal to normal |

(continued)

| Nr. | Author | Years | FUT (years) | Joint-space narrowing (mean) | Fairbank (average) | IKDC radiological evaluation |
|---|---|---|---|---|---|---|
| 14. | | 2006 | 3.3 | NS | NA | 50 % nearly normal to normal |
| 15. | Graf et al. | 2004 | 9.7 | Progression in 75 %. Mean of 0,38 mm | NA | 12.5 % nearly normal to normal (=same as preoperatively) |
| 16. | Von Lewinski et al. | 2007 | 20 | Kellgren-Lawrence score: mean of 2.4 | NA | 40 % nearly normal to normal |
| 17. | Barrett et al. | 1996 | 5 | NS | NA | NA |

*FUT* follow-up time, *NS* not significant
Fairbank changes
Average = zo berekend
*Kellgren-Lawrence radiographic grading scale of osteoarthritis of the tibiofemoral joint* 0: No radiographic findings of osteoarthritis, 1: Minute osteophytes of doubtful clinical significance, 2: Definite osteophytes with unimpaired joint space, 3: Definite osteophytes with moderate joint space narrowing, 4: Definite osteophytes with severe joint space narrowing and subchondral sclerosis

In order to overcome the observed discrepancy between clinical outcome and meniscal allograft status and to assess any progression of degenerative articular changes after this type of surgery, objective outcome measures such as MRI have to be included in outcome studies. Only limited literature data are available reporting that meniscal allografting halts or slows down further degeneration [14– 17]. In one recent long-term study progression of cartilage degeneration according to MRI and radiological criteria was halted in 35 % of patients, indicating a potential chondroprotective effect [18]. A recent controlled large animal study also confirmed this chondroprotective effect [19]. These data could support the use of prophylactic meniscal transplantation in meniscectomized patients without clinical symptoms, thus potentially limiting secondary cartilage degeneration. Further prospective comparative studies are mandatory to test this hypothesis.

Using MRI, meniscal allograft extrusion has been described independent of the surgical fixation technique. In our experience, using soft-tissue fixation, extrusion is observed in the corpus and anterior horn of the lateral graft, while the posterior horn is most frequently within normal values [18]. This extrusion could reduce the functional surface of the graft and thus potentially also its biomechanical function. Biological reasons for the observed extrusion posttransplantation could include progressive stretch and failure of the circumferential collagen bundle due to insufficient repair potential or increased catabolism. Future research should focus on the biology involved in ongoing metabolic and cellular processes after transplantation.

Lyophilized allografts showed more shrinkage and degeneration, indicated by altered signal intensity, than did other grafts. Therefore, this preservation technique is no longer used. In the long term, all allograft types show some shrinkage. The exact meaning of the observed shrinkage has yet to be determined. Possible hypotheses are tissue loss due to mechanical wear or a biological process of contraction often observed in scar tissue formation and healing.

In general, healing of the allograft to the rim is observed in the vast majority of patients. The meniscus allograft signal is most frequently abnormal with a more greyish appearance. The authors believe that this change in signal reflects biological remodeling of the extracellular matrix of the allograft, rather than true degenerative changes.

#### 5.2.2.4 Second-Look Arthroscopy

Some authors have demonstrated that clinical evaluation only based on symptoms and physical examination does not allow reliable assessment of the status of the meniscus. Arthroscopic evaluation, however, should not be used as a routine postoperative evaluation tool. Most frequently, it is performed upon clinical suspicion of an intra-articular problem. In some cases, arthroscopic evaluation can be performed in association with another procedure around the knee (Table 5.7).

In general, and in accordance with the MRI evaluation, good healing of the allograft to the rim is observed in the vast majority of patients. Tearing and shrinkage can be present. The status of the allograft, however, correlates poorly with the clinical outcome.

### 5.3 Failures and Survival Analysis

In the literature, no consensus exists on the criteria for failure or success. A number of authors use the clinical outcome, while others propose more objective outcome parameters such as MRI or second-look arthroscopy. In general, using objective parameters, the clinical success rate is higher than estimated. In the majority of studies, a clinical success rate of 70 % and higher has been reported at the final follow-up. Because the success rate has a tendency to decrease over time, it would be preferable to use survivorship analysis rather than failure rate to describe the success of such a procedure. A survivorship is much more powerful to describe the results irrespective of the duration of follow-up. We all are aware that nothing ruins good results more than a long-term follow-up… (Table 5.8).

Based on the available survivorship data, a clinical survivorship of 70 % at 10 years can be anticipated for both medial and lateral allografts. Ligament instability, axial

malalignment and cartilage degeneration are considered by most authors to be associated with a higher failure rate and inferior results, although some authors have reported satisfactory results in degenerative knees.

### 5.4 Conclusion

In conclusion, ample evidence has been presented to support meniscus allograft transplantation in meniscectomized painful knees, with observance of the proper indications. Significant relief of pain and improvement in function have been achieved in a high percentage of patients. These improvements appear to be longlasting in 70 % of patients. Based on plain radiology and MRI, a subset of patients does not show further cartilage degeneration, indicating a potential chondroprotective effect. The lack of a conservatively treated control group is considered a fundamental flaw in the reported studies, making it difficult to establish the true chondroprotective effect of this type of treatment.

Based on the presented results, meniscus allograft transplantation should no longer be considered experimental surgery for the meniscectomized painful knee.

# COLLAGEN MENISCAL IMPLANT (CMI)

### 6.1.1 Introduction

The meniscus performs critical physiological as well as biomechanical functions within the knee. It distributes loads across adjacent articular cartilage thereby protecting the hyaline cartilage from wear. Meniscal tears are one of the most common injuries of this joint leading to the surgical excision of the injured tissue in most of the cases. However, it is well known since the pioneering works of King [1] and Fairbank [2] that the loss of meniscal tissue frequently leads to osteoarthritis and irreversible joint damage. The advent of arthroscopic partial meniscectomy contributed to improve these results. Nevertheless, the long-term follow-up still shows that a substantial number of patients suffered the effect of a lost meniscus [3, 4].

In an effort to keep the knee joint functional and pain free, a renewed interest in meniscal preservation techniques appeared in the last three decades. Due to the poor ability of prosthetic replacement to reproduce the meniscus behavior and the limited availability of allografts, tissue engineering techniques were developed for the same purpose. The Collagen Meniscus Implant (CMI. ReGen Biologics, Hackensack, New Jersey, USA) is a collagen based meniscus implant consisting in a resorbable scaffold designed to support ingrowths of new tissue to eventually regenerate the lost meniscus. It is a biologically resorbable implant with a spongy texture consisting of a highly purified type I collagen. The CMI was developed from bovine collagen in the early 90s in order to promote regeneration in segmental defects of meniscal tissue [5]. Stone et al. [6, 7], firstly demonstrated the ability of the implant to regenerate meniscal tissue in both dogs and humans.

To date, experimental and clinical experiences with the medial CMI have shown promising results [7–11] and a lateral implant has been developed and recently tested in several European centres.

The purpose of this chapter is to describe the CMI background and surgical technique along with some tricks and limitations gleaned from the author’s experience of 15 years

with its use that might help the reader to achieve the most successful outcome. The ten-year results of a medial CMI series are also presented.

### 6.1.2 Background

Collagen matrices, acting as templates for the growth of fibrous tissue, were developed in the early eighty's with different purposes [12–14]. Following the same investigational line, a resorbable collagen meniscus implant (CMI) was developed to support the regeneration of meniscal tissue. Experimental studies in a canine model showed that the scaffold was able to support substantial meniscal regeneration while slowly reabsorbed. In these studies, the regenerated neomeniscus had a histological and biochemical appearance that was similar to that of original canine meniscal fibrocartilage [5, 6]. Genovese et al. [15] have recently characterized the ultrastructure of the implant at a minimum of 6 moths after implantation. These biopsy findings demonstrate that host cells (likely derived from the adjacent synovium) migrate into the collagen meniscus scaffold, differentiate into fibroblast-like cells, and synthesize appropriate extracellular matrix.

### 6.1.3 The Implant

The CMI was conceived to conduct meniscal regeneration in the early 80s. It has physical size and shape approximating the original human meniscus. The implants are made of type I collagen fibres derived from bovine Achilles tendon. After the tendon tissue is trimmed and minced, the type I collagen fibres are purified by using various chemical treatments to remove non-collagenous proteins and lipids. Next, the purified collagen fibres are swelled in hyaluronic acid and chondroitin sulphate and then homogenized. The swollen collagen fibres plus the glycosaminoglycans are co-precipitated by the addition of ammonium hydroxide. The precipitated fibres are dehydrated, manually oriented in a mould, lyophilized, and chemically cross-linked. Finally, terminal sterilization is performed by c irradiation [5].

### 6.1.4 Patient Selection Criteria

The CMI is not a prosthetic device. It is intended to provide a resorbable scaffold that will be replaced by the patient's own tissue over time. Unlike meniscus allografts that

are used to replace the entire meniscus, the CMI is designed to solely replace the damaged or missing portion of the meniscus. The ideal patient must have an intact meniscal rim and anterior and posterior horns for a good attachment and stability of the scaffold. Otherwise, would not accomplish the hoop stress law and the final construct will be extruded from the tibial plateau, resulting in a non-effective procedure. In addition, the surgically prepared site for the CMI must extend at least into the red-white zone of the meniscus to provide sufficient vascular supply.

Patients were excluded if they had had a previous treatment with collagen or if they had an allergy to collagen, inflammatory arthritis or degenerative joint disease and evidence of osteonecrosis in the targeted area. It is also contraindicated in patients allergic to bovine or other animal derived products, with an overly sensitized immune system, systemic or local infection.

# POLYURETHANE IMPLANT (ACTIFIT)

### 7.1.1 Introduction

Increased awareness of potentially detrimental outcomes following partial meniscectomy led to the development of a novel meniscal scaffold, Actifit™, by Orteq Bioengineering. It received the CE Mark in July 2008 for treatment of medial or lateral irreparable partial meniscal tears. Actifit™ consists of highly interconnected porous synthetic material (Fig. 7.1) enabling tissue ingrowth. Over time, transformation into meniscus-like tissue takes place as the implant slowly degrades. Furthermore, Actifit™ is made of an aliphatic polyurethane, which provides optimal mechanical strength, biocompatibility, porosity, safe degradation and ease of use required for the indication.

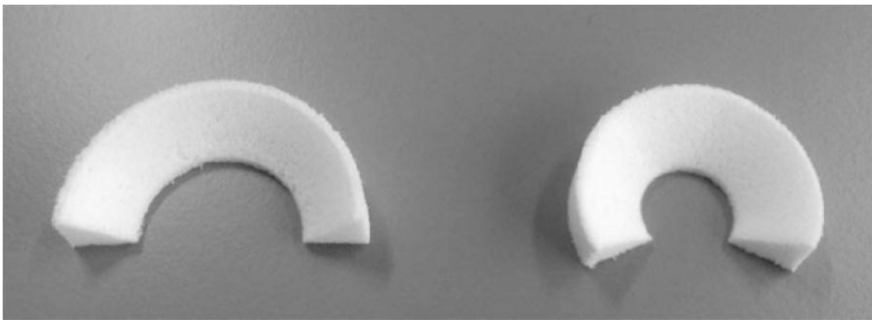


**Figure 22:** Medial and lateral ActifitTM

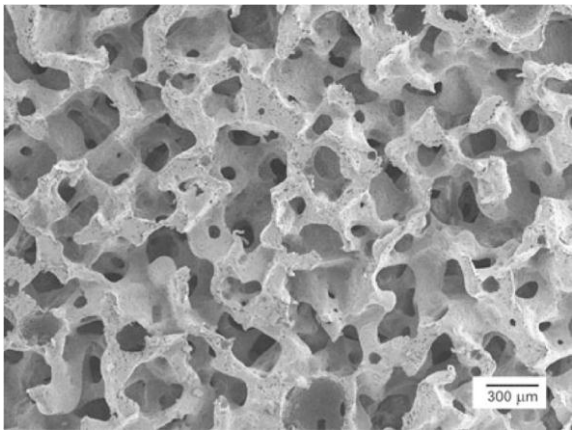



Figure 23 Scanning electron micrograph of the porous structure of ActifitTM

### 7.1.2 Background

Development of the meniscal scaffold started in the 1980s. Scaffold materials made of various synthetic polymers were tested in animal studies as meniscal repair or meniscal replacement material [1–22]. Based on these studies, a set of requirements for the optimal implant with respect to pore size, porosity, rate of degradation, degradation products, mechanical properties, and importantly ease of use in an arthroscopic procedure were developed. With respect to the mechanical properties, a high suture pull-out strength and sufficient stiffness became essential. Synthetic polymers currently used as biodegradable polymers for implantable devices are mainly copolymers based on lactide, e-caprolactone, glycolide and trimethylene carbonate, and cannot fulfill all these requirements.

Polyurethanes are a class of materials with properties ranging from very brittle and hard to very tough, soft and tacky, and viscous [14]. The molecular structure can be tuned and consequently also the mechanical properties and rate of degradation. They are composed of alternating polydisperse blocks of soft and hard segments (Fig. 7.3). These qualities combined with excellent biocompatibility make polyurethanes one of the most promising synthetic biomaterials [23]. Apart from the Orteq implant, marketed polyurethanes all contain (aromatic) diisocyanate moieties, which may yield a small amount of toxic diamines upon degradation. Although it has never been proven that toxic diamines are released or that such a release would cause problems, and aromatic polyurethanes have successfully been implanted in dogs as meniscal reconstruction material in the past [1–4, 7–11, 17, 18, 20–22, 24], the possibility of toxic amine release has given polyurethanes a negative perception. Therefore, it was decided to focus on polyurethanes based on 1,4-butanediisocyanate [16, 25–33]. Upon degradation, this aliphatic polyurethane will release 1,4-butanediamine, also known as putrescine, already naturally present in the body.

### 7.1.3 A New Synthetic Polymer

The Actifit™ polymer consists of two components, polyester (soft segments) and polyurethane (hard segments), specifically developed and tuned for meniscal

application [29]. The soft segment, 80 % of the polymer, is a biodegradable polyester, poly (e-caprolactone). It provides flexibility and determines the degradation rate. The semi-degradable, semicrystalline, polyurethane hard segments (20 % of the polymer) are of uniform size and provide mechanical strength.

Poly (e-caprolactone) (lines in polymer chain in Fig. 7.3) is a degradable polyester found in several implantable biodegradable medical devices, mainly sutures (Monocryl by Ethicon; Caprosyn by Tyco Healthcare) and coatings of sutures (Vicryl and Panacryl by Ethicon; Dexon and Polysorb by Tyco Healthcare). The polyurethane hard segments (white boxes in polymer chain in Fig. 7.3) contain two 1,4-butanediisocyanate (BDI) and one 1,4- butanediol (BDO) moieties and are designed to be very small (2–3 nm), i.e. approximately 5,000 times smaller than a human cell.

In order to obtain a polyurethane with excellent mechanical properties comparable to the properties of aromatic polyurethanes, the conventional polyurethane synthesis process had to be changed [25]. The polyurethane is made without a catalyst, which contributes to the polymer biocompatibility. The absence of a

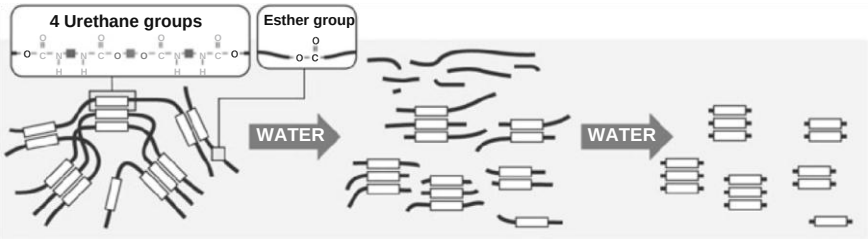



**Figure 24: Hydrolysis of the Actifit™ polyurethane**

catalyst also contributes to the uniformity of the hard segments, and therefore to the mechanical properties of the polyurethane [29].

### 7.1.4 Degradation

The Actifit™ polyurethane has a very low degradation rate. The degradation mechanism takes place in the presence of water through hydrolysis of the ester bonds in the poly (e-caprolactone) soft segments (Fig. 7.3). The polyurethane hard segments are more stable than the polycaprolactone segments and remain after hydrolysis of polycaprolactone. It

is expected that these segments do not degrade in when integrated in. In case the polyurethane segments are phagocytized by macrophages (or giant cells), the hard segments degrade safely. This was determined in scientific studies of a polyurethane with similar polyurethane hard segments [34, 35] and was confirmed in Orteq's biocompatibility testing program on hard segments [36].

Degradation of the polycaprolactone segments is expected to take 4–6 years. In-vitro degradation testing (at 37 C in phosphate buffer at pH 7.4) showed that after 1.5 years the molecular weight of the polyurethane decreased to 50 % of its original molecular weight while the implant weight was not reduced [16].

The biocompatibility of identified degradation products has either been tested by Orteq, or extensive documentation of their nontoxicity in the quantities released was already available. An overview of the tests performed is shown in the next section [37–39].

### 7.1.5 Preclinical Biocompatibility and Animal Testing

Orteq has completed a number of biocompatibility tests on the Actifit™ implant and on hard segments (Table 7.1). Actifit™ has passed all tests.

Two dog (beagles) studies were performed with the Actifit™ material [24, 40]. In the first study Actifit™ was implanted following total meniscectomy [24]. The follow-up period was 6 months. The implant horns were fixed on the tibial plateau with sutures pulled through drill holes in the tibia. Total meniscectomy served as control. In the second study Actifit™ was implanted for 6 and 24 weeks, with total meniscectomy and native menisci as controls [40]. The Actifit™ implants were fully integrated into the tissue without capsule formation, and the immunological response was very mild, not exceeding grade I. Histological examination of the tissue ingrowth disclosed formation of meniscus-like tissue containing proteoglycans and type II collagen (Fig. 7.4). A chondroprotective effect was not expected nor observed, due to limitations of the animal model. Nevertheless, it was hypothesized that absence of chondroprotection could be implant material-related [24]. No definite conclusions could be drawn since in this

particular model the tibial plateaus were severely damaged due to technical issues in the group

Table 7 Tests Orteq has performed on Actifit™

| Testing requirements | Relevant standards |
|---|---|
| Cytotoxicity | ISO10993-05 |
| Sensitization | ISO10993-10 |
| Intracutaneous irritation | ISO10993-10 |
| Acute systemic toxicity | ISO10993-11 |
| Combined subchronic toxicity and local tolerance (implant and hard segments) | ISO 10993-06 and ISO10993-11 |
| Combined chronic toxicity and local tolerance (implant and hard segments) | ISO 10993-06 and ISO10993-11 |
| Genotoxicity: bacterial reverse mutation | ISO10993-03 |
| Genotoxicity: chromosomal aberration test in mammalian cell in vitro | ISO10993-03 |
| Genotoxicity: mouse bone marrow micronucleus | ISO10993-03 |
| Wear debris on small particles rabbit knee | ISO10993-06 ( adapted ) |

receiving the implant. In a subsequent, recent sheep study Actifit™ was implanted after partial meniscectomy, with partial meniscectomy serving as control [41]. The material was found not to negatively affect the articular cartilage. In addition, the friction coefficient of the Actifit™ did not appear to be significantly different from that of native meniscus after 3 months.

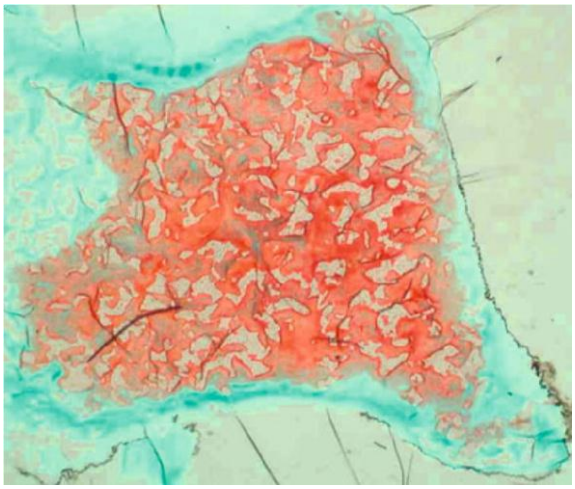


**Figure 25: Light micrograph of the posterior part of an Actifit™ implant**

, 24 months after implantation in a dog. White areas polymer; green areas fibrous tissue mainly containing type I collagen; red areas fibrocartilage-like tissue containing proteoglycans and mainly type II collagen

### 7.1.6 Clinical Results

Clinical results for Actifit™ showed significant improvement from baseline at 3, 6 and 12 months postimplantation, as evidenced by the Visual Analogue Scale (VAS), and the International Knee Documentation Committee (IKDC), Knee Injury and Osteoarthritis Outcome (KOOS) and Lysholm scores. DCMRI scans showed tissue ingrowth in 85.7 % of subjects already at 3 months postimplantation, while biopsies at 12 months showed cells with meniscus-like differentiation potential [42]. In conclusion, Actifit™ is a novel, biocompatible, polymer device specifically designed for use as a matrix for tissue ingrowth to treat irreparable meniscal defects.

# MATERIALS AND METHODS

## Literature search

A systematic review of multiple databases was performed. Two independent reviewers searched PubMed, Embase, and the Cochrane Library up to January 12, 2017. The following search phrase was used: "(meniscus OR meniscal) AND (scaffold OR implant)". A total of 480 studies were reviewed by title and/or abstract to determine study relevance based on inclusion/exclusion criteria. Inclusion criteria included studies that assessed the clinical outcomes of meniscal scaffold implantation (level of evidence I–IV). Studies reporting on meniscal allograft transplantation and non-English studies were excluded. Disparities in eligible studies were resolved by discussion between the two reviewers. Nineteen studies met inclusion and exclusion criteria (Fig. 26).

## Reporting outcomes

Outcomes assessed included treatment failure rate and patient-reported outcome scores.

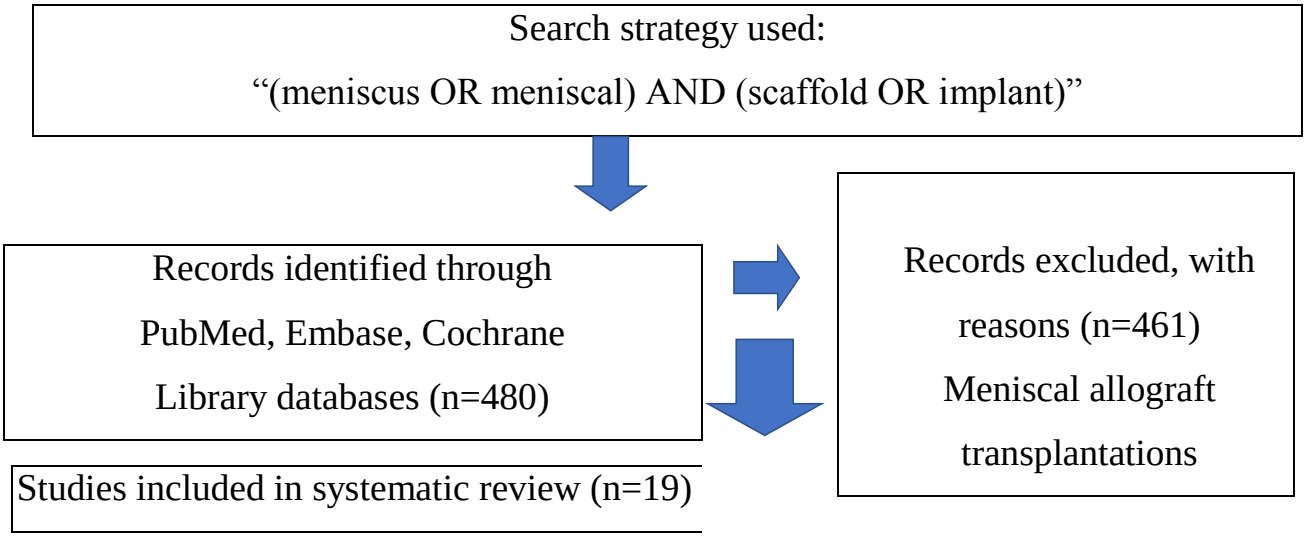



*Figure 26:* ***Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram***

**Magnetic resonance imaging**

Morphology and signal intensity were recorded using the Genovese scale [15]. Grade 1 was defined by complete absorption of the meniscus or a hyperintense signal; grade 2 was defined by reduced size or irregular morphology and isointense; grade 3 was defined by normal morphology and signal intensity. The Yulish score [41] was used to assess the articular cartilage. Grade 0 was considered normal cartilage; grade 1 if cartilage had signal alteration with a regular edge; grade 2 if superficial fraying and erosion or ulceration of less than 50% of lesion thickness; grade 3 if a partial-thickness defect was present that was higher than 50% but lower than 100%; grade 4 was defined by a full-thickness ulceration.

**Statistical analysis**

A weighted average was calculated for numerical demographics (patient age, follow-up, mean lesion size, and patient-reported outcome scores). A Chi-square test was used to determine significant differences in treatment failure rates between Actifit polyurethane scaffolds and CMI.

## STATISTICAL ANALYSIS

The collected data was revised, coded, tabulated and introduced to a PC using Statistical package for Social Science (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp). Data was presented and suitable analysis was done according to the type of data obtained for each parameter.

- Description of quantitative variables as mean, SD and range.
- Description of qualitative variables as number and percentage.
- **Chi-square test** was used to compare qualitative variables.
- **Two sample t-test** was used to compare quantitative variables between independent groups in parametric data.

- **Paired t-test** was used to assess the statistical significance of the difference between two means measured twice for the same study group
- **McNemar test** was used assess the statistical significance of the difference between a qualitative variable measured twice for the same study group.
- P- value: level of significance
    - $P > 0.05$: Non significant (NS).
    - $P < 0.05$: Significant (S).
    - $P < 0.01$: Highly significant (HS).

# RESULTS

## Literature search

Nineteen studies [2–4, 7, 8, 11–13, 20, 24, 25, 28, 29, 31, 32, 37, 42–44] (1 level I, 1 level II, 17 level IV evidence) met inclusion and exclusion criteria (Table 1).

## Surgical technique

### Actifit polyurethane meniscal scaffold

Twelve studies [2, 3, 7, 8, 11–13, 20, 24, 31, 32, 37] used the Actifit® polyurethane meniscal scaffold. The scaffolds were implanted arthroscopically via standard anterolateral and anteromedial portals using a standard meniscectomy technique. The meniscus is debrided back to the vascular zone and the defect is measured using a measuring device. The implant is then measured and cut to the exact size. The implant is sutured in place using a hybrid suture technique with a median of three ultra fast-fix implants (Smith & Nephew, Andover, MA) and a maximum of two outside-in sutures [7–9, 11]. However, multiple suture techniques and devices can be used.

### Collagen Meniscus Implant

Seven studies [4, 25, 28, 29, 42–44] used a Menaflex ® CMI with one study[30] using a self-produced CMI. A total of three portals are made about the knee, one for outflow and two as working portals. The damaged meniscus tissue is debrided until healthy tissue is reached. If debridement does not reach the red zone of the meniscus, then a microfracture awl is used along the peripheral rim to enhance blood supply [29, 42–44]. Before the CMI is implanted, the exact size of the defect is measured using a Teflon measuring device (RenGen Biologics, Inc). A standard inside-out suture technique using 2-0 non-absorbable braided sutures is used to attach the implant to the remnant healthy meniscus [44].

**Patient and lesion characteristics**

A total of 658 patients were treated (347 Actifit, 311 CMI). Three studies [12, 31, 32] did not report gender. Among the remaining studies, 443 males and 159 females were treated. The mean follow-up time for the included studies was 45 months. The mean patient age was 36 years (Table 1).

**Reporting outcomes**

The most commonly used reporting outcomes were the Visual Analog Scale (VAS) for pain [18], the Lysholm score [23], Tegner activity scale [36], Subjective International Knee Documentation Committee (IKDC) score [16], and the Knee Injury and Osteoarthritis Outcome Score (KOOS) [30] (Table 2).

**Table 8:** Demographic data

| References | Level of evidence | Implant | *n* | M/F | Follow-up mean (range), months | Mean patient age, years |
|---|---|---|---|---|---|---|
| Bouyarmane [2] | IV | Actifit | 54 | 37/17 | 24 | 28 |
| Bulgheroni [3] | IV | Actifit | 19 | 17/2 | 24 (24–46) | 32.8 |
| De Coninck [7] | IV | Actifit | 24 | 12/12 | 24 | 35 |
| Dhollander [8] | IV | Actifit | 44 | 24/20 | 60 (24–60) | 32.13 |
| Faivre [11] | IV | Actifit | 20 | NR | 24 | 28.7 |
| Filardo [12] | IV | Actifit | 16 | 9/7 | 72 (24–72) | 45 |
| Gelber [13] | IV | Actifit | 54 | 42/12 | 39 (25–63) | 40.2 |
| Kon [20] | IV | Actifit | 18 | 11/7 | 24 | 45 |
| Martín-Hernández [24] | IV | Actifit | 10 | 6/4 | 34.7 (24–46) | 30.6 |
| Schüttler, [32] | IV | Actifit | 18 | NR | 24 | 32.5 |
| Schüttler [31] | IV | Actifit | 18 | NR | 48 | 32.5 |
| Verdonk [37] | IV | Actifit | 52 | 39/13 | 24 | 30.8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Total | – | – | 347 | 246/65 | 35 | 34 |
| Rodkey [28] | I | CMI | 160 | 126/34 | 59 (16–92) | 39 |
| Zaffagnini [44] | II | CMI | 17 | 17/0 | 135 (120–152) | 38 |
| Bulgheroni [4] | IV | CMI | 34 | 25/9 | 24 | 39 |
| Monllau [25] | IV | CMI | 25 | 20/5 | 120 (121.2–150) | 42.3 |
| Rodkey [29] | IV | CMI | 8 | 8/0 | 24 (24–32) | 40 |
| Zaffagnini [43] | IV | CMI | 24 | 20/4 | 26 (24–31) | 36.3 |
| Zaffagnini [42] | IV | CMI | 43 | 30/13 | 24.2 | 30.1 |
| Total | – | – | 311 | 197/94 | 56 | 38 |
| Overall | – | – | 658 | 443/159 | 45 | 36 |

NR not reported, M male, F female, n number of patients

Fifteen studies [3, 4, 7, 8, 11–13, 20, 25, 28, 29, 37, 42–44] performed concomitant procedures (Table 3). The most common concomitant procedure was anterior cruciate ligament reconstruction (ACLR). The second most common concomitant procedure was a high tibial osteotomy (HTO), followed by microfracture procedures. Mean defect size and lesion location are shown in Table 4.

**Treatment failures**

Eight studies [2, 11, 12, 24, 25, 28, 37, 42] evaluated treatment failure rates, though failure definitions varied among the studies (Table 5). Eleven studies [3, 4, 7, 8, 13, 20, 29, 31, 32, 43, 44] did not clearly define treatment failure. Overall, the treatment failure rates among Actifit and CMI patients were 9.9% at a mean follow-up of 40 months and 6.7 % at a mean follow-up of 44 months, respectively (n.s.).

Patient-reported outcome scores are presented in Table 6. Both Actifit polyurethane and CMI scaffold groups had meaningful improvements in patient-reported outcome scores from preoperatively to latest follow-up. KOOS subscores improved from preoperatively to latest follow-up in every study (Table 7).

**Magnetic resonance imaging findings**

Overall, patients receiving CMI scaffolds had higher grades for Genovese morphology and signal intensity when compared to Actifit scaffold patients (Table 8). MRI demonstrated minimal joint space narrowing, no apparent chondral damage, and no exuberant tissue growth in the patients receiving CMI scaffolds [28, 44]. Likewise, in the Actifit scaffold patients, MRI demonstrated minimal joint space narrowing, moderately stable cartilage and no significant chondral damage [8, 24, 31, 32]. Furthermore, MRI demonstrated that implantation of the Actifit scaffold was followed by an increase of coronal meniscal extrusion [12, 31, 32], particularly when implanted into the medial compartment [7, 11].

**Second‑look arthroscopic inspection**

Second-look arthroscopy demonstrated new tissue by the CMI and appeared to be grossly meniscus-like with minimal reductions in size and no apparent negative effects [4, 28]. The new tissue had a stable interface with the host meniscus rim, and had a variable degree of maturity [25, 28, 29]. Second-look arthroscopy in the Actifit scaffold patients revealed a yellowish implant that was integrated into the surrounding tissues and appeared to be reduced in size [3].

**Table 9:** Patient-reported outcomes

| **Study** | VAS | IKDC | KOOS | Lysholm | Tegner | WOMET | Kujala | Patient satisfaction | KSS | UCLA |
|---|---|---|---|---|---|---|---|---|---|---|
| Actifit | | | | | | | | | | |
| Bouyarmane [2] | + | + | + | − | − | − | − | − | − | − |
| Bulgheroni [3] | + | − | − | + | + | − | − | − | − | − |
| De Coninck [7] | + | + | + | + | − | − | − | − | − | − |
| Dhollander [8] | + | + | + | − | − | − | − | − | − | − |
| Faivre [11] | − | + | + | − | − | − | − | − | − | − |
| Filardo [12] | − | + | − | − | + | − | − | − | − | − |
| Gelber [13] | + | + | − | − | − | + | + | + | − | − |
| Kon [20] | − | + | − | − | + | − | − | − | − | − |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Martín−Hernández [24] | + | − | + | + | − | − | − | − | − | − |
| Schüttler [32] | + | − | + | − | − | − | − | − | + | + |
| Schüttler [31] | + | − | + | − | − | − | − | − | + | + |
| Verdonk [37] CMI | + | + | + | + | − | − | − | − | − | − |
| Rodkey [28] | + | − | − | + | + | − | − | + | − | − |
| Zaffagnini [44] | + | − | − | + | + | − | − | − | − | − |
| Bulgheroni [4] | − | − | − | + | + | − | − | − | − | − |
| Monllau [25] | + | − | − | + | − | − | − | + | − | − |
| Rodkey [29] | + | − | − | + | + | − | − | − | − | − |
| Zaffagnini [43] | + | + | − | + | + | − | − | − | − | − |
| Zaffagnini [42] | + | − | − | + | + | − | − | + | − | − |

***"+/−" indicates that outcome measure was/was not performed***

***VAS Visual Analog Pain Scale, IKDC Subjective International Knee Documentation Committee score, KOOS Knee Injury and Osteoarthritis Outcome Score, WOMET Western Ontario Meniscal Evaluation tool, KSS Knee Society Score, UCLA University of California, Los Angeles Ultrasonography, SF-36 36-Item Short Form Survey***

*Table 10:* ***Number of concomitant procedures performed***

| References | ACLR | ACL repair | PCLR | HTO/DFO | ACI | MAT | Meniscal debridement | Mosaicplasty | MFx | Osteochondral scaffold implantation | Chondroabrasion | Articular cartilage shaving | Lateral release | Loose body | ≥ 1 procedu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actifit | | | | | | | | | | | | | | | |
| Bouyarmane [2] | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| Bulgheroni [3] | 8 | 1 | 0 | 7/1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| De Coninck [7] | 6 | 0 | 0 | 1/1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dhollander [8] | 4 | 0 | 0 | 4/0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Faivre [11] | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Filardo [12] | 3 | 0 | 0 | 4* | 0 | 0 | 0 | 0 | 3 | 2 | 1 | 1 | 2 | 1 | 0 |
| Gelber [13] | 15 | 1 | 0 | 5/0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 11 |
| Kon [20] | 3 | 0 | 0 | 4* | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 2 | 1 | 0 |
| Martín-Hernández [24] | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| Schüttler [32] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Schüttler [31] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Verdonk [37] | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 45 | 2 | 0 | 17/28* | 1 | 1 | 2 | 1 | 11 | 4 | 2 | 2 | 4 | 2 | 11 |
| CMI | | | | | | | | | | | | | | | |
| Rodkey [28] | 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zaffagnini [44] | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bulgheroni [4] | 11 | 0 | 0 | 2/0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Monllau [25] | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Rodkey [29] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zaffagnini [43] | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zaffagnini [42] | 6 | 0 | 0 | 0/2 | 1 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 84 | 0 | 0 | 2/2 | 1 | 0 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 1 |
| Overall total | 129 | 2 | 0 | 19/48* | 2 | 1 | 2 | 1 | 27 | 4 | 2 | 2 | 4 | 2 | 12 |

*NR* not reported, *ACLR* anterior cruciate ligament reconstruction, *ACL* anterior cruciate ligament, *PCLR* posterior cruciate ligament reconstruction, *HTO* high tibial osteotomy, *DFO* distal fer
ral osteotomy, *ACI* autologous chondrocyte implantation, *MAT* meniscal allograft transplantation, *MFx* microfracture

"*" indicates no specific osteotomy procedure type was described

**Table 11:** Lesion characteristics

| References | Defect size, mm | Lesion location (medial/lateral) |
|---|---|---|
| Actifit | | |
| Bouyarmane [2] | 43 (32–60) | 0/54 |
| Bulgheroni [3] | 42.3 | 16/2 1 bilateral |
| De Coninck [7] | 43.2 (31.2–55.2) | 18/8 |
| Dhollander [8] | 45.51 (29–70) | 29/15 |
| Faivre [11] | NR | 8/12 |
| Filardo [12] | NR | 12/4 |
| Gelber [13] | 42.7 (25–55) | 40/14 |
| Kon [20] | NR | 13/5 |
| Martín-Hernández [24] | NR | 9/1 |
| Schüttler [32] | 45 (35–62) | 18/0 |
| Schüttler [31] | 44.5 (35–62) | 18/0 |
| Verdonk [37] | NR | 34/18 |
| Total | 44 | 215/133 |
| CMI | | 1 bilateral |
| Rodkey [28] | NR | 160/0 |
| Zaffagnini [44] | 36 (27–45) | 17/0 |
| Bulgheroni [4] | 45 (26–60) | 34/0 |
| Monllau [25] | 48.2 (32–67) | 25/0 |
| Rodkey [29] | 42.5 (27–55) | 8/0 |
| Zaffagnini [43] | 45.2 (34.0-64.5) | 24/0 |
| Zaffagnini [42] | 46 (35–57) | 0/38 5 bilateral |
| Total | 45 | 268/38<br>5 bilateral |
| Overall total | 44 | 483/171, 6 bilateral |

***Defect size is reported as a mean (range) (when available), NR not reported***

# DISCUSSION

The menisci are critical to the biomechanical function of the knee joint, and the loss of meniscal tissue can lead to decreased clinical function and activity levels [37]. Although MAT has been associated with improved clinical outcomes in patients following a complete or near complete meniscectomy, there can be high reoperation and failure rates resulting from complications such as allograft removal and infection [6]. Additionally, MAT is not suitable following partial meniscal resection. In cases such as these, meniscal scaffolds are an option for meniscal replacement to improve biomechanical function of the knee joint by producing fibrocartilage comparable to the native meniscus as well as to decrease the risk of inflammatory and immune responses [27, 35]. Though the best meniscal scaffold type remains controversial, both Actifit polyurethane and CMI scaffolds have been shown to provide functional and clinical benefits. Actifit polyurethane scaffolds are designed to provide mechanical support to the knee joint and slowly degrade over a 5-year period as the scaffold is replaced by regenerated tissue [39]. Likewise, the goal of the CMI scaffold as described by Rodkey et al. [29] is to support ingrowth and regeneration of new meniscal tissue and is designed to be reabsorbed in 12 –18 months.

A recent systematic review [6] compared the success and failure rates of meniscal allograft transplantation and meniscal scaffolds and found that the limited number of randomized controlled trials using meniscal scaffolds [22, 28] makes it difficult to assess long-term clinical outcomes, and that the literature to date may contain various biases including conflict of interest [6]. However, the previous systematic review only reported these outcomes for 271 patients and did not report radiological outcomes, concomitant procedures, lesion location or size of the meniscal defect in patients receiving a meniscal scaffold. Additionally, this updated systematic review points out the variance in patient-reported outcomes among studies examining meniscal scaffolds, thus there is a need for future studies to choose and report on the best and most commonly used, validated patient-reported outcome scales.

The results of this updated systematic review suggest that, at a mean follow-up of 45 months, patients receiving both meniscal scaffold implantation types can expect to experience similar patient-reported outcomes. Although not significant, treatment failure rate was higher in Actifit polyurethane scaffolds (9.9%) than in CMI (6.7%). We observed postoperative improvement of subjective IKDC scores and KOOS subscores in patients receiving Actifit polyurethane scaffolds. Both Actifit polyurethane and CMI scaffolds showed improvement in the VAS, Lysholm scores, and Tegner activity scale. However, the two groups demonstrated considerable differences in preoperative VAS scores, making it difficult to compare improvement in these scores.

Among the studies included in this systematic review, the failure rate was often defined as the need for reoperation. However, the failure rate based on MRI is likely much higher. Meniscal scaffolds may be non-functional due to fragmentation or extrusion without necessarily causing symptoms that would warrant the patient to seek reoperation.

| References | *n* (% of total) | Failure definition |
|---|---|---|
| Actifit | | |
| Bouyarmane [2] | 3/54 (5.5%) | Need for reoperation due to pain |
| Faivre [11] | 3/20 (15%) | Need for revision procedure to remove all or part of the substitute |
| Filardo [12] | 1/16 (6.3%) | Need for reoperation due to symptoms related to index defect |
| Martín- Hernández [24] | 1/10 (10%) | Need for reoperation due to pain |
| Verdonk [37] | 9/52 (17.3%) | Need for reoperation on index defect |
| Bulgheroni [2] | 1/19 (5.3%) | NR |
| De Coninck [7] | NR | NR |

| | | |
|---|---|---|
| Dhollander [8] | 14/44 (31.8%) | NR |
| Gelber [13] | 0/54 (0%) | NR |
| Kon [20] | 0/18 (0%) | NR |
| Schüttler [32] | 0/18 (0%) | NR |
| Schüttler [31] | 0/18 (0%) | NR |
| Total CMI | 32 /323 (9.9% ) | |
| Rodkey [28] | 12/160 (7.5%) | Need for reoperation that was an unplanned additional surgery on index defect due to mechanical symptoms and pain |
| Monllau [25] | 2/25 (8%) | Infection due to the implant or mechanical failure of the implant |
| Zaffagnini [42] | 3/43 (7%) | Need for reoperation |
| Zaffagnini [44] | 2/17 (12%) | NR |
| Bulgheroni [4] | 2/34 (5.9%) | NR |
| Rodkey [29] | 0/8 (0%) | NR |
| Zaffagnini [43] | 1/24 (4%) | NR |
| Total | 22 /327 (6.7% ) | |
| Overall total | 54 /650 (8.3% ) | |

**Table 12:** Treatment failures

***NR not reported***

The combination of shrinkage and extrusion of the implant may result in failure to increase articular cartilage coverage, reduce peak pressure, and achieve a balanced load distribution [11]. This is supported by a recent meta-analysis by Shin et al. [33] who found that articular cartilage and absolute meniscal extrusion worsens between baseline and final

follow-up in patients following polyurethane meniscal scaffold implantation. Additionally, despite being unrelated to functional outcomes, patients with no chondral injuries have been shown to present with better size and morphology of the Actifit meniscal scaffold implant at a mean follow-up of 39 months [12, 13]. Furthermore, MAT failure due to extrusion appears to be correlated with the degree of articular cartilage wear [6]. The degree of articular cartilage degeneration likely plays a critical role in the functional knee outcomes of meniscal scaffold patients.

The alteration of MRI signal intensity as well as histological findings after biopsy shows the reabsorbing properties of these scaffolds [4, 25]. Twelve of the included studies [3, 4, 8, 11–13, 24, 25, 31, 32, 43, 44] showed morphology and signal intensities that indicated a meniscus slightly reduced in size with an isointense signal or a completely reabsorbed meniscus with a hyperintense signal in both CMI and Actifit polyurethane scaffolds according to the Genovese scale, though this grading system may indeed may not be the most ideal in regard to evaluation of meniscal scaffolds [17]. Although Schüttler et al. [31] suggested a tendency of the polyurethane implant to improve signal intensity from 2 to 4 years, the 5-year reabsorption rate of the Actifit polyurethane scaffolds could explain the persisting significant abnormalities at 6 years found in a study by Filardo et al. [12, 39]. The Yulish score showed slight to no alterations in the articular cartilage in four studies [3, 4, 43, 44]. These results suggest comparable regenerative and resorbable properties of these two scaffold options. These MRI findings may indicate improved clinical outcomes when compared with baseline values [26]. Papalia et al. [26] confirmed that the two scaffold options were equivalent using radiological and histological assessments. However, factors such as medial or lateral meniscus, duration of condition, prior knee surgeries, concomitant procedures, and expected postoperative activity level may influence the outcomes of this treatment [26].

**Table 13:** Patient-reported outcome scores

| Study | *N* Preoperative score | Postoperative score |
|---|---|---|
| Rodkey [29] | 8 4 | 5 |
| Zaffagnini [43] | 24 3 | 5* |
| Zaffagnini [42] | 43 3 | 5 |
| Weighted average | 132 3 | 5 |
| Weighted improvement | 2 | |
| Actifit: IKDC Subjectiv | | |
| Bouyarmane [2] 54 | 56.96 ± 15.67 | 66.97 ± 18.34* |
| De Coninck [7] 24 | 39.18 ± 18.24 | 64.17 ± 24.65 |
| Dhollander [8] 44 | 38.7 ± 14.8 | 66.9 ± 23.1* |
| Faivre [11] 20 | 48.1 | 56.4 |
| Filardo [12] 16 | 45.6 ± 17.5 | 75.0 ± 16.8* |
| Gelber [13]54 | 32.5 ± 11.1 | 78.2 ± 14.8* |
| Kon [20] 18 | 47.3 ± 17.5 | 74.6 ± 15.3 |
| Verdonk [37] 52 | 45.4 ± 17.8 | 70.1 ± 23.0 |
| Weighted average 282 | 44 | 70 |
| Weighted improvement | 26 | |

***Mean ± standard deviation (when available), VAS based on 0 to 100 mm scale. *(p < 0.05)***

**Table 14:** ***VAS Visual Analog Scale for pain, IKDC Subjective International***

| ***Study*** | ***n*** | ***Preoperative score*** | ***Postoperative score*** |
|---|---|---|---|
| ***Actifit: VAS*** | | | |
| ***Bouyarmane [2]*** | ***54*** | ***55.1 ± 23.2*** | ***29.4 ± 25.2**** |
| ***Bulgheroni [3]*** | ***19*** | ***62.3*** | ***19.4*** |

| | | | |
|---|---|---|---|
| ***De Coninck [7]*** | ***24*** | ***54.1 ± 22.3*** | ***21.3 ± 22.8**** |
| ***Dhollander [8]*** | ***44*** | ***56.2 ± 21.6*** | ***19.3 ± 26.9**** |
| ***Gelber [13]*** | ***54*** | ***75 ± 12*** | ***23 ± 15**** |
| ***Martín-Hernández [24]*** | ***10*** | ***57*** | ***19*** |
| ***Schüttler [32]*** | ***18*** | ***51 ± 20*** | ***15 ± 21**** |
| ***Schüttler [31]*** | ***18*** | ***52 ± 20*** | ***10 ± 14**** |
| ***Verdonk [37]*** | ***52*** | ***45.7 ± 26.2*** | ***20.3 ± 23.5**** |
| ***Weighted average*** | ***293*** | ***57*** | ***21*** |
| ***Weighted improvement CMI: VAS*** | | ***36*** | |
| ***Rodkey [28]*** | ***160*** | ***29*** | ***12*** |
| ***Rodkey [29]*** | ***8*** | ***23*** | ***1.8*** |
| ***Monllau [25]*** | ***25*** | ***55*** | ***20**** |
| ***Zaffagnini [43]*** | ***24*** | ***55.2 ± 29.4*** | ***19.5 ± 25.6**** |
| ***Zaffagnini [42]*** | ***43*** | ***20 ± 25*** | ***2 ± 6*** |
| ***Weighted average*** | ***260*** | ***32*** | ***12*** |
| ***Weighted improvement Actifit: Lysholm score*** | | ***20*** | |
| ***Bulgheroni [3]*** | ***19*** | ***66.2*** | ***90.5*** |
| ***De Coninck [7]*** | ***24*** | ***52.13 ± 17.46*** | ***76.23 ± 20.12**** |
| ***Martín-Hernández [24]*** | ***10*** | ***63.5*** | ***84.4**** |

| | | | |
|---|---|---|---|
| ***Verdonk [37]*** | ***52*** | ***60.1 ± 19.2*** | ***80.7 ± 19.5*** |
| ***Weighted average*** | ***105*** | ***60*** | ***82*** |
| ***Weighted improvement*** | | ***22*** | |
| ***CMI: Lysholm score*** | | | |
| ***Rodkey [28]*** | ***160*** | ***63*** | ***84*** |
| ***Bulgheroni [4]*** | ***34*** | ***58*** | ***94**** |
| ***Monllau [25]*** | ***25*** | ***59.9*** | ***87.56**** |
| ***Rodkey [29]*** | ***8*** | ***75*** | ***85*** |
| ***Zaffagnini [43]*** | ***24*** | ***64.0 ± 16.2*** | ***92.7 ± 13.8**** |
| ***Zaffagnini [42]*** | ***43*** | ***64.3 ± 18.4*** | ***93.2 ± 7.2*** |
| ***Weighted average*** | ***294*** | ***63*** | ***88*** |
| ***Weighted improvement*** | | ***25*** | |
| ***Actifit: Tegner activity scale*** | | | |
| ***Bulgheroni [3] 19*** | | ***3.8*** | ***4.9*** |
| ***Filardo [12] 16*** | | ***2*** | ***3.5**** |
| ***Kon [20] 18*** | | ***2*** | ***3**** |
| ***Weighted average 53*** | | ***3*** | ***4*** |
| ***Weighted improvement*** | | ***1*** | |
| ***CMI: Tegner activity scale*** | | | |
| ***Bulgheroni [4] 34*** | | ***2*** | ***5**** |

Knee Documentation Committee

Concomitant procedures and prior knee surgeries may play a crucial role in outcomes following meniscal scaffold implantation. Degeneration of the medial compartment

following a medial meniscectomy may increase the occurrence of a varus malaligned knee [40]. Therefore, concomitantly addressing this loss of meniscal tissue using a meniscal scaffold during a HTO in a varus knee is attractive due to the fact that alignment of the knee and the menisci are important in tibiofemoral load transmission [14, 19, 20]. A study by Gelber et al. [14] examined patients undergoing HTO for varus knees and medial meniscectomies, with half of the patients also undergoing Actifit polyurethane scaffold implantation. While this study found significant clinical improvement in both groups at 31.2 months, the scaffold-free group demonstrated superior improvement in their functional scores at this short-term follow-up [14]. The lack of randomized controlled trials using meniscal scaffolds without any associated procedures makes it difficult to accurately assess short-term clinical outcomes.

There are several limitations to this systematic review. First, the majority of included studies were case series, making it difficult to draw strong conclusions or to accurately compare clinical outcomes between the two scaffold types. Although 658 patients were included in this review, not all patients were evaluated using the same outcome measures, and therefore sample sizes were limited for particular outcomes. Furthermore, the Genovese scale may not be the

**Table 15:** KOOS subscores

| References | *n* | Preoperative score | Postoperative score |
|---|---|---|---|
| Actifit KOOS-pain | | | |
| Bouyarmane [2] | 54 | 56.57 ± 17.61 | 78.53 ± 17.24* |
| De Coninck [7] | 24 | 53.2 ± 21.02 | 74.56 ± 23.89* |
| Dhollander [8] | 44 | 48.3 ± 20.3 | 77.2 ± 24.5* |
| Faivre [11] | 20 | 58.2 | 68.8 |
| Schüttler [32] | 18 | 47 ± 14.5 | 83 ± 18.6* |
| Schüttler [31] | 18 | 47 ± 14.5 | 89 ± 12.8* |

| | | | |
|---|---|---|---|
| Verdonk [37] | 52 | 57.5 ± 22.2 | 78.6 ± 22.5 |
| Weighted average | 230 | 53 | 78 |
| Weighted improvement Actifit KOOS-symptom s | | 25 | |
| Bouyarmane [2] | 54 | 59.16 ± 19.42 | 79.01 ± 16.11 |
| De Coninck [7] | 24 | 53.5 ± 19.67 | 77.23 ± 20.11* |
| Dhollander [8] | 44 | 52.4 ± 19.7 | 69.4 ± 20.9* |
| Faivre [11] | 20 | 67.6 | 71.5 |
| Schüttler [32] | 18 | 60 ± 16.2 | 81 ± 13.4* |
| Schüttler [33] | 18 | 60 ± 16.2 | 86 ± 9.3* |
| Verdonk [37] | 52 | 64.6 ± 22.3 | 78.3 ± 18.5 |
| Weighted average | 230 | 59 | 77 |
| Weighted improvement Actifit KOOS-ADL | | 18 | |
| Bouyarmane [2] | 54 | 64.06 ± 23.05 | 84.21 ± 15.26* |
| De Coninck [7] | 24 | 58.78 ± 21.93 | 78.45 ± 25.78* |
| Dhollander [8] | 44 | 54.4 ± 21.5 | 80.2 ± 26.1* |
| Faivre [11] | 20 | 67.2 | 74.5 |
| Schüttler [32] | 18 | 53 ± 16.0 | 91 ± 14.7* |
| Schüttler [12] | 18 | 53 ± 16.0 | 94 ± 8.4* |
| Verdonk [37] | 52 | 68.8 ± 21.4 | 84.2 ± 21.2 |
| Weighted average | 230 | 61 | 83 |
| Weighted improvement Actifit KOOS-SR | | 22 | |
| Bouyarmane [2] | 54 | 30.05 ± 26.87 | 54.03 ± 27.25* |
| De Coninck [7] | 24 | 20.18 ± 22.14 | 52.13 ± 28.49* |

| | | | |
|---|---|---|---|
| Dhollander [8] | 44 | 19.1 ± 20.0 | 49.7 ± 34.8* |
| Faivre [11] | 20 | 42.9 | 55* |
| Schüttler [32] | 18 | 26 ± 20.5 | 66 ± 28.5* |
| Schüttler [31] | 18 | 26 ± 20.5 | 81 ± 15.1* |
| Verdonk [37] | 52 | 30.5 ± 28.7 | 59.0 ± 33.4 |
| Weighted average | 230 | 28 | 57 |
| Weighted improvement Actifit KOOS-QOL | | 29 | |
| Bouyarmane [2] | 54 | 29.59 ± 16.94 | 50.93 ± 21.38* |
| De Coninck [7] | 24 | 30.01 ± 18.99 | 51.99 ± 28.87* |
| Dhollander [8] | 44 | 32.2 ± 14.2 | 56.9 ± 24.0* |
| Faivre [11] | 20 | 36.5 | 51.9 |
| Schüttler [32] | 18 | 28 ± 16.6 | 63 ± 18.9* |

| References | *n* | Preoperative score | Postoperative score |
|---|---|---|---|
| Schüttler [31] | 18 | 28 ± 16.6 | 68 ± 20.7* |
| Verdonk [37] | 52 | 33.9 ± 19.3 | 56.6 ± 24.2 |
| Weighted average | 230 | 31 | 56 |
| Weighted improve-ment | | 25 | |

Scores are reported as a mean ± standard deviation (when available) ADL activities of daily living, KOOS Knee Injury and Osteoarthritis Outcome Score, QOL quality of life, SR sports and recreation *($p < 0.05$)

**Table 16:** Radiological findings at final follow-up

| References | Genovese morphology | Genovese signal intensity | Yulish score |
|---|---|---|---|
| Actifit | | | |
| Bulgheroni [2] | 1.4 | 2 | 1.1 |
| Faivre [11] | 1.7 | 1.7 | – |
| Gelber [13] | 2 | 2 | – |
| Martín-Hernández [24] | 2 | 1.6 | – |
| Schüttler [32] | 1 | 1 | – |
| Dhollander [8] | 2 | 1.4 | – |
| Filardo [12] | 1.7 | 1.7 | – |
| Schüttler [31] | 2 | 1 | – |
| Total | 1.7 ± 0.4 | 1.6 ± 0.4 | 1.1 |
| CMI | | | |
| Bulgheroni [4] | 2.3 | 1.5 | 0.9 |
| Monllau [25] | 1.9 | 2.1 | - |
| Zaffagnini [44] | 2 | 2 | 2.5 |
| Zaffagnini [43] | 2 | 1 | 1 |
| Total | 2.1 ± 0.2 | 1.7 ± 0.5 | 1.5 ± 0.9 |

Mean Genovese morphology and signal intensity scores and Yulish scores are reported. Total scores are reported as a mean ± standard deviation

"–" indicates that outcome measure was not performed most ideal grading system in regard to evaluation of meniscal scaffolds [17]. Multiple studies [2–4, 7, 8, 11–13, 20, 25, 28, 29, 31, 32, 37, 42–44] may include overlapping patients. Although there is no mention of overlapping patients within these studies, it is possible that there may be overlap due to research center collaboration. Another limitation includes the variation in meniscal defect

location and size. Additionally, the beneficial outcomes of the 5-year reabsorption rate of the polyurethane biomaterial lack evidence as there are very few studies that evaluate the reabsorbing properties of the Actifit polyurethane scaffolds after this time point. Similarly, the minimum and maximum follow-up of patients is not defined in many of the studies. Thus, the currently available literature may only represent a preview of the longterm outcomes of this degrading property. In addition, rate of failure ranged from 0 to 31.8% and treatment failure definitions varied amongst studies. Finally, 15 studies [3, 4, 7, 8, 11–13, 20, 25, 28, 29, 37, 42–44] performed concomitant procedures which may have an effect on clinical outcomes.

This updated systematic review suggests that similar clinical outcomes can be achieved in patients undergoing meniscal scaffold implantation with either the Actifit polyurethane or the CMI scaffold. Thus, the type of meniscal scaffold should not play a significant role in the decision making process for surgeons treating patients indicated for this procedure.

# SUMMARY AND CONCLUSION

Patients undergoing meniscal scaffold implantation can be expected to experience improvement in short-term clinical outcomes postoperatively when used in association with concomitant procedures such as ACLR and HTO without a significant difference between Actifit polyurethane and CMI scaffold groups. However, high-quality, comparative studies with long-term follow-up are needed to accurately assess and compare outcomes between patients undergoing meniscal scaffold implantation with different implants.

# REFFERENCES


1. McDermott ID, Masouros SD, Amis AA (2008) Biomechanics of the menisci of the knee. Curr Orthopaed 22:193–201
2. Smillie IS (1972) Injuries of the knee joint, 4th edn. Churcill Livingstone, Edinburgh
3. Fayard JM, Pereira H, Servien E, Lustig S, Neyret P (2010) Meniscectomy global resultscomplications. Springer-Verlag, Berlin Heidelberg
4. Verdonk PC, Forsyth RG, Wang J et al (2005) Characterisation of human knee meniscus cell phenotype. Osteoarthritis Cartilage 13:548–560
5. Kurosawa H, Fukubayashi T, Nakajima H (1980) Load-bearing mode of the knee joint:physical behavior of the knee joint with or without menisci. Clin Orthop Relat Res 283–290
6. Fukubayashi T, Kurosawa H (1980) The contact area and pressure distribution pattern of the knee. A study of normal and osteoarthrotic knee joints. Acta Orthop Scand 51:871–879
7. Levy IM, Torzilli PA, Warren RF (1982) The effect of medial meniscectomy on anteriorposterior motion of the knee. J Bone Joint Surg Am 64:883–888
8. Walker PS, Hajek JV (1972) The load-bearing area in the knee joint. J Biomech 5:581–589
9. Bourne RB, Finlay JB, Papadopoulos P, Andreae P (1984) The effect of medial meniscectomy on strain distribution in the proximal part of the tibia. J Bone Joint Surg Am 66:1431–1437
10. Brody JM, Hulstyn MJ, Fleming BC, Tung GA (2007) The meniscal roots: gross anatomic correlation with 3-T MRI findings. AJR Am J Roentgenol 188:W446 –W 450

11. Wilmes P, Pape D, Kohn D, Seil R (2007) The reproducibility of radiographic measurement of lateral meniscus horn position. Arthroscopy 23:1079–1086

12. Wilmes P, Anagnostakos K, Weth C, Kohn D, Seil R (2008) The reproducibility of radiographic measurement of medial meniscus horn position. Arthroscopy 24:660–668

13. Beaupre A, Choukroun R, Guidouin R, Garneau R, Gerardin H, Cardou A (1986) Knee menisci. Correlation between microstructure and biomechanics. Clin Orthop Relat Res 72 – 75

14. Bullough PG, Munuera L, Murphy J, Weinstein AM (1970) The strength of the menisci of the knee as it relates to their fine structure. J Bone Joint Surg Br 52:564–567

15. Bursac P, Arnoczky S, York A (2009) Dynamic compressive behavior of human meniscus correlates with its extra-cellular matrix composition. Biorheology 46:227–237

16. Killian ML, Lepinski NM, Haut RC, Haut Donahue TL (2010) Regional and zonal histomorphological characteristics of the lapine menisci. Anat Rec (Hoboken) 293:1991–2000

17. Pereira H, Frias AM, Oliveira JM, Espregueira-Mendes J, Reis RL (2011) Tissue engineering and regenerative medicine strategies in meniscus lesions. Arthroscopy 27:1706–1719

18. Pereira H, Frias AM, Caridade SG et al (2011) Cellular and biomechanical segmental characterization of human meniscus. Osteoarthritis Cartilage 19:S205

19. Kohn D, Moreno B (1995) Meniscus insertion anatomy as a basis for meniscus replacement: a morphological cadaveric study. Arthroscopy 11:96–103

20. Gupte CM, Smith A, McDermott ID, Bull AM, Thomas RD, Amis AA (2002) Meniscofemoral ligaments revisited. Anatomical study, age correlation and clinical implications. J Bone Joint Surg Br 84:846–851

21. Gupte CM, Bull AM, Thomas RD, Amis AA (2003) The meniscofemoral ligaments: secondary restraints to the posterior drawer. Analysis of anteroposterior and rotary laxity in the intact and posterior-cruciate-deficient knee. J Bone Joint Surg Br 85:765–773

22. Makris EA, Hadidi P, Athanasiou KA (2011) The knee meniscus: structure-function, pathophysiology, current repair techniques, and prospects for regeneration. Biomaterials 32:7411–7431

23. Herwig J, Egner E, Buddecke E (1984) Chemical changes of human knee joint menisci in various stages of degeneration. Ann Rheum Dis 43:635–640

24. Sweigart MA, Athanasiou KA (2001) Toward tissue engineering of the knee meniscus. Tissue Eng 7:111–129

25. Cheung HS (1987) Distribution of type I, II, III and V in the pepsin solubilized collagens in bovine menisci. Connect Tissue Res 16:343–356

26. McDevitt CA, Webber RJ (1992) The ultrastructure and biochemistry of meniscal cartilage. Clin Orthop Relat Res 252:8–18

27. Ghosh P, Taylor TK (1987) The knee joint meniscus. A fibrocartilage of some distinction. Clin Orthop Relat Res 52 – 63

28. Scott PG, Nakano T, Dodd CM (1997) Isolation and characterization of small proteoglycans from different zones of the porcine knee meniscus. Biochim Biophys Acta 1336:254–262

29. Miller RR, McDevitt CA (1991) Thrombospondin in ligament, meniscus and intervertebral disc. Biochim Biophys Acta 1115:85–88

30. Ghadially FN, Thomas I, Yong N, Lalonde JM (1978) Ultrastructure of rabbit semilunar cartilages. J Anat 125:499–517

31. Nakata K, Shino K, Hamada M et al (2001) Human meniscus cell: characterization of the primary culture and use for tissue engineering. Clin Orthop Relat Res S208–S218

32. Melrose J, Smith S, Cake M, Read R, Whitelock J (2005) Comparative spatial and temporal localisation of perlecan, aggrecan and type I, II and IV collagen in the ovine meniscus: an ageing study. Histochem Cell Biol 124:225–235

33. Van der Bracht H, Verdonk R, Verbruggen G, Elewaut D, Verdonk P (2007) Cell based meniscus tissue engineering. In: Ashammakhi N, Reis RL, Chiellini E (eds) Topics in Tissue Engineering

34. Gunja NJ, Dujari D, Chen A, Luengo A, Fong JV, Hung CT (2012) Migration responses of outer and inner meniscus cells to applied direct current electric fields. J Orthop Res 30:103–111

35. Mauck RL, Martinez-Diaz GJ, Yuan X, Tuan RS (2007) Regional multilineage differentiation potential of meniscal fibrochondrocytes: implications for meniscus repair. Anat Rec (Hoboken) 290:48–58

36. Brian D, Mackenzie WG, Shim SS, Leung G (1985) The vascular and nerve supply of the human meniscus. Arthroscopy 1:58–62

37. Arnoczky SP, Warren RF (1982) Microvasculature of the human meniscus. Am J Sports Med10:90–95

38. Baker BE, Peckham AC, Pupparo F, Sanborn JC (1985) Review of meniscal injury and associated sports. Am J Sports Med 13:1–4

39. Bouyarmane H, Beaufils P, Pujol N et al (2014) Polyurethane scaffold in lateral meniscus segmental defects: clinical outcomes at 24 months follow-up. Orthop Traumatol Surg Res 100:153–157

40. Bulgheroni P, Bulgheroni E, Regazzola G, Mazzola C (2014) Polyurethane scaffold for the treatment of partial meniscal tears. Clinical results with a minimum two-year follow-up. Joints
1:161–166
41. Bulgheroni P, Murena L, Ratti C, Bulgheroni E, Ronga M, Cherubino P (2010) Follow-up of collagen meniscus implant patients: clinical, radiological, and magnetic resonance imaging results at
5 years. Knee 17:224–229
42. Cole BJ, Dennis MG, Lee SJ et al (2006) Prospective evaluation of allograft meniscus transplantation: a minimum 2-year follow-up. Am J Sports Med 34:919–927
43. Dangelmajer S, Familiari F, Simonetta R, Kaymakoglu M, Huri G (2017) Meniscal transplants and scaffolds: a systematic review of the literature. Knee Surg Relat Res 29:3–10
44. De Coninck T, Huysse W, Willemot L, Verdonk R, Verstraete K, Verdonk P (2013) Two-year follow-up study on clinical and radiological outcomes of polyurethane meniscal scaffolds. Am J Sports Med 41:64–72
45. Dhollander A, Verdonk P, Verdonk R (2016) Treatment of painful, irreparable partial meniscal defects with a polyurethane scaffold: midterm clinical outcomes and survival analysis. Am J Sports Med 44:2615–2621
46. Efe T, Getgood A, Schofer MD et al (2012) The safety and short-term efficacy of a novel polyurethane meniscal scaffold for the treatment of segmental medial meniscus deficiency. Knee Surg Sports Traumatol Arthrosc 20:1822–1830 10. Elattar M, Dhollander A, Verdonk R, Almqvist KF, Verdonk P (2011) Twenty-six years of meniscal allograft transplantation: is it still experimental? A meta-analysis of 44 trials. Knee Surg Sports Traumatol Arthrosc 19:147–157

11. Faivre B, Bouyarmane H, Lonjon G, Boisrenoult P, Pujol N, Beaufils P (2015) Actifit ® scaffold implantation: influence of preoperative meniscal extrusion on morphological and clinical outcomes. Orthop Traumatol Surg Res 101:703–708
12. Filardo G, Kon E, Perdisa F et al (2016) Polyurethane-based cell-free scaffold for the treatment of painful partial meniscus loss. Knee Surg Sports Traumatol Arthrosc 25:459–467
13. Gelber PE, Petrica AM, Isart A, Mari-Molina R, Monllau JC (2016) The magnetic resonance aspect of a polyurethane meniscal scaffold is worse in advanced cartilage defects without deterioration of clinical outcomes after a minimum two-year followup. Knee 22:389–394
14. Gelber PE, Isart A, Erquicia JI, Pelfort X, Tey-Pons M, Monllau JC (2015) Partial meniscus substitution with a polyurethane scaffold does not improve outcome after an open-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 23:334–339
15. Genovese E, Angeretti MG, Ronga M et al (2007) Follow-up of collagen meniscus implants by MRI. Radiol Med 112:1036–1048
16. Hefti F, Muller W, Jakob RP, Staubuli HU (1993) Evaluation of knee ligament injuries with the IKDC form. Knee Surg Sports Traumatol Arthrosc 1:226–234
17. Hirschmann A, Schiapparelli FF, Schenk L, Keller L, Amsler F, Hirschmann MT (2017) The Genovese grading scale is not reliable for MR assessment of collagen meniscus implants. Knee
    24:9–15
18. Hoher J, Munster A, Klein J, Eypasch E, Tiling T (1995) Validation and application of a subjective knee questionnaire. Knee Surg Sports Traumatol Arthrosc 3:26–33
19. Iorio R, Pagnottelli M, Vadalà A et al (2013) Open-wedge high tibial osteotomy: comparison between manual and computerassisted techniques. Knee Surg Sports Traumatol Arthrosc 21:113–119

20. Kon E, Filardo G, Zaffagnini S et al (2014) Biodegradable polyurethane meniscal scaffold for isolated partial lesions or as combined procedure for knees with multiple comorbidities: clinical results at 2 years. Knee Surg Sports Traumatol Arthrosc 22:128–134
21. Lee SJ, Aadalen KJ, Malaviya P et al (2006) Tibiofemoral contact mechanics after serial medial meniscectomies in the human cadaveric knee. Am J Sports Med 34:1334–1344
22. Linke RD, Ulmer M, Imhoff AB (2006) Replacement of the meniscus with a collagen implant (CMI). Oper Orthop Traumatol 18:453–462
23. Lysholm J, Gillquist J (1982) Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med 10:150–154
24. Martín-Hernández C, Ranera-García M, Díaz-Martínez JV et al (2015) Results of polyurethane implant for persistent knee pain after partial meniscectomy with a minimum of two years followup. Rev Esp Cir Ortop Traumatol 59:44–51
25. Monllau JC, Gelber PE, Abat F et al (2011) Outcome after partial medial meniscus substitution with the collagen meniscal implant at a minimum of 10 years' follow-up. Arthroscopy 27:933–943
26. Papalia R, Franceschi F, Diaz Balzani L, D'Adamio S, Maffulli N, Denaro V (2013) Scaffolds for partial meniscal replacement: an updated systematic review. Br Med Bull 107:19–40
27. Pereira H, Frias AM, Oliveira JM, Espregueira-Mendes J, Reis RL (2011) Tissue engineering and regenerative medicine strategies in meniscus lesions. Arthroscopy 27:1706–1719
28. Rodkey WG, DeHaven KE, Montgomery WH 3rd et al (2008) Comparison of the collagen meniscus implant with partial meniscectomy. A prospective randomized trial. J Bone Jt Surg Am 90:1413–1426

29. Rodkey WG, Steadman JR, Li ST (1999) A clinical study of collagen meniscus implants to restore the injured meniscus. Clin Orthop Relat Res 367:281–292
30. Roos EM, Lohmander LS (2003) The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. Health Qual Life Outcomes 1:64
31. Schüttler KF, Haberhauer F, Gesslein M et al (2016) Midterm follow-up after implantation of a polyurethane meniscal scaffold for segmental medial meniscus loss: maintenance of good clinical and MRI outcome. Knee Surg Sports Traumatol Arthrosc 24:1478–1484
32. Schüttler KF, Pöttgen S, Getgood A et al (2015) Improvement in outcomes after implantation of a novel polyurethane meniscal scaffold for the treatment of medial meniscus deficiency. Knee Surg Sports Traumatol Arthrosc 23:1929–1935
33. Shin YS, Lee HN, Sim HB, Kim HJ, Lee DH (2017) Polyurethane meniscal scaffolds lead to better clinical outcomes but worse articular cartilage status and greater absolute meniscal extrusion. Knee Surg Sports Traumatol Arthrosc. https://doi.org/10.1007/s00167-017-4650-3
34. Spencer SJ, Saithna A, Carmont MR, Dhillon MS, Thompson P, Spalding T (2012) Meniscal scaffolds: early experience and review of the literature. Knee 19:760–765
35. Steadman JR, Rodkey WG (2005) Tissue-engineered collagen meniscus implants: 5- to 6-year feasibility study results. Arthroscopy 21:515–525
36. Tegner Y, Lysholm J (1985) Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res 198:43–49
37. Verdonk P, Beaufils P, Bellemans J et al (2012) Successful treatment of painful irreparable partial meniscal defects with a polyurethane scaffold: two-year safety and clinical outcomes. Am J Sports Med 40:844–853

38. Verdonk PC, Verstraete KL, Almqvist KF et al (2006) Meniscal allograft transplantation: long-term clinical results with radiological and magnetic resonance imaging correlations. Knee Surg Sports Traumatol Arthrosc 14:694–706
39. Verdonk R, Verdonk P, Huysse W, Forsyth R, Heinrichs EL (2011) Tissue ingrowth after implantation of a novel, biodegradable polyurethane scaffold for treatment of Zaffagnini S, Marcheggiani Muccioli GM, Bulgheroni P et al (2012) Arthroscopic collagen meniscus implantation for partial lateral meniscal defects: a 2-year minimum follow-up study. Am J Sports Med 40:2281–2288
40. Zaffagnini S, Marcheggiani Muccioli GM, Lopomo N et al (2011) Prospective long-term outcomes of the medial collagen meniscus implant versus partial medial meniscectomy: a minimum 10-year follow-up study. Am J Sports Med 39:977–985
41. partial meniscal lesions. Am J Sports Med 39:774–782
42. Yoon KH, Lee SH, Bae DK, Park SY, Oh H (2013) Does varus alignment increase after medial meniscectomy? Knee Surg Sports Traumatol Arthrosc 21:2131–2136
43. Yulish BS, Montanez J, Goodfellow DB, Bryan PJ, Mulopulos GP, Modic MT (1987) Chondromalacia patellae: assessment with MR imaging. Radiology 164:763–766
44. Zaffagnini S, Grassi A, Marcheggiani Muccioli GM et al (2015) Two-year clinical
45. results of lateral collagen meniscus implant: a multicenter study. Arthroscopy 31:1269–1278
46. Verdonk PC, Demurie A, Almqvist KF, Veys EM, Verbruggen G, Verdonk R (2006) Transplantation of viable meniscal allograft. Surgical technique. J Bone Joint Surg Am Mar 88:109–118. Review
47. Goble EM, Verdonk R, Kohn D (1999) Arthroscopic and open surgical techniques for meniscus replacement–meniscal allograft transplantation and tendon autograft transplantation. Scand J Med Sci Sports 9(3):168–176

48. Messner K, Verdonk R (1999) It is necessary to anchor the meniscal transplants with bone plugs? A mini-battle. Scand J Med Sci Sports 9(3):186–187

49. Paletta GA Jr, Manning T, Snell E, Parker R, Bergfeld J (1997) The effect of allograft meniscal replacement on intraarticular contact area and pressures in the human knee. A biomechanical study. Am J Sports Med 25:692–698

50. Huang A, Hull ML, Howell SM (2003) The level of compressive load affects conclusions from statistical analyses to determine whether a lateral meniscal autograft restores tibial contact pressure to normal: a study in human cadaveric knees. J Orthop Res 21:459–464

51. Chen MI, Branch TP, Hutton WC (1996) Is it important to secure the horns during lateral meniscal transplantation? A cadaveric study. Arthroscopy 12:174–181

52. Alhalki MM, Howell SM, Hull ML (1999) How three methods for fixing a medial meniscal autograft affect tibial contact mechanics. Am J Sports Med 27:320–328

53. Berlet GC, Fowler PJ (1998) The anterior horn of the medial meniscus: an anatomic study of its insertion. Am J Sports Med 26:540–543

54. Sekaran SV, Hull ML, Howell SM (2002) Nonanatomic location of the posterior horn of a medial meniscal autograft implanted in a cadaveric knee adversely affects the pressure distribution on the tibial plateau. Am J Sports Med 30:74–82

55. Iñigo-Pavlovich R (2005) Radiofrequency and meniscus. From excision to repair. Sports Med Arthrosc Rev 13:193–197

56. Monllau JC, Leal J, Voss C, Pelfort X, Tey M, Pavlovich RI (2010) Good outcome after meniscal repair using an all-inside suturing system in combination with high-frequency biostimulation. Orthopedics 33(6):407–412

57. Cameron JC, Saha S (1997) Meniscal allograft transplantation for unicompartmental arthritis of the knee. Clin Orthop 337:164–171

58. Noyes FR, Barber-Westin SD (1995) Irradiated meniscus allografts in the human knee: a two to five year follow-up study. Orthop Trans 19:417

59. Verdonk PCM, Demurie A, Almqvist KF, Veys EM, Verbruggen, Verdonk R (2005)

60. Transplantation of viable meniscal allograft: survivorship analysis and clinical outcome of one hundred cases. J Bone Joint Surg Am 87:715–724

61. Ryu RK, Dunbar VWH, Morse GG (2002) Meniscal allograft replacement: a 1-year to 6- year experience. Arthroscopy 18:989–994

62. Stone KR, Walgenbach AW, Turek TJ, Freyer A, Hill MD (2006) Meniscus allograft survival in patients with moderate to severe unicompartmental arthritis: a 2- to 7-year follow-up. Arthroscopy 22(5):469–478

63. Bhosale AM, Myint P, Roberts S, Menage J, Harrison P, Ashton B, Smith T, McCall I, Richardson JB (2007) Combined autologous chondrocyte implantation and allogenic meniscus transplantation: a biological knee replacement. Knee 14(5):361–368

64. Walker PS, Erkman MJ (1975) The role of the menisci in force transmission across the knee. Clin Orthop 109:184–192

65. Johnson DL, Bealle D (1999) Meniscal allograft transplantation. Clin Sports Med 18:93–108

66. Cole BJ, Carter TR, Rodeo SA (2003) Allograft meniscal transplantation: background, techniques, and results. Instr Course Lect 52:383–396

67. Rodeo SA (2001) Meniscal allografts—where do we stand? Am J Sports Med 29:246–261

68. Cole BJ, Cohen B (2000) Chondral injuries of the knee. A contemporary view of cartilage restoration. Orthop Spec Ed 6:71–76

69. Rijk PC (2004) Meniscal allograft transplantation—part i: background, results, graft selection and preservation, and surgical considerations. Arthroscopy 20:728–743

70. Potter HG, Rodeo SA, Wickiewicz TL et al (1996) MR imaging of meniscal allografts: correlation with clinical and arthroscopic outcomes. Radiology 198:509–514

71. Zukor DJ, Cameron JC, Brooks PJ et al (1990) The fate of human meniscal allografts. In:

72. Ewing JW (ed) Articular cartilage and knee joint function. Raven, New York, pp 147–152 15. Garrett JC (1993) Meniscal transplantation: a review of 43 cases with 2- to 7- year follow-up. Sports Med Arthrosc Rev 1:164–167

73. Kuhn JE, Wojtys EM (1996) Allograft meniscal transplantation. Clin Sports Med 15:537–556

74. Stollsteimer GT, Shelton WR, Dukes A, Bomboy AL (2000) Meniscal allograft transplantation: a 1-to-5 year follow-up of 22 patients. Arthroscopy 16:343–347

75. Verdonk PCM, Demurie A, Almqvist KF, Veys EM, Verbruggen G, Verdonk R (2006)

76. Transplantation of viable meniscal allograft. J Bone Joint Surg Am 88(1 Suppl 1):109–118

77. Aagaard H, Jorgensen U, Bojsen-Moller F (2003) Immediate versus delayed meniscal allograft transplantation in sheep. Clin Orthop 406:218–227

78. Monllau JC, Gonzalez-Lucena G, Gelber P, Pelfort X (2010) Allograft meniscus transplantation: a current review. Tech Knee Surg 9(2):107–113

79. Kohn D, Moreno B (1995) Meniscus insertion anatomy as a basis for meniscus replacement: a morphological cadaveric study. Arthroscopy 11:96–103

80. Farr J, Meneghini RM, Cole BJ (2004) Allograft interference screw fixation in meniscus transplantation. Arthroscopy 20:322–327

81. King D (1936) The function of semilunar cartilages. J Bone Joint Surg 18A:1069

82. Fairbank TD (1948) Knee joint changes after meniscectomy. J Bone Joint Surg 30B:664–670

83. Burks RT, Metcalf MH, Metcalf RW (1997) Fifteen-year follow-up of arthroscopic partial meniscectomy. Arthroscopy 13(6):673–679

84. Higuchi H, Kimura M, Shirakura K, Terauchi M, Takagishi K (2000) Factors affecting longterm results after arthroscopic partial meniscectomy. Clin Orthop Relat Res 377:161–168

85. Stone KR, Rodkey WG, Webber RJ et al (1990) Future directions: collagen-based prostheses for meniscal regeneration. Clin Orthop 252:129–135

86. Stone KR, Rodkey WG, Webber RJ et al (1992) Meniscal regeneration with copolymeric collagen scaffolds. In vitro and in vivo studies evaluated clinically, histologically, and biochemically. Am J Sports Med 20:104–111

87. Stone KR, Steadman JR, Rodkey WG, Li S-T (1997) Regeneration of meniscal cartilage with use of a collagen scaffold. Analysis of preliminary data. J Bone Joint Surg Am 79:1770–1777

88. Steadman JR, Rodkey WG (2005) Tissue-engineered collagen meniscus implants: 5- to 6year feasibility study results. Arthroscopy 21(5):515–525

89. Zaffagnini S, Giordano G, Vascellari A et al (2007) Arthroscopic collagen meniscus implant results at 6–8 years follow up. Knee Surg Sports Traumatol Arthrosc 15(2):175–183

90. Bulgheroni P, Murena L, Ratti C, Bulgheroni E, Ronga M, Cherubino P (2010) Follow-up of collagen meniscus implant patients: clinical, radiological, and magnetic resonance imaging results at 5 years. Knee 17(3):224–229

91. Monllau JC, Gelber PE, Abat F et al (2011) Outcome after partial medial meniscus substitution with the collagen meniscal implant at a minimum of 10 years' follow-up. Arthroscopy 27(7):933–943

92. Burke JF (1983) Observations on the development of an artificial skin. J Trauma 23:543–551

93. Yannas IV, Orgill DP, Silver J et al (1985) Polymeric template facilitates regeneration of sciatic nerve across a 15 mm gap. Polym Mater Sci Eng 53:216–218

94. Li ST, Archibald SJ, Krarup C et al (1990) Semipermeable collagen nerve conduits for peripheral nerve regeneration. Polym Mater Sci Eng 62:575–582

95. Genovese E, Angeretti MG, Ronga M et al (2007) Follow-up of collagen meniscus implants by MRI. Radiol Med 112(7):1036–1048

96. Stone KR, Rosenberg T (1993) Surgical technique of meniscal replacement. Arthroscopy 9(2):234–237

97. Zaffagnini S, Marcheggiani Muccioli GM, Lopomo N et al (2011) Prospective long-term outcomes of the medial collagen meniscus implant versus partial meniscectomy: a minimum 10-year follow-up study. Am J Sports Med 39(5):977–985

98. Rodkey WG, DeHaven KE, Montgomery WH III et al (2008) Comparison of the collagen meniscus implant with partial meniscectomy: a prospective randomized trial. J Bone Joint Surg Am 90(7):1413–1426

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| **Actifit** | Actifit polyurethane scaffold |
| **CMI** | Collagen Meniscal Implant |
| **DMSO** | dimethyl sulfoxide ( |
| **ECM** | extracellular matrix |
| **GAGs** | glucosaminoglycans |
| **IKDC** | Knee Documentation Committee |
| **KOOS** | Osteoarthritis Outcome Score |
| **MAT** | meniscal allograft transplantation () |
| **PDS** | polydioxanone surgical sutures ( |
| **PT** | popliteus tendon ( |
| **VAS** | Visual Analog Scale |

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