Chapter

The Meniscus Deficient Knee: Options for Repair and Reconstruction

Matthew Brown

Abstract

The preservation of the structure of the meniscus despite a tear has been widely discussed in the literature. However, meniscectomy continues to be the most-performed meniscus surgery. In a percentage of patients, knee pain and swelling, as well as tibial plateau bony edema, follow meniscus resection; this panoply of symptoms is known as "post-meniscectomy syndrome". The management of this condition requires meniscus transplant in case of total meniscectomy or a meniscus scaffold in the case of a partial resection. This chapter aims to discuss the indication, surgical technique, and outcomes of collagen meniscus implants (CMI) for partial resections and meniscus transplants for full resections.

Keywords: meniscus transplant, collagen meniscus implant, post-meniscectomy syndrome, meniscus scaffold, osteoarthritis

1. Introduction

It is essential to understand the anatomy and biomechanics of the knee joint before performing a sub-total or total meniscectomy due to the possible catastrophic consequences at a long-term follow-up. Moreover, the medial and the lateral compartment of the knee have different kinematic properties and the clinician must take into account the different degree of mobility, bony structure, and load distribution between these two compartments. Biomechanical studies have demonstrated the essential role of the menisci on load transfer, in that a total meniscectomy can increase the contact area by 33 to 50 percent in a fully extended knee [1].

Walker et al. demonstrated that the lateral compartment is much more dependent on meniscal function than the medial one. The lateral meniscus carries a higher percentage of load transfer than the medial meniscus. This is due to a higher load being transferred directly by the exposed cartilage surface of the medial compartment [1]. The different bony morphology of the tibiofemoral compartments also play a part in this. In the sagittal plane, the medial convexity of the femoral condyle and the concavity of the tibial plateau provide a degree of congruity, even after a meniscectomy. While, on the lateral side, both the convexity of the femoral condyle and the lateral tibial plateau make this compartment much more prone to an increase in peak contact pressures after meniscectomy [2].

Clinically, the differences between the medial and lateral meniscus have been confirmed by worse results reported after lateral meniscectomy compared to medial meniscectomy at a long-term follow-up [3, 4]. These findings are even more stark if the meniscectomy is performed during adolescence: in a prospective 30 years of follow-up study, about 80% of patients after medial meniscectomy maintained good or excellent clinical results; in comparison to less than 50% for lateral meniscectomy [5].

The causal relationship of knee arthritis with meniscectomy led to the investigation of meniscal allograft transplantation for the post-meniscectomy patient experiencing pain and demonstrating arthritic changes [6]. Basic science studies have shown that although meniscal allografts cannot fully replicate the function of the native meniscus, the grafts are able to significantly improve joint contact area and decrease contact pressures [7, 8]. Also, early clinical series demonstrated isolated meniscal allograft transplantation to be a feasible procedure [9, 10]. However, the initial studies had variable outcomes due to significant differences in indications, surgical techniques, and tissue processing methods.

As experience was gained, the variables became more defined and the results improved. Numerous short and midterm studies have shown that meniscal allografts are able to provide pain relief and increase function with high rates of graft survivorship [11, 12]. More recently, a long-term study has been published demonstrating >50% graft survival at 20 years [13].

However, if a subtotal meniscectomy has previously been performed, a meniscal scaffold may be a more appropriate procedure, despite the relative lack of relevant articles with extended follow-up. There are two different scaffold types available on the market: the collagen meniscus implant (CMI) derived from a bovine collagen and the Actifit, a polyurethane scaffold [14, 15]. 3D printed scaffolds have been recently proposed as an experimental treatment and only a few case reports are available, while CMI and Actifit have been widely studied.

2. Biomechanics

After a meniscal tear, the effectiveness of meniscal repair strictly relies on the tissue quality and defect location with respect to the vascular supply. Tears in the vascularized “red” peripheral zone are more likely to heal, while the more common lesions in the avascular “white” zone have poor healing potential [16, 17]. When the majority of the meniscus is not salvageable, a meniscectomy is usually performed. It has been well documented that meniscectomy increases the risk of degenerative joint disease of the knee. For example, Persson et al. demonstrated that in almost 2,500 patients followed for more than 20 years, the risk of developing arthritis after a partial meniscectomy was almost 6 times higher than the standard population, with a 17% absolute risk [18].

Structurally, it has been demonstrated that meniscal allografts should be frozen, not sterilized using chemicals or radiation. It the first published series of isolated meniscal allografts, Milakowski et al. found that graft processing methods were vital to the success of the procedure [19]. He reported that lyophilized grafts lead to inferior results compared to fresh frozen grafts. While clinical series have not shown benefit of cryopreserved over fresh frozen, basic science studies have shown slightly better mechanic properties with cryopreserved, with a higher elastic modulus and point of rupture [20].

While meniscus allograft transplantation appropriately addresses a prior total or subtotal meniscectomy, an allograft is not a solution for the treatment of a partial meniscus defect. The Collagen Meniscus Implant (Ivy Sports Medicine, Germany) is a porous biologic scaffold. It consists of 97% type I collagen purified from bovine Achilles tendon while the remaining portion is composed of glycosaminoglycan (GAG). The specific size of the scaffold’s micropores are controlled to increase the fibrocartilage maturation while avoiding pseudo-capsule formation and foreign body reaction [21].

The second scaffold type consists of a synthetic polyurethane-based material composed of flexible segments made from polycaprolactone 80% and stiff segments made from urethane 20% (Actifit; Orteq Sports Medicine, London, UK). The scaffold slowly biodegrades, with an estimated decomposition time of 4 to 6 years. The implant itself is also highly porous to allow for sufficient ingrowth [22]. Both the Actifit and the CMI implants come in separate configurations for medial or lateral meniscus defects.

3. Surgical technique

The indications for both meniscus allograft and scaffold vary by surgeon, but in general, the patient should have previously undergone a total or partial meniscectomy, respectively, and present with discomfort only in the compartment previously operated upon. Maximal osteoarthritis allowed is grade III and a minimum 2 mm joint space. Also, if the knee is clinically unstable, it should be stabilized at the time of the procedure with respect to the anterior cruciate ligament. If operative knee alignment is more than 3–5 degrees different concerning the involved compartment compared to the contralateral knee, an osteotomy should be performed to unload the affected compartment.

For meniscus allograft transplant, the traditional methodology denotes the use of medial side double bone plugs, and a press-fit bone bridge (keyhole) method on the lateral side (**Figure 1**). On the medial side bone plugs are used due to graft size and anterior attachment variability, while on the lateral side bone bridges are used due to horn proximity [13]. In the case of a concomitant ACL and lateral meniscus, the femoral and tibial ACL tunnels are drilled initially and then the lateral meniscus trough is made. The femoral side of the ACL is then secured, followed by placement of the lateral meniscal allograft, and finally the tibial side of the ACL is secured. While a number of papers have investigated all-soft tissue constructs, several basic science studies have demonstrated improved biomechanical function with bony meniscal attachments [23, 24].

For meniscus scaffolds, surgical technique is similar for both devices. This begins with arthroscopic resection of the surrounding damaged tissue and subsequent implantation of a custom-sized scaffold. The sized scaffold is then sutured to the meniscal rim and capsule using standard techniques (**Figure 2**).

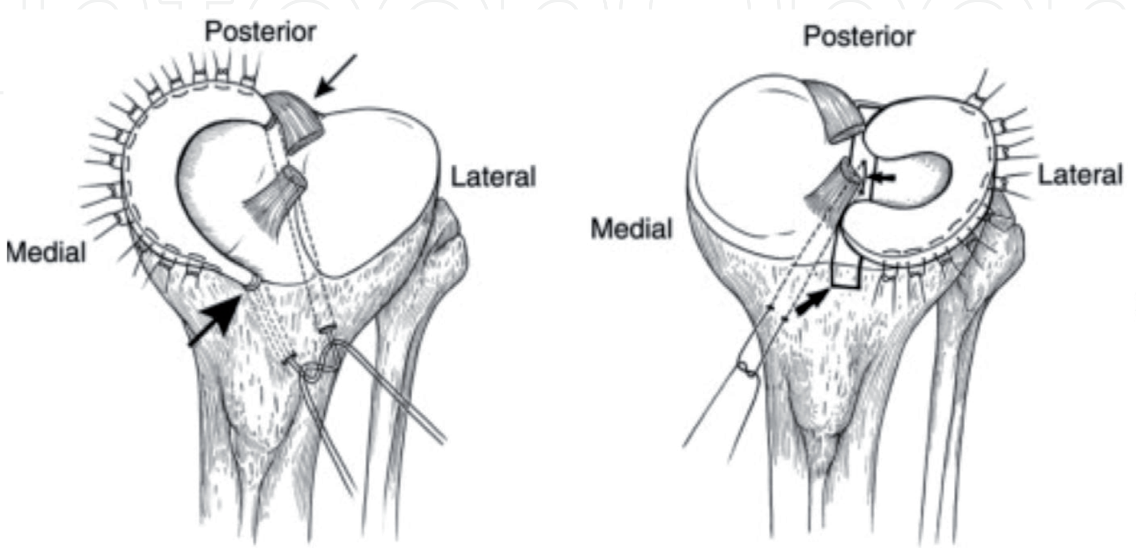

Figure 1.
Lateral keyhole technique with suture fixation and medial bone plug technique with suture fixation.

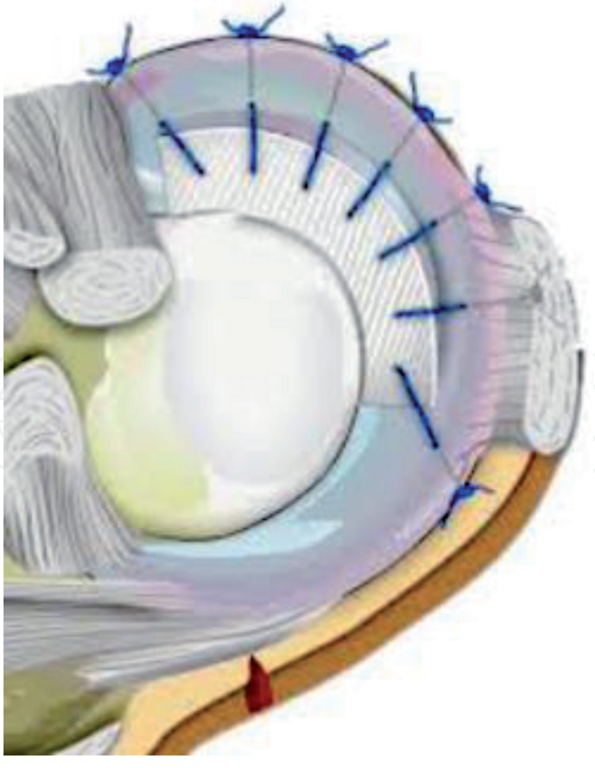

Figure 2.
Custom meniscal scaffold sizing and fixation.

Initially, a partial meniscectomy is performed, with surgical debridement back to the vascularized zone of the damaged portion of the native meniscus. It is particularly important that the meniscal rim be continuous, especially at the popliteal hiatus of the lateral meniscus. If there is complete loss of the tissue in front of the popliteus tendon, it should be considered a total loss and thus a contraindication for a meniscus scaffold. After debridement, the resulting void is sized along the peripheral edge using the meniscal ruler supplied with the scaffold. The scaffold is then cut to fit, placed into the knee, and finally sutured to the native meniscus. The surgeon can use an all-inside, inside-out, or outside-in suture technique depending on the area to be sutured and their experience and preference [25].

4. Clinical outcomes

Early results showed meniscus transplant could be a viable procedure; however, the initial results were mixed and raised concerns of long-term durability. It the first series of isolated meniscal allografts, Milakowski et al. demonstrated that graft processing methods were vital to the success of the procedure [9]. He reported the use of lyophilized grafts lead to inferior results compared to fresh frozen grafts. In the first American published series, Garrett et al. reported success in 35 of 43 patients (81%) at 2 to 7-year follow-up [26]. However, 6 of the 11 patients with grade IV chondromalacia failed, leading to the conclusion that while beneficial, grafts should not be placed in knees with advanced arthritis.

In the early experience of Noyes et al. they reported a high failure rate [27]. They evaluated 38 patients with 40 grafts, with a follow-up at an average of 40 months (24–62 months). While clinically the patients did significantly better, on MRI 30% of grafts demonstrated "altered characteristics" with another 28% demonstrating gross failure. Patients with no pre-operative arthritis demonstrated 10 abnormal MRIs out of 22, while the arthritic group showed abnormalities in 13 of 18, again demonstrating the folly of allograft implantation in arthritic knees.

Over time, graft processing methods, patient selection parameters, and surgical techniques were refined. With these improvements, meniscus allograft transplant ceased being seen as experimental (**Table 1**) [28].

Numerous short and mid-term studies reported that the vast majority of the grafts did not require reoperation, and a significant number of patients had decreased pain and improved function [29–32]. In a large series, Verdonk et al. reported a survivorship of 79% in the first 100 patients at a mean of 7.2 years [33].

Kim et al. published the most optimistic longer-term data on meniscal allograft transplantation, with 2 failures in 49 knees after a minimum follow-up of 8 years. The 10-year survival rate was 98.0% and the 15-year survival rate was 93.3% according to their Kaplan–Meier analysis [34].

Carter et al. demonstrated 10-year results in 40 of his original 46 patients [35]. Thirty-two (80%) stated they had improvement in symptoms from the preoperative level. The 10 year mean IKDC score improved from the pre-op mean 50.6 (range 32.2–68.9) to 70.1 (range 39.1–93.1). Seven patients required partial meniscectomies, for a 10-year graft survivorship of 83%. Of thirty-four patients with plain radiographs available at the time of implantation and at 10 years for comparison, fourteen had no change, 15 had mild osteoarthritis, and 5 moderate to advanced progression.

Noyes et al. in his later series, 58/72 patients had follow-up at a mean of 11.9 years ± 3.2 years [36]. Twenty-six underwent reoperation for a total graft survival rate of 55.2%. While demonstrating lower survivorship, their study group had greater chondral abnormalities and malalignment at baseline. Twenty patients underwent OATS procedures, and fourteen underwent an osteotomy in conjunction with the meniscal allograft at the time of implantation.

Van der Wal et al. reported on 63 meniscal allografts transplanted in 57 patients evaluated at 13.8 ± 2.8 years. Nineteen patients had grade IV chondromalacia at baseline, and their grafts were not secured with bone [37]. Their failure rate was 29% (18 grafts) and twelve patients (21%) were converted to a TKR at a mean follow-up of 10.8 years (range 4.3–13.7). They acknowledged that the degree of chondromalacia, ACL deficiency, and graft fixation contributed to failures, with these results confirming that strict patient selection is vital for long term success.

Case studies	**Year**	**Follow-up (y)**	**Survivorship (%)**
Garrett	1993	2+	81
Noyes	2004	2+	72
Verdonk	2006	5+	79
Kim	2017	8+	98
Carter	2012	10+	83
Noyes	2016	8+	55
Van der Waal	2009	11+	71
Carter	2020	20+	56
Systematic reviews			
Novaretti		10	73.5
		15	60
Bin	Medial	10+	53
	Lateral	10+	57

Table 1.
Selected meniscal transplant studies survivorship rates.

Systematic reviews have emerged providing data with compiled results at ten-plus years after meniscal transplant implantation. Novaretti et al. combined 11 studies with 688 meniscal allograft transplants and found a 10-year survivorship of 73.5%, and a 15-year survivorship of 60.3% [18]. Bin et al. evaluated the long-term survivorship of medial versus lateral meniscal transplants at greater than ten years in a meta-analysis of 9 studies totaling 694 grafts, and found that 52.6% of medial and 56.6% of lateral grafts were intact [19].

The one study to discuss 20-year follow-up was Carter et al. where 48/56 (86.7%) of patients were able to be contacted, and of those, had 21 required surgical treatment of the graft. Thirteen patients had an isolated partial meniscectomy. Eight patients had knee arthroplasty with 1 having prior partial graft removal and one also had a high tibial osteotomy (HTO). The average time to arthroplasty was 12.7 years. The graft survivorship was therefore 56.2% [13].

The take-away points from the usage of meniscal transplants involve proper patient selection, use of a properly prepared graft, and implantation in an appropriate knee. When an average-weight patient without varus or valgus knee abnormalities has a fresh meniscal allograft placed in a stable knee without moderate or severe arthritis or chondral loss, the graft survival can potentially be greater than twenty years.

The data supporting meniscal scaffold implantation does not go back nearly as long as meniscal transplant but is also robust. Clinical studies report outcomes for CMI ranging up to 12 years, while the longest study on Actifit reports up to 8 years, both demonstrating improvements in all knee clinical outcome scales (**Table 2**).

For the CMI implant, Monllau et al. demonstrated 83% good and excellent results at 10-year follow-up for 22 patients [38]. In a randomized trial comparing the long-term results of patients with ACL rupture and partial medial meniscus defects treated with ACL reconstruction and partial medial meniscectomy versus medial CMI implant, Bulgheroni et al. demonstrated significant improvement of all clinical scores at an average of 9.6 years [39]. Also, Zaffagnini et al. showed prospective study results between medial CMI implantation and partial medial meniscectomy [40]. The CMI group showed significantly lower VAS for pain, higher objective IKDC, and Tegner scores at 10-year follow-up.

The Actifit results are similarly impressive. Schuttler et al. demonstrated significant improvement in VAS from 5 preoperatively to 1 at 4 years of follow-up in a group of 18 Actifit patients [41]. Leroy et al. also showed, with a minimal follow-up of 5 years, 15 patients improved from 5.3 and 50 preoperative VAS and subjective IKDC scores respectively to 2.9 and 79 [42]. Finally, a meta-analysis of 613 Actifit patients demonstrated both VAS and Tegner scores improving significantly remaining higher up to 72 months [43]. Overall, there has been degeneration of the

Case studies (CMI)	Year	Follow-up (y)	Survivorship (%)
Monllau	2011	10+	83
Bulgheroni	2015	6+	not listed
Zaffagnini	2011	10+	88
Leroy	2017	5+	77
(Actifit)			
Schuttler	2016	2+	100
Systematic reviews			
Filardo	2015	CMI/Actifit 2+	94

Table 2.
Selected meniscal scaffold studies survivorship rates.

scaffold over time with some resulting increase in osteoarthritis, with a reported rate of 9.9% at a mean follow-up of 40 months and 6.7% at a mean follow-up of 44 months, for the Actifit and CMI patients, respectively [43].

The vast majority of meniscal scaffold literature has been published on medial implants, with a recent systematic review including 396 CMI with only 10% of them were implanted in the lateral compartment [44]. Zaffagnini et al. investigated 43 patients at 24± 1.9 months after lateral CMI implant. Their Lysholm score improved from 64.3 ± 18.4 preoperatively to 93.2 ± 7.2 at final follow-up, with pain experienced during strenuous activity and at rest was significantly reduced. At 2 years of follow-up, roughly 60% of patients reported activity levels similar to their preinjury values with a satisfaction rate of 95%. The presence of a higher BMI, the need for concomitant procedures, and a chronic injury pattern resulted in reduced outcomes [45].

Finally, Hirschmann et al. demonstrated the results of a series of 67 patients undergoing medial or lateral CMI implantation associated with ACL reconstruction (45%), high tibial osteotomy (7.5%) or microfracture (4.5%). At one year the cohort demonstrated a marked decrease in pain with a subsequent improvement in the Tegner, IKDC and Lysholm scores, with comparable results of the medial and the lateral groups [46].

And so, for the meniscal scaffolds, the useage and survivorship appear to be similar to those of the transplants; however, these implants are placed into patients with contained meniscal defects as opposed to the full meniscal loss which necessitates the use of a meniscus transplant. When an average-weight patient without varus or valgus knee abnormalities has a meniscal scaffold placed in a partially debreided meniscus in an otherwise stable knee without moderate or severe arthritis or chondral loss, the graft survival can potentially be greater than ten years based on current data.

5. Conclusions

For the patient with "post-meniscectomy syndrome" with either a partially or entirely deficient meniscus, surgical treatment options exist which have demonstrated both short, medium, and in the case of meniscus allograft, long term success. Allografts have demonstrated greater than 50% survivorship at 20-year follow-up, while scaffolds have demonstrated the progressive reabsorption with substitution with a meniscus-like tissue with a potential chondroprotective effect in shorter-term studies. For both allografts and scaffolds, patient selection and the treatment of concomitant knee pathology is mandatory in order to achieve both short and long-term clinical improvement.

Author details

Matthew Brown
University of Arizona, Phoenix, AZ, USA

*Address all correspondence to: mjb9rc@mail.missouri.edu

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