

## Current Concepts

# Meniscal Allograft Transplantation— Part I: Background, Results, Graft Selection and Preservation, and Surgical Considerations

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**Abstract:** Removal of the meniscus leads to progressive degenerative arthritis of the knee on a long-term basis. Therefore, meniscal allograft transplantation has been proposed as an alternative to meniscectomy. Although several experimental and clinical studies have documented that meniscal allografts show capsular ingrowth in meniscectomized knees, it remains to be established whether meniscal allograft transplantation can prevent degenerative changes after meniscectomy. Part 1 of this Current Concepts review will discuss the function, anatomy, and composition of the meniscus, followed by the history of surgery of meniscal tears and the healing of meniscal allografts in experimental and clinical studies. In addition, issues concerning preservation techniques, immunological reactions, sizing, disease transmission, indications, surgical technique, graft fixation, rehabilitation, and complications, will be taken into consideration. It can be concluded that the use of meniscal allografts in clinical practice has progressed to a point where relief of pain may be expected for the short-term. **Key Words:** Meniscus—Meniscectomy—Meniscal transplantation—Allograft—Articular cartilage—Degenerative changes.

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Many experimental and clinical studies have shown that meniscectomy results in osteoarthritis and joint deterioration in the long term.<sup>1-6</sup> As a consequence, advancements have been made in the treatment of meniscal tears toward more meniscus-retaining procedures. Meniscal repair is the treatment of choice when the tear is in an appropriate region, but this procedure cannot be performed on all damaged menisci or in previously meniscectomized knee joints.<sup>7-9</sup> In this situation, meniscal allograft transplantation may offer an attractive alternative. However,

meniscal allograft transplantation is still in its investigational phase and the long-term viability and function of meniscal allografts remain to be established. Although experimental and clinical studies have shown that meniscal allografts can heal to the surrounding capsule, their ability to prevent degenerative arthritis is yet to be evaluated.<sup>10-14</sup> The aim of this review is to evaluate the values of meniscal allograft transplantation and the potential of this procedure to prevent degenerative changes of the articular cartilage.

### FUNCTION, ANATOMY, AND COMPOSITION OF THE MENISCUS

Recognition of the importance of the meniscus has induced numerous studies describing the functions of knee joint menisci.<sup>15-19</sup> Menisci are weight-bearing, increase joint congruency, stabilize the knee, facilitate the rotation of the opposing articular surfaces of the

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0749-8063/04/2007-3930\$30.00/0  
doi:10.1016/j.arthro.2004.06.015

joint, and improve articular cartilage nutrition and lubrication. The load transmission across the medial compartment is shared equally between the articular cartilage and medial meniscus, whereas the lateral meniscus carries 70% of the load transmitted across the lateral compartment.<sup>19</sup> The anatomic configuration of the meniscus, which forms a semilunar wedge-shaped structure, enhances tibiofemoral stability by filling the void created by the incongruous femoral condyle and tibial plateau. The medial meniscus is oval in shape and covers approximately 30% of the medial tibial plateau. The anterior horn is secured in front of the anterior cruciate ligament (ACL) to the tibia and to the transverse ligament, which is attached to the anterior horn of the lateral meniscus. At its midportion, the medial meniscus is attached to the tibial plateau by the meniscotibial or coronary ligaments and to the femur and tibia by the medial collateral ligament. The posterior horn is attached to the posterior intercondylar fossa of the tibia between the insertion of the posterior cruciate ligament and the posterior insertion of the lateral meniscus. The circumference of the medial meniscus is firmly attached to the capsule. The lateral meniscus is the more mobile of the 2 menisci. It is relatively circular in shape and covers approximately 50% of the lateral tibial plateau. The anterior horn is attached to the transverse ligament and to the tibial eminence behind the insertion of the ACL, with which it partially blends. The posterior horn is attached to the tibia in the intercondylar region anterior to the posterior horn of the medial meniscus and also to the medial femoral condyle by the ligaments of Humphry and Wrisberg.<sup>20</sup> The loose peripheral attachment to the plateau, also known as the coronary ligament, is interrupted by the popliteus tendon.

The vascularization to the menisci is supplied from the medial and lateral genicular arteries. A premeniscal capillary network, arising from branches of these arteries, originates in the synovial and capsular tissues of the knee along the periphery of the menisci.<sup>21</sup> These perimeniscal vessels show a circumferential pattern, with radial branches directed toward the center of the joint supplying the peripheral 10% to 25% of the menisci. Nutrition of the remaining central portions of the menisci relies on diffusion from the synovial fluid, as these portions are avascular. Neuroreceptors are present in menisci that have mechanoreceptive and proprioceptive functions.<sup>22</sup> The horn insertions and the outer third of the menisci contain larger concentrations of these nerve endings than the central part. This may reflect the need for afferent information at

the extremes of flexion and extension, which contributes to a reflex arc that stimulates protective or postural muscular reflexes.<sup>23</sup>

Menisci are fibrocartilaginous structures that contain about 75% water, 20% collagen fibers, and a small amount of proteoglycans and cells. Type I collagen accounts for more than 90% of the total collagen present, but types II, III, V, and VI have also been shown to be present in small amounts.<sup>24,25</sup> These collagen fibers are circumferentially oriented, woven together by radially oriented fibers.<sup>26</sup> During compressional loading, the femoral condylar surfaces displace the menisci radially because of their concave wedge shape and convert axial load into tensile strain. Because menisci are anchored anteriorly and posteriorly, this displacement generates circumferential hoop stresses that resist extrusion of the menisci from between the femoral condyle and the tibial plateau.

## HISTORY

Fairbanks<sup>3</sup> was the first to discuss the importance of the meniscus in the protection of articular cartilage of the knee joint in his study on radiological changes in the knee after meniscectomy. Before this publication, menisci were considered to be vestigial remnants of leg muscle which could be removed without any harmful effect.<sup>27</sup> Because it has been shown that removal of the meniscus leads to degenerative changes of the knee joint, attempts have been made to preserve the injured meniscus whenever possible. Although partial meniscectomy reduces degeneration of articular cartilage, compared with total meniscectomy, it results in stresses on the underlying cartilage that are higher than in normal knees and, therefore, osteoarthritis is not prevented.<sup>2,28-30</sup>

In 1885, Annandale<sup>31</sup> was the first to repair a torn meniscus. King,<sup>32</sup> and later Arnoczky and Warren,<sup>21</sup> reported that for tears to heal, menisci have to be in contact with the peripheral vascular area of the meniscus. In efforts to repair peripheral meniscal tears, open and arthroscopic repair, synovial abrasion, fibrin clots, and trephination have been used successfully in experimental studies and clinical trials.<sup>8,33-37</sup> To improve healing of tears in the avascular part of menisci, the use of fibrin clots and porous polymers has been investigated.<sup>38,39</sup> However, partial meniscectomy and meniscal repair are not applicable to all injured menisci and, in these cases, replacement of the meniscus with an allograft, an autograft, or a prosthesis can be considered. The concept of meniscal replacement can be traced back to Lexer and Gebhardt who performed,

in 1916 and 1933, respectively, fat tissue interposition arthroplasty in an attempt to replace a meniscus.<sup>40</sup> The first meniscal allograft procedures were combined with complete knee transplantation during limb-sparing reconstructions almost a century ago.<sup>41</sup> Loch et al.<sup>42</sup> transplanted massive proximal osteochondral allografts with meniscal allografts after tibial plateau fractures and reported encouraging results. In 1984, the first meniscal allograft transplantation in humans was reported by Milachowski.<sup>40</sup> Replacement of the meniscus cartilage by artificial materials and meniscal scaffolds has been performed with little success so far.<sup>43-52</sup>

## STUDY RESULTS

### Animal Studies

Meniscus transplantation has been investigated in various animal models. In a sheep model, Milachowski et al.<sup>53</sup> reported uneventful capsular healing 6 weeks after implantation of both lyophilized gamma-sterilized allografts and deep-frozen allografts. Mikic et al.<sup>54</sup> transplanted 25 fresh meniscal allografts in 15 dogs and found complete healing in 18 knees, incomplete healing in 3, and healing by massive fibrovascular scar tissue in 4 knees. In a rabbit study, Cummins et al.<sup>12</sup> performed 16 meniscal transplantations and observed peripheral healing of all allografts and only partial extrusion in 2 animals 3 months after implantation. These findings were in agreement with those of Tachibana<sup>55</sup> who showed good healing of allografts in rabbit knees 4 weeks after implantation. The transplanted menisci showed repopulation with cells from 2 sources; synovial tissue and parameniscal connective tissue. Host cell graft repopulation was confirmed by Jackson et al.<sup>56</sup> who found no donor DNA within meniscal allografts in goats at 4 weeks after transplantation whereas the host DNA content approached or exceeded the amount present in the contralateral control meniscus. Arnoczky et al.<sup>10</sup> transplanted cryopreserved menisci in dogs and found a normal gross appearance of the grafts with a normal cell population and proteoglycan component 6 months after surgery and revascularization with small vessels originating from capsular and synovial tissue. In another study using dogs, Arnoczky et al.<sup>57</sup> studied cellular repopulation of deep-frozen meniscal autografts after reimplantation. Autoradiography showed that the freezing process effectively killed all cells in the meniscus. All implanted autografts demonstrated complete healing to the periphery. However,

a change in the collagen structure of the superficial and subsuperficial layers of the meniscus was found that could result in an alternation of the material properties of the meniscus. Six months after reimplantation, the menisci were repopulated with host cells from the synovium. Mikic et al.<sup>54</sup> observed a decreased number of cells in meniscal transplants compared with controls at 8 and 12 months after transplantation using fresh allografts in dogs. Jackson et al.<sup>13</sup> reported initially good-appearing allografts in goats but observed an increase in water content and a decrease in uronic acid in the extracellular matrix 6 months after transplantation, suggesting degeneration. In a sheep study, Szomor et al.<sup>58</sup> transplanted 8 medial meniscal allografts and showed uneventful healing to the surrounding capsule at 4 months follow-up. Nevertheless, there was clear fibrinoid degeneration, areas of hypocellularity, and cloning of meniscal cells in all of the allografts. Bylski-Austrow et al.<sup>59</sup> showed incomplete peripheral healing of deep-frozen meniscal allografts in goat knees 6 months after transplantation. Furthermore, they found that, despite the presence of cells in the center of meniscal allografts 8 months after transplantation, restoration of meniscal load-bearing function was only partial. In contrast, it has been shown in dogs that mechanical properties of transplanted cryopreserved menisci, such as tensile strength and elastic modulus, were similar to those of normal control menisci 6 months after transplantation.<sup>60</sup> In addition, Canham and Stanish<sup>61</sup> found a reduction in the area of the tibial surface covered by meniscal tissue after implantation in dog knees caused by shrinkage of the allografts, resulting in a doubling of the exposed articular cartilage. Rijk and Van Noorden<sup>62</sup> evaluated fresh meniscal allografts in rabbits 6 weeks and 1 year after immediate transplantation and 1 year after delayed transplantation performed 6 weeks after meniscectomy. Eighteen of 20 menisci showed capsular ingrowth. Two allografts in the delayed transplant group were completely degenerated. No clear differences in histologic architecture were observed between primary and secondarily transplanted specimen. However, the results showed that delayed meniscal allograft transplantation leads to more graft shrinkage than immediate allograft transplantation. In conclusion, it can be stated that healing of meniscal allografts has been reported in several experimental studies, but concerns about graft shrinkage, hypocellularity, biochemical changes, and long-term functional survival remain.

## Clinical Studies

Meniscal allograft transplantation in humans has been performed despite the conflicting results of allografting in several experimental studies. Most series of patients have been small and there is a lack of uniformity between patient selection, surgical technique, and follow-up. The wide variability among clinical studies in the literature so far is summarized in Table 1. In addition, different measures of outcome have been used without discrimination between lateral and medial transplantations. Garrett<sup>63</sup> has demonstrated that clinical evaluation using symptoms and physical examination only as outcome does not allow reliable assessment of the status of the meniscus. For objective evaluation of meniscal allografts after transplantation, the use of second-look arthroscopy and magnetic resonance imaging (MRI) has been described. Table 2 reviews the results of the published clinical follow-up studies. At second-look arthroscopy 6 months after surgery, Keene et al.<sup>64</sup> reported a single case of successful lateral meniscal transplantation with a fresh allograft using arthroscopic technique. Milachowski et al.<sup>40</sup> transplanted 22 menisci (16 lyophilized, 6 fresh-frozen) into the medial compartment in combination with reconstruction of the ACL and rated 3 as failures (1 fresh frozen graft and 2 lyophilized graft) at a mean follow-up of 14 months. Probably the results in this study were positively affected by the additional effect of the regained stability. Recently, Wirth et al.<sup>65</sup> re-evaluated the results of these first meniscal transplantations and reported a deterioration of clinical results after implantation of both deep-frozen and lyophilized meniscal allografts during a follow-up of 14 years. Although patients with deep-frozen meniscal transplants generally showed better results than patients with lyophilized meniscal allografts, significant differences between transplanted patients and a meniscectomy control group were not found. Zukor et al.<sup>66</sup> performed simultaneous transplantation of fresh meniscal and osteochondral allografts in 28 knees of 26 patients with an average follow-up of 4.5 years and reported a 75% success rate. Garrett<sup>63</sup> performed 6 isolated meniscal transplantations and 37 transplantations in combination with either an ACL reconstruction or an osteotomy. A well-healed meniscal rim and no significant graft shrinkage was reported in 20 of the 28 patients who were evaluated arthroscopically at a 2-year minimum follow-up. Fifteen other patients who did not undergo arthro-

scopic re-evaluation remained asymptomatic. Carter<sup>67</sup> evaluated 38 of 46 meniscal transplants in 38 patients arthroscopically 24 to 73 months after implantation and found 4 patients with shrinkage of the meniscus and 4 failures. Thirty-two patients had relief of pain and improvement in activities. Ryu et al.<sup>68</sup> evaluated 16 lateral and 10 medial meniscal allografts in 25 patients retrospectively at 12 to 72 months follow-up. Twelve patients underwent concomitant ACL reconstruction. Clinical evaluation showed significantly reduced pain and improved function compared with the preoperative findings. At second-look arthroscopy in 10 patients, 5 menisci appeared to be normal, 3 showed some degree of shrinkage, and 2 showed a meniscal tear. Veltri et al.<sup>69</sup> performed 6 lateral, 6 medial, and 2 bilateral meniscal transplantations in 14 patients. Ten patients had associated ACL reconstructions, one had an associated posterior cruciate ligament reconstruction, and one had an ACL and posterior cruciate ligament reconstruction. Two patients complained of persistent joint line pain over the affected compartment at an average follow-up of 8 months. Of the 11 patients with more than 6 months of follow-up, 7 underwent second-look arthroscopy showing complete peripheral healing in 5 of 7 allografts. The patients who were not evaluated arthroscopically were clinically asymptomatic. Goble et al.<sup>70</sup> performed 47 cryopreserved meniscal allograft transplantations in 45 patients. Seventeen of 18 patients at 2 year follow-up reported a significant decrease in knee pain and improvement in function on a subjective evaluation. Ten of 13 patients who underwent second-look arthroscopy showed a well-healed and functional meniscus. Biopsies performed on 8 grafts revealed an average of 80% viable meniscal tissue. Noyes et al.<sup>71</sup> evaluated 96 fresh-frozen irradiated grafts in 82 patients. Twenty-nine menisci failed within 24 months after implantation and were removed. Arthroscopy and/or MRI data from all 96 allografts showed that 22% of the grafts healed, 34% healed partially, and 44% failed. Verdonk<sup>70</sup> evaluated 54 fresh meniscal allograft transplantations in 51 patients (26 medial, 22 lateral, 3 both medial and lateral) with a mean follow-up of 4.5 years. Meniscal transplantation only was performed in 35 patients, combined with a valgus osteotomy of the tibia in 14 cases, and with an intra-articular ACL reconstruction in 1 patient. Another patient underwent lateral meniscal transplantation combined with a femoral varus osteotomy. There was a significant difference between

**TABLE 1.** *Materials and Methods of Published Clinical Studies Evaluating Meniscal Transplantation*

| Study                                | No. of Patients (No. of Grafts) | Mean Follow-up (range) | Preservation/Fixation of Horns                                     | Concomitant Procedures/Surgical Technique  | Compartment (med/lat/combined) |
|--------------------------------------|---------------------------------|------------------------|--|--|--------------------------------|
| Milachowski et al. <sup>40</sup>     | 22 (22)                         | 14 mo (4-24)           | 16 lyophilized<br>6 fresh-frozen gamma irradiated/sutures          | 22 ACL reconstruction/open   | 22/0/0                         |
| Zukor et al. <sup>66</sup>           | 26 (28)                         | 4.5 yr (1-unknown)     | Fresh/26 left attached to donor tibial plateau, 2 unknown fixation | 26 osteochondral allograft TP<br>2 osteochondral allograft FC/open   | 6/22/0                         |
| Garret and Stevenson <sup>88</sup>   | 6 (6)                           | 30 mo (24-44)          | Fresh/sutures  | 3 ACL reconstruction<br>2 osteochondral allograft FC<br>1 ACL reconstruction + osteochondral allograft FC/open   | 4/2/0                          |
| Garret <sup>63</sup>                 | 43 (44)                         | Mean unknown (2-7 yr)  | 16 fresh<br>27 cryopreserved/bone bridge                           | 24 ACL reconstruction<br>13 osteotomy<br>11 osteochondral allograft/open   | 34/8/1                         |
| Veltri et al. <sup>69</sup>          | 14 (16)                         | 8 mo (range unknown)   | Cryopreserved and deep frozen/bone blocks                          | 10 ACL reconstruction<br>1 PCL reconstruction<br>1 ACL + PCL reconstruction/open and arthroscopically assisted   | 6/6/2                          |
| Van Arkel and De Boer <sup>14</sup>  | 23 (25)                         | 3 yr (2-5)             | Cryopreserved/sutures  | Open   | 7/14/2                         |
| Cameron and Saha <sup>11</sup>       | 63 (67)                         | 31 mo (12-66)          | Deep-frozen, gamma irradiated/sutures                              | 5 ACL reconstruction<br>28 tibial osteotomy<br>6 femoral osteotomy<br>7 ACL reconstruction + tibial osteotomy/open   | 37/30/0                        |
| Verdonk <sup>70</sup>                | 51 (54)                         | 4.6 yr (1.5-8.4)       | Fresh/sutures  | 1 ACL reconstruction<br>14 tibial osteotomy<br>1 femoral osteotomy/open  | 26/22/3                        |
| Carter <sup>67</sup>                 | 46 (46)                         | 35 mo (24-73)          | Cryopreserved/medial bone blocks lateral bone bridge               | 30 ACL reconstruction<br>4 tibial osteotomy<br>1 MCL repair/arthroscopically assisted  | 39/7/0                         |
| Stollsteimer et al. <sup>72</sup>    | 22 (23)                         | 40 mo (13-69)          | Cryopreserved/bone blocks  | Arthroscopically assisted  | 11/12/0                        |
| Van Arkel and De Boer <sup>139</sup> | 57 (63)                         | 60 mo (4-126)          | Cryopreserved/sutures  | 2 ACL reconstruction/open  | 17/34/6                        |
| Rath et al. <sup>73</sup>            | 18 (22)                         | 54 mo (24-97)          | Cryopreserved/medial bone blocks lateral bone bridge               | 11 ACL reconstruction<br>1 transfer tibial tubercle<br>3 partial meniscectomy opposite meniscus<br>1 contralateral meniscal repair/arthroscopically assisted | 13/5/2                         |
| Wirth et al. <sup>65</sup>           | 22 (22)                         | 14 yr (12-15)          | 16 lyophilized<br>6 deep-frozen/sutures                            | 22 ACL reconstruction<br>19 femoral advancement MCL/open   | 22/0/0                         |
| Ryu et al. <sup>68</sup>             | 25 (26)                         | 33 mo (12-72)          | Cryopreserved/medial bone blocks lateral bone bridge               | 12 ACL reconstruction/open   | 10/16/0                        |

Abbreviations: ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MCL, medial collateral ligament; TP, tibial plateau; FC, femoral condyle.

preoperative and postoperative pain evaluation; 83% of the patients who were unable to work preoperatively because of pain went back to their original work. However, the clinical results deteriorated over the years, especially between the fifth and sixth year postoperatively. MRI evaluation was performed 103 times in 34 patients with 39 allografts after 2 to 73 months postoperatively. Although the anterior horn of the transplanted menisci seemed to be absent in 65% of the cases, 80% of the patients showed a normal shape and position of the posterior horn. Stollsteimer et al.<sup>72</sup> performed 12 lateral and 11 medial transplantations in 22 patients with cryopreserved allografts and reported improvement of preoperative pain in all knees at 1 to 5 year follow-up. In 12 patients, MRI was performed and showed on average a 37% shrinkage of the allografts compared with the normal contralateral meniscus. Van Arkel and De Boer<sup>14</sup> transplanted 25 cryopreserved menisci in 23 patients (14 lateral, 7 medial, 2 both medial and lateral) and reported 3 failures at a mean follow-up of 3 year because of partial loosening of the graft. Cameron and Saha<sup>11</sup> transplanted 67 deep-frozen gamma-irradiated meniscal allografts (37 medial, 30 lateral) in the knees of 63 patients with advanced unicompartmental arthritis. Twenty-one knees received isolated allografts, 5 knees received an allograft combined with an ACL reconstruction, 34 received an allograft in combination with an osteotomy, and 7 knees underwent a combined medial meniscal allograft transplantation, valgus high tibial osteotomy, and ACL reconstruction. Eighty-seven percent of the patients had a good to excellent result on the basis of a 100-point functional knee score at a 1- to 5.5-year follow-up. Seventeen of 20 patients (85%) with transplants more than 3 years after surgery showed good to excellent results. Rath et al.<sup>73</sup> showed alleviation of symptoms after transplantation of 15 medial and 7 lateral menisci in 18 patients at a mean follow-up of 54 months. However, at second-look arthroscopy in 10 patients, 8 symptomatic meniscal tears were found, necessitating 6 partial and 2 total meniscectomies. Cole et al.<sup>74</sup> reported on 20 meniscal transplantations at over 2 year follow-up showing 12 nearly normal knees and 4 normal knees according to the International Knee Documentation Committee (IKDC) rating system.<sup>75</sup> Four allografts failed, all in patients with grade 4 arthrosis. In a histologic evaluation of small biopsy specimens of 28 meniscal allografts, Rodeo et al.<sup>76</sup> found repopulation of allografts with cells that appeared to be derived from the synovial

membrane. The process of cellular repopulation and graft revascularization actively remodeled the extracellular matrix. It is suggested that this remodeling may weaken the meniscal tissue and make the allograft more susceptible to injury. It can be concluded that most early studies showed meniscal healing to the periphery and improvements in pain and knee function after transplantation. However, the long-term outcome of meniscal allografts on pain relief and in reducing or slowing degenerative changes in articular cartilage remains to be established.

### PRESERVATION OF ALLOGRAFTS

Fresh- and deep-frozen, lyophilized (freeze-dried), and cryopreserved meniscal allografts can heal and function.<sup>12,13,53,54,56</sup> Fresh allografts may well be the ideal type of transplant because fresh tissue contains large numbers of viable cells. Several studies have suggested that a viable chondrocyte population may have a beneficial effect in maintaining the extracellular matrix and the mechanical integrity of the allograft after transplantation.<sup>77,78</sup> Verdonk<sup>79</sup> transplanted 40 fresh grafts in 36 patients and found intact grafts using MRI in all patients and arthroscopic inspection in 12 patients. The rationale for maintaining cell viability in meniscal tissue is based on findings in articular cartilage that showed a change in the material properties of nonviable articular cartilage following transplantation.<sup>80,81</sup> Fresh allografts can be kept at 4°C in sterile tissue culture medium for 7 days without loss of viability.<sup>82</sup> However, in clinical practice, the availability of a fresh transplant is limited and the impossibility of matching the meniscal size of donor and receiver may limit further the applicability of this type of graft. Furthermore, the risk of disease transmission is greater in unprocessed grafts, as serologic testing may not be complete before graft transplantation, and secondary methods of graft sterilization cannot be used, as they would destroy the viable donor cells. On the other hand, Jackson et al.<sup>56</sup> performed DNA typing after transplantation in goats, and showed that donor DNA in the transplanted meniscus was entirely replaced by host DNA at 4 weeks follow-up. These findings are in agreement with those of DeBeer et al.<sup>83</sup> who found that, in a human cryopreserved meniscal allograft 1 year after transplantation, 95% of donor cells were replaced by host cells. Because of these findings, it is questionable whether viability at the time of transplantation is really necessary.

Lyophilization and deep freezing have been shown to destroy viable cells of connective tissue and to

**TABLE 2.** Results of Published Studies of Meniscal Allograft Transplantation in Humans

| Study                                | Patients (Grafts) | Clinical  | Healing   | Protection Articular Cartilage  | Comments  |
|--------------------------------------|-------------------|---|---|---|---|
| Milachowski et al. <sup>40</sup>     | 22 (22)           | 6 deep frozen:<br>90% good/excellent<br>16 lyophilized:<br><40% good/excellent              | Arthroscopy in 15 patients<br>shrinkage in 1 of 5 deep-frozen and 9 of 10 lyophilized grafts<br>3 failures                    | —   | Frozen grafts better than lyophilized                               |
| Zukor et al. <sup>66</sup>           | 26 (28)           | 75% successful (knee rating score)  | Arthroscopy in 8 patients<br>all 10 grafts healed<br>6 with minor tears or degenerative changes                               | Tibial cartilage underlying the meniscus had a more normal appearance than uncovered cartilage (arthroscopically)   | —   |
| Garret and Stevenson <sup>88</sup>   | 6 (6)             | 3 no pain<br>3 minimal pain<br>no locking (questionnaire)                                   | Arthroscopy in 4 patients<br>complete healing of all grafts<br>no shrinkage   | No progression of degenerative changes (radiographically)   | —   |
| Garret <sup>63</sup>                 | 43 (43)           |   | Arthroscopy in 28 patients<br>20 complete healing, no shrinkage<br>8 failures   | —   | Failures related to grade III-IV chondromalacia                     |
| Veltri et al. <sup>69</sup>          | 14 (16)           | 2 persistent pain<br>no locking   | Arthroscopy in 7 patients<br>5 complete healing, 2 partial<br>no shrinkage<br>1 degenerative changes                          | —   | —   |
| Van Arkel and De Boer <sup>14</sup>  | 23 (25)           | 20 successful (KASS)<br>10 good<br>13 fair/poor (mod Lysholm score)                         | Arthroscopy in 12 patients<br>7 complete healing<br>5 partial healing<br>7 degenerative changes<br>3 failures                 | Articular surfaces not changed (arthroscopically)<br>18 unchanged<br>5 less degenerative changes (radiographically) | Better clinical outcome in stable knee joints with normal alignment |
| Cameron and Saha <sup>11</sup>       | 63 (67)           | 58 good/excellent<br>9 fair/poor (mod Lysholm score)  | Arthroscopy in 13 patients<br>10 complete healing, no shrinkage<br>3 failures   | —   | —   |
| Verdonk <sup>70</sup>                | 51 (54)           | <3 year: pain relief and improved function<br>>3 year: deterioration of results (HSS-score) | MRI in 34 patients (39 grafts)<br>80% normal shape + position<br>75% normal signal posterior horn<br>65% absent anterior horn | —   | Poor relation MRI-clinical outcome                                  |
| Carter <sup>67</sup>                 | 46 (46)           | 45 improvement in pain<br>most patients had an increase in activity level (IKDC form)       | Arthroscopy in 38 patients<br>4 shrinkage<br>4 failures   | 2 progression of arthritis (arthroscopically and radiographically)  | —   |
| Stollsteimer et al. <sup>72</sup>    | 22 (23)           | All patients pain relief (questionnaire)<br>overall, improved function (Lysholm score)      | MRI in 12 patients<br>mean size graft 62% of control<br>5 abnormal signal<br>1 peripheral extrusion                           | 12 unchanged<br>10 joint space narrowing mean 1.7 mm (1-3 mm) (radiographically)                                    | —   |
| Van Arkel and De Boer <sup>139</sup> | 57 (63)           | Cumulative survival rate 76%, 50%, and 67% for lateral, medial, and combined, respectively  | —   | —   | Survival medial may improve when combined with ACL reconstruction   |

TABLE 2. Continued

| Study                      | Patients (Grafts) | Clinical   | Healing   | Protection Articular Cartilage                          | Comments  |
|----------------------------|-------------------|--|---|---|---|
| Rath et al. <sup>73</sup>  | 18 (22)           | Pain relief and improved function (short form-36)  | Arthroscopy in 10 patients<br>all complete healing                                    | 1/11 joint space narrowing >1mm (radiographically)      | 8 symptomatic recurrent tears                   |
| Wirth et al. <sup>65</sup> | 22 (22)           | Deterioration during follow-up (Lysholm and Tegner score)                                    | MRI in 9 patients<br>6/6 lyophilized abnormal signal<br>3/3 deep frozen normal signal | 11/11 increased degenerative changes (radiographically) | Frozen grafts better than lyophilized           |
| Ryu et al. <sup>68</sup>   | 25 (26)           | Reduced pain (VAS) improved function (Lysholm score) 17 activity (nearly normal (IKDC score) | Arthroscopy in 10 patients<br>5 normal<br>3 shrinkage<br>2 recurrent tears            | 3/8 joint space narrowing >1 mm (radiographically)      | Chondromalacia grade IV related to poor outcome |

Abbreviations: KASS, Knee Assessment Scoring System<sup>140</sup>; IKDC, International Knee Documentation Committee rating<sup>75</sup>; HSS, Hospital for Special Surgery knee rating system<sup>141</sup>; VAS, visual analogue scale<sup>142</sup>; MRI, magnetic resonance imaging; ACL, anterior cruciate ligament.

denature histocompatibility antigens, making frozen allografts less likely to provoke an immune response.<sup>84</sup> However, it was noted that although deep-frozen and lyophilized meniscal allografts were similar in tensile strength several months after transplantation in sheep knees, they did not reach values of normal control menisci, even at 48 weeks after transplantation.<sup>53</sup> In a clinical study, Milachowski et al.<sup>40</sup> performed second-look arthroscopy in 15 of 22 patients after transplantation and reported shrinkage in 1 of 5 deep-frozen meniscal allografts and in 9 of 10 lyophilized and gamma-sterilized allografts. One of these latter allografts was completely destroyed. All lyophilized allografts were remodeled and completely revascularized at 48 weeks, whereas the deep-frozen grafts showed little revascularization or remodeling. This remodeling process of lyophilized meniscal allografts has been shown in animal studies as well, in which significant reduction in size of the grafts has been observed.<sup>85,86</sup> Furthermore, the use of gamma irradiation may be at least partially responsible for the comparatively poor results after transplantation of lyophilized allografts. Yahia and Zukor<sup>87</sup> reported a significant reduction in compliance to long-term creep in frozen irradiated meniscal transplants in rabbits as compared with nonirradiated fresh or frozen transplants. In addition, synovitis and effusion were observed more frequently after lyophilized allograft transplantation than after deep-frozen or fresh allograft transplantation.<sup>40,88</sup> Finally, alterations like tissue hydration, swelling, and size changes that occur during reconstitution of lyophilized transplants may

make sizing difficult.<sup>78</sup> These findings suggest that lyophilization may not be an appropriate processing method for meniscal allografts.

Cryopreservation, which is usually accomplished with dimethyl sulfoxide or glycerol, at least partially preserves cell membrane integrity and donor chondrocyte viability.<sup>89</sup> However, the percentage of viable cells decreases with storage time.<sup>90</sup> Furthermore, secondary sterilization techniques that affect cell viability cannot be applied, and this may increase the risk of disease transmission from a donor with false-negative serologic test results. In a goat study, Fabbriani et al.<sup>91</sup> compared cryopreserved and deep-frozen meniscal allografts and found no differences in appearance and healing between both groups. Arnoczky et al.<sup>90</sup> demonstrated that the material properties of transplanted cryopreserved allografts in dogs were similar to those of normal menisci after 6 months. Whether the expense and difficulty of cryopreservation techniques in meniscal transplantation is warranted is not clear at present because deep-frozen meniscal allografts have been transplanted with apparently similar results.

A number of studies used glutaraldehyde to preserve meniscal allografts, which is toxic to donor cells but preserves the collagen matrix. Canham and Stanish<sup>61</sup> evaluated glutaraldehyde-treated meniscal allografts in 5 dog knees and showed less satisfactory postoperative healing and recurrent joint effusions compared with meniscal autografts and allografts preserved for 2 to 3 weeks in tissue culture. These findings are consistent with those of Powers et al.,<sup>92</sup> who

also found shrinkage and articular degenerative changes 12 weeks after transplantation of glutaraldehyde-preserved allografts in dogs. In addition, the toxic products left in the graft have been reported to produce a chronic synovitis.<sup>93</sup> For these reasons, glutaraldehyde preservation of meniscal tissue has been abandoned.

In summary, it can be stated that the role of cell viability in the ultimate fate of meniscal transplants is unclear at present and that there is no evidence that the additional costs associated with fresh or cryopreserved allografts will be justified by improved results. The use of lyophilized and glutaraldehyde-preserved grafts generally is not recommended.

### IMMUNOLOGIC REACTIONS TO MENISCAL ALLOGRAFTS

Menisci are considered to be immunoprivileged because the resident cells are embedded in a dense matrix not accessible to immunoreactive cells.<sup>94</sup> Most clinical and experimental studies have found that meniscal allograft transplantation does not exhibit macroscopic or microscopic signs of a systemic or localized immune response.<sup>66,77,95</sup> However, Hamlet et al.<sup>96</sup> have presented a case of presumed acute rejection of a cryopreserved allograft. In addition, Wada<sup>97</sup> reported that fresh meniscal allografts in rats without immunosuppression produce histologic evidence of rejection, whereas allografts survived in immunosuppressed rats up to 21 weeks after transplantation. In an experimental study in rabbits, Rijk and Van Noorden<sup>62</sup> observed a mild proliferation of synovial tissue surrounding the meniscal allografts after transplantation which is in agreement with the findings of Ochi et al.<sup>98</sup> Evidence of rejection of the allografts was not observed. Nevertheless, Khoury et al.<sup>99</sup> demonstrated class I and II histocompatibility antigens on the cells of a meniscal allograft, indicating the possibility of an immune response. In addition, Van Arkel et al.<sup>100</sup> showed sensitization to class I and class II human leukocyte antigens in 11 of 18 recipients of cryopreserved non-tissue-antigen-matched meniscal allografts without clinical evidence of rejection. Rodeo et al.<sup>76</sup> found a small number of immunologically active cells (B lymphocytes and/or T-cytotoxic cells) in the majority of transplanted allografts in humans. The presence of these cells suggests a subtle immune reaction that may modulate graft healing, incorporation, and graft revascularization.

It has been shown that allogenic bone grafts tend to be more antigenic than meniscal cartilage.<sup>101,102</sup>

Therefore, meniscal allografts may be at higher risk of eliciting an immunologic response if they are transplanted with bone plugs. However, Zukor et al.<sup>66</sup> transplanted fresh meniscal allografts in conjunction with osteochondral allografts in humans without any significant immunologic response to these fresh tissues at a mean follow-up of 4.5 years. The clinical importance of immune responses to meniscal allografts is not exactly known yet but, in general, there is no evidence for graft failure or rejection.

### DISEASE TRANSMISSION IN MENISCAL TRANSPLANTATION

The use of meniscal allografts creates a risk of transmission of diseases. Meniscal transplantation is an attempt to preserve knee function and improve quality of life rather than a life-saving measure and, therefore, the risk of allograft-related infections can only be justified when it is exceedingly small. Deep freezing and lyophilization cannot destroy human immunodeficiency virus (HIV) in blood products, making disease transmission more likely. The current risk of HIV transmission by frozen connective-tissue allografts is estimated to be one in 8 million.<sup>103</sup> HIV and other transmissible life-threatening viral diseases, such as hepatitis B, made secondary sterilization techniques a major concern in meniscal allograft transplantation.<sup>89</sup> Three sterilization techniques have been applied so far: gamma irradiation, treatment with ethylene oxide, and other chemical means. Gamma irradiation is the most common secondary sterilization method. It has been shown that a dose of 2.4 mrad kills nearly all pathogens with the exception of HIV, which requires more than 3.6 mrad to inactivate all but 1 in a million HIV-infected bone cells.<sup>104</sup> Unfortunately, 2.5 mrad produce significant changes in the mechanical properties of meniscal tissue.<sup>87</sup> Ethylene oxide treatment has been abandoned for use in intra-articular grafts because at least 1 of the byproducts (ethylene chlorohydrin) has been found to induce synovitis.<sup>105</sup> Chemical sterilization can be performed with appropriate bactericidal/virucidal solutions. Concerns that this type of sterilization kills the cells of the meniscus may not have practical application. Jackson et al.<sup>56</sup> observed that cellular DNA in fresh allografts was entirely replaced by host DNA 4 weeks after transplantation in goats, suggesting that fresh allograft cells probably do not survive in nonsterilized allografts either. When these findings are indeed true, sterilized and nonsterilized meniscal allografts may produce similar results.

## SIZING OF ALLOGRAFTS

Selection of an appropriately sized meniscal allograft is likely to be critical for successful incorporation and function after transplantation.<sup>82,106</sup> In several experimental studies, approximate size matching of the allografts was performed by weight matching of the donor and recipient animals.<sup>13,107</sup> In the first meniscal transplantation studies in humans, allografts were shaped with a scalpel and then placed on the tibia plateau.<sup>40</sup> Reduction of a too-large allograft does not present a problem technically. However, it was concluded by Kohn<sup>108</sup> that reduction of the meniscus size destroys the collagenous network and that it not only alters the shape of the meniscus but its mechanical properties as well. Although estimates have been made that graft size should be within 5% of the native meniscus, the knee's tolerance for measure mismatch has not been determined yet.<sup>87,109</sup> Imaging methods that may be used to size the transplant include plain radiographs, MRI, and computed tomography (CT).<sup>110</sup> Garrett and Stephenson<sup>88</sup> developed a technique to match the meniscal size with an accuracy of more than 95% using standard anteroposterior radiographs. More recently, it has been suggested to size the allografts preoperatively on the basis of bone measurements. Two studies have demonstrated reproducible relationships between menisci and established radiographic bone landmarks.<sup>111,112</sup> However, these reports also showed significant variability in the relationship between meniscal length and width and tibial plateau dimensions. Several studies reported that MRI is slightly more accurate than radiography in preoperative sizing of menisci for allograft transplantation.<sup>110,113</sup> On the other hand, MRI and CT have been shown to consistently underestimate the size of menisci.<sup>82,114</sup> Although Veltri et al.<sup>69</sup> recommended the use of MRI or CT of the contralateral meniscus for preoperative sizing, other studies have found considerable anatomic variability between right and left knees in a person, indicating that opposite menisci are not necessarily mirror images of each other.<sup>109,115</sup>

## INDICATIONS FOR TRANSPLANTATION

The indications for meniscal allograft transplantation still have to be defined. It is generally believed that skeletally mature patients should have pain associated with early arthrosis of the involved compartment of the knee after meniscectomy. Garrett<sup>63</sup> found that meniscal transplantation is more successful in patients with mild unicompartmental degenerative

changes of the knee (Outerbridge grade 1 or 2). Advanced compartment degeneration, Outerbridge grade 3 or 4, or incongruent joint surfaces lead to a less successful and predictable outcome. These findings were confirmed by Noyes et al.,<sup>71</sup> who observed a significant relationship between failure and the degree of arthrosis. Of the knees with less than grade 4 degeneration of the articular cartilage, 70% healed completely and 30% healed partially, whereas knees with grade 4 arthrosis showed a 50% failure rate. In an MRI study, Rodeo<sup>106</sup> observed that knees with advanced arthrosis had a greater propensity for graft extrusion and are probably associated with an increased failure risk. Veltri et al.<sup>69</sup> reserved meniscal transplantation for patients younger than 45 years with symptomatic early osteoarthritis of the involved compartment and a ligamentously stable knee or a knee that can be stabilized by concomitant ligamentous reconstruction. In addition, Cole et al.<sup>74</sup> stated that only minor degrees of degenerative changes in the knee are considered acceptable in a candidate for meniscal transplantation and that range of motion should be normal.

Another important factor is the mechanical axis of the knee joint. When meniscal transplantation is performed in a knee joint with an abnormal axis, this malalignment is likely to cause abnormal pressure on the meniscal allograft resulting in impaired revascularization that will lead to degeneration and loosening of the graft. However, Cameron and Saha<sup>11</sup> implanted meniscal allografts in malaligned human knees and performed a realignment at the time of surgery with an osteotomy. Of the 41 knees that underwent realignment in addition to receiving a meniscal allograft, 35 (85%) had achieved good to excellent clinical results at a mean follow-up of 31 months. It remains to be established which part of the procedure, the meniscal allograft or the realignment, is more important in pain relief. In addition, it is unclear whether patients who are candidates for an osteotomy to correct malalignment benefit from meniscal transplantation.

Johnson and Bealle<sup>116</sup> stated that young athletic individuals who have undergone complete meniscectomy might be candidates for meniscal transplantation before the onset of symptoms in an attempt to prevent early degenerative changes. It is possible that such prophylactic meniscal transplantation may be beneficial, especially in the lateral compartment where there is a more rapid progression to degeneration after meniscectomy compared with the medial compartment because of the greater role in stress protection of the lateral meniscus.<sup>1,117</sup> Meniscal allograft transplan-

tation may also be considered for patients with concomitant ACL instability. To improve stability in ACL-deficient and medial meniscus-deficient knees, meniscal transplantation may be combined with ACL reconstruction.<sup>118</sup> Garrett<sup>82</sup> reported significantly improved KT-1000 arthrometer results for ACL reconstructions when performed in combination with medial meniscal allograft transplantation compared with a group of patients who underwent ACL reconstruction only with persistent medial meniscal deficiency. On the other hand, it has been shown that isolated ACL reconstruction in osteoarthritic knees can provide pain relief.<sup>119</sup> At present, it is unclear whether concomitant meniscal transplantation in ACL reconstruction gives pain relief and prevents or delays degenerative changes of the joint because there are no studies that have compared isolated ACL reconstruction with ACL reconstruction combined with meniscal transplantation in patients with similar degrees of arthrosis and meniscal deficiency. In contrast, the lateral meniscus has not been found to act as a secondary restraint to anterior tibial translation in the ACL-deficient knee in cadaveric studies, and clinical follow-up has found no differences in KT-1000 arthrometer results after ACL reconstruction in lateral meniscus-deficient knees compared with ACL reconstruction in knees with intact menisci.<sup>16,120</sup> It can be concluded that there is still limited information available on the indications for meniscal allograft transplantation. At present, meniscal transplantation is indicated in young patients with a prior meniscectomy, persistent pain in the involved compartment, intact articular cartilage, normal alignment, and a stable joint.

### SURGICAL TECHNIQUE

Meniscal allograft transplantation may be performed using either open or arthroscopically assisted techniques, or a combination of these, with a miniarthrotomy to insert the graft and arthroscopic preparation and fixation. Advantages of arthroscopic procedures include decreased morbidity in comparison with open techniques, no disruption of collateral ligaments, and early rehabilitation. On the other hand, arthroscopically assisted techniques to implant meniscal allografts are much more technically demanding and time consuming. Therefore, it should be performed only after considerable practice. Milachowski et al.<sup>40</sup> transplanted medial meniscal allografts in combination with ACL reconstruction using a medial hockey-stick incision. In cases of grade II anteromedial insta-

bility, the medial collateral ligament was split longitudinally, whereas in cases of grade III anteromedial instability, the bony tibial insertion was detached with a chisel. Remarkably, evaluating the same group of patients in a long term follow-up study, Wirth et al.<sup>65</sup> described an advancement of the femoral insertion of the medial collateral ligament in case of anteromedial instability. Garrett and Stevenson<sup>88</sup> performed a parapatellar arthrotomy with ipsilateral collateral ligament transection from the femoral origin and subsequent repair of the collateral ligament at the end of the procedure. In addition, a tibial tubercle osteotomy was used in cases of lateral meniscal transplantation. Verdonk<sup>79</sup> performed a medial anterior arthrotomy in combination with a posteromedial incision for medial meniscal transplantation and a lateral parapatellar arthrotomy for the lateral meniscus, which may be combined with an incision in the posterolateral corner. Keene et al.<sup>64</sup> reported a single case of lateral meniscus transplantation performed arthroscopically. Arthroscopically assisted meniscal transplantations in experimental studies have not been reported yet. In animals, a medial or lateral arthrotomy is usually performed with detaching the ipsilateral collateral ligament from the femoral insertion with a bone block.<sup>10,13,58,121</sup> However, other studies showed sufficient exposure of the medial compartment after 2 medial capsulotomies: 1 anterior and 1 posterior to the collateral ligament or even after a single parapatellar arthrotomy.<sup>12,62,122</sup> It can be concluded that several surgical techniques are described in the literature. Although many now believe that arthroscopically assisted procedures are much more desirable, no controlled studies have been reported so far comparing the results of open and arthroscopic techniques.<sup>63,64,67,72</sup>

### GRAFT FIXATION

Two types of fixation are distinguished in meniscal allograft transplantation: bony fixation of the meniscal horns to the tibia and capsular fixation of the peripheral margin of the allograft. Fixation of the meniscal horns has been performed with the use of soft-tissue attachments, suture anchors, bone plugs, and a bony bridge connecting the anterior and posterior horns of the graft.<sup>13,58,65,72,79,88</sup> There is conflicting evidence whether bone plugs are required to provide adequate fixation of meniscal transplants to the tibia. Cadaveric studies in humans have shown that secure, anatomic fixation of bone plugs attached to the anterior and posterior horns is required to restore optimally normal

contact mechanics for both medial and lateral transplants.<sup>123-126</sup> However, fixation with bone plugs requires an exact size match of donor and recipient, which may be difficult to acquire in clinical practice. In addition, the optimal position for bone plugs is uncertain and rigid nonanatomic placement adversely affects the contact pressure distribution patterns in human cadaveric knees.<sup>127</sup> These findings are in agreement with those of Lazovic et al.,<sup>128</sup> who found an increase in degenerative changes after nonisometric placement of meniscal autografts in sheep knees at 24 weeks' follow-up compared with knees that underwent isometric placement. In addition, Szomor et al.<sup>58</sup> hypothesized that the damage to articular cartilage observed after meniscal allograft transplantation in sheep was secondary to nonisometric positioning and tensioning and to rigidity of fixation of the grafts with suture anchors. In a clinical evaluation, Rodeo et al.<sup>76</sup> noted that the average histologic score was significantly better for meniscal transplants without attached bone plugs than it was for transplants with bone plugs. However, meniscal allografts transplanted with bone plugs gave better clinical results than allografts without bone plugs. Furthermore, many animal studies demonstrated that allogenic bone plugs are more immunogenic than allografts that contain collagen only.<sup>101,102</sup> Grafts may also be inserted by using the "keyhole" technique, in which the grafts contain a common bone bridge attached to both anterior and posterior horns. This bone bridge is then inserted into a similarly shaped slot in the recipient tibia. It has been recommended that this technique should be used with implantation of a lateral meniscus because the distance between the horns is only 1 cm or less.<sup>74</sup> Use of bone plugs with a lateral meniscus presents a risk of tibia tunnel communication with compromised fixation. When both medial and lateral menisci are transplanted in combination with ACL reconstruction, Rodeo<sup>106</sup> recommended implantation of the grafts with one common bone bridge containing the attachments of both menisci.

Several experimental studies showed good healing without extrusion of the transplanted allografts when the anterior and posterior horns are sutured to the ligamentous tibial bone attachments without bone plug fixation.<sup>62,107</sup> There are also clinical studies in which satisfactory results have been obtained with this technique.<sup>11,65,79</sup> However, Gao et al.<sup>129</sup> reported that the tensile strength of a healed anterior meniscal attachment after detachment and repair to bone in a rabbit model was only 20% of the strength of the normal meniscal horn attachment. Alternatively, the

meniscus may be attached by transosseous sutures tied over a bony bridge over the anterior aspect of the proximal tibia. However, early degenerative changes of the articular cartilage as well as extrusion of the transplanted allografts have been reported in animal studies using this technique, which are likely caused by failure of the posterior horn of the transplanted meniscus.<sup>122,130</sup>

The graft must also be securely sutured to the capsule using standard meniscal repair techniques. Peripheral capsular fixation is a prerequisite for healing and vascularization of the graft. A peripheral meniscal remnant is considered to be important in establishing and maintaining vascular supply to allow ingrowth of the meniscal allograft. The absence of peripheral healing and revascularization induces cell death and matrix disorganization, leading to failed meniscal transplantation.<sup>131</sup> Furthermore, the medial meniscus is firmly attached to the deep collateral and coronary ligament but the lateral meniscus is more loosely attached. It is stabilized principally by popliteomeniscal fasciculi at the popliteus hiatus and by menisocofemoral ligaments.<sup>132</sup> These ligaments and fasciculi are not restored with lateral meniscus transplantation. The consequences are not determined yet but different fixation techniques may be appropriate for medial and lateral allograft transplantation. Whereas nonabsorbable sutures have been advocated for capsular fixation, absorbable material has been successfully applied as well.<sup>40,82</sup> Vertical stitches give the best primary stability.<sup>45</sup> All-inside bioabsorbable devices are a reasonable alternative to sutures but their pull-out strength is less than that of vertical sutures and they provide only single-point fixation.<sup>133</sup> Boss et al.<sup>134</sup> demonstrated increased peripheral healing creating a circumferential subchondral trough along the entire length of the meniscus to prepare a bleeding cancellous bed to which the meniscus is stabilized. Further clinical controlled long-term studies are needed to compare different fixation techniques in meniscal allograft transplantation.

### REHABILITATION AFTER MENISCAL TRANSPLANTATION

Different rehabilitation regimens have been proposed after meniscal allograft transplantation in clinical practice, but a consensus does not exist as a guide for postoperative rehabilitation.<sup>11,40,69</sup> Often, protocols are determined by concomitant surgery performed at the time of meniscal transplantation. Although the effects of loading of a healing meniscus

after transplantation are unknown, it has been shown that motion of menisci during knee flexion and extension as well as rotation of the tibia against the femur are substantial.<sup>135,136</sup> Based on these biomechanical facts, restriction of motion and weight bearing seems reasonable after meniscus transplantation when fixations are not stable. On the other hand, Stollsteimer et al.<sup>72</sup> allowed for full range-of-motion exercises immediately after transplantation and reported good clinical results. Furthermore, full weight bearing immediately after surgery showed uneventful healing of transplanted meniscal allografts in several experimental studies.<sup>13,54,62</sup> It can be concluded that controlled studies are needed to establish the optimal rehabilitation program.

### COMPLICATIONS

Complications of meniscal transplantation in humans are relatively rare. Zukor et al.<sup>66</sup> reported 1 postoperative hematoma requiring evacuation and 2 cases of anemia requiring transfusion in 26 patients. Milachowski et al.<sup>40</sup> reported 2 soft-tissue infections in 22 patients and severe synovitis in 4 other patients after meniscal allograft transplantation. In a group of 10 patients, Kuhn and Wojtys<sup>89</sup> observed 1 presumed low-grade infection that finally resulted in removal of the graft 4 months postoperatively. In the series of Goble et al.,<sup>70</sup> of 47 cryopreserved meniscal allografts in 45 patients, complications included 1 removal due to infection, 3 removals because of pain, and 3 partial meniscectomies due to recurrence of a meniscal tear. In a study by Noyes et al.,<sup>71</sup> 29 of 96 menisci had to be removed less than 2 years after transplantation. The most frequent complication observed by Cameron and Saha<sup>11</sup> was a traumatic tear of the posterior horn, which occurred in 6 of 67 allografts at a mean of 21 months postoperatively. Rath et al.<sup>73</sup> showed that 8 of 22 implanted menisci tore and became symptomatic, requiring subsequent meniscectomy (2 total, 6 partial). Three of these patients did not recall an injury. In another study, Verdonk<sup>70</sup> reported that manipulation under general anesthesia was necessary in 3 of 51 patients who underwent meniscal transplantation combined with valgus osteotomy. Shelton and Dukes<sup>137</sup> reported 1 of 15 patients with loss of bone plug fixation requiring reoperation at 6 days after implantation. De Boer and Koudstaal<sup>138</sup> investigated 3 late failures and suggested that patients with knee instability, malalignment, or severe osteoarthritis may not benefit from meniscal transplantation.

**Acknowledgment:** The author thanks Prof. Dr. C.J.F. Van Noorden, Department of Cell Biology and Histology, Academic Medical Centre, Amsterdam, The Netherlands, for critically reading the manuscript.

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