1996

Meniscal Substitution: A Literature Review

Kerry L. Muir

University of North Dakota

Follow this and additional works at: https://commons.und.edu/pt-grad

Part of the Physical Therapy Commons

Recommended Citation


https://commons.und.edu/pt-grad/323

This Scholarly Project is brought to you for free and open access by the Department of Physical Therapy at UND Scholarly Commons. It has been accepted for inclusion in Physical Therapy Scholarly Projects by an authorized administrator of UND Scholarly Commons. For more information, please contact zeinebyousif@library.und.edu.
MENISCAL SUBSTITUTION: A LITERATURE REVIEW

by

Kerry L. Muir
Bachelor of Science in Physical Therapy
University of North Dakota, 1995

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
1996
This Independent Study, submitted by Kerry Muir in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

Michelle LaBrecque
(Faculty Preceptor)

[Signature]

[Signature]
(Graduate School Advisor)

[Signature]
(Chairperson, Physical Therapy)
PERMISSION

Title Meniscal Substitution: A Literature Review

Department Physical Therapy

Degree Master of Physical Therapy

In presenting this Independent Study Report in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Department of Physical Therapy shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my work or, in her absence, by the Chairperson of the department. It is understood that any copying or publication or other use of this independent study or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of North Dakota in any scholarly use which may be made of any material in my Independent Study Report.

Signature

Date 4/30/96

iii
# TABLE OF CONTENTS

**ACKNOWLEDGMENTS** ................................................................. vi  
**ABSTRACT** ................................................................. vii  

## CHAPTER

**I**  
**INTRODUCTION** ................................................................. 1  

**II**  
**OVERVIEW OF THE MENISCUS** ........................................... 3  
  - Anatomy ................................................................. 3  
  - Composition ............................................................... 4  
  - Vascularity ................................................................. 6  
  - Functions ................................................................. 6  

**III**  
**PATHOLOGY AND TREATMENT OF MENISCAL LESIONS** ........... 9  
  - Pathology ................................................................. 9  
  - History of Treatment .................................................. 10  
  - Treatment Options .................................................... 13  
  - Indications for Substitutions ...................................... 15  
  - Rehabilitation ............................................................ 16  

**IV**  
**MENISCAL AUTOGRAFTS** ................................................... 19  
  - Surgical Procedure .................................................... 20  
  - Results ................................................................. 21  

**V**  
**MENISCAL ALLOGRAFTS** ................................................... 24  
  - Surgical Procedures .................................................... 25  
  - Results ................................................................. 26  
  - Types of Allografts .................................................... 29  
  - Considerations ............................................................ 30
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI MENISCAL PROSTHESES</td>
<td>36</td>
</tr>
<tr>
<td>Surgical Procedures</td>
<td>37</td>
</tr>
<tr>
<td>Results</td>
<td>38</td>
</tr>
<tr>
<td>Considerations</td>
<td>41</td>
</tr>
<tr>
<td>VII CONCLUSION</td>
<td>48</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>51</td>
</tr>
</tbody>
</table>
ACKNOWLEDGMENTS

Many thanks to my family, Jim, Brandi, and Jimmy. Their invaluable help, support, and encouragement were generously given.
ABSTRACT

With the increased awareness that meniscectomy results in degenerative changes in the knee joint, research is now aimed at substituting the meniscus that had been previously removed. Surgical attempts at replacing the meniscus include the use of autografts, allografts, and artificial synthetic prosthesis.

This paper will review the available literature regarding each type of meniscal substitute. Surgical procedures, results, and considerations relating to the different substitutes will be examined.

While studies indicate that meniscal transplantation is technically feasible, the long-term results are unknown. More research is necessary to determine if meniscal substitutes can survive for a prolonged time and function to prevent further degenerative changes from occurring.
CHAPTER I

INTRODUCTION

For years, it was standard practice to excise the meniscus as treatment for a variety of problems associated with the knee. The meniscus was, in fact, once described as the functionless remains of leg muscle. Over the last several decades, attitudes toward the menisci have evolved from a perception of inconsequential, functionless structures to a view that the menisci are vital, integral components of normal knee biomechanics.

Scientific evidence has progressively mounted to substantiate the vital role of the meniscus in the function of the knee. The menisci have several functions, including tibiofemoral load transmission, shock absorption, joint lubrication, and passive stabilization of the knee joint.

Over the last several years, studies have documented the association of meniscectomy with degenerative arthritis. This evidence has led researchers to adopt an increasingly conservative approach in treating meniscal lesions, with the goal to conserve as much meniscal tissue as possible. Partial meniscectomy rapidly supplanted total meniscectomy and research continued to determine the healing capacity of the torn meniscus. From these efforts, meniscal repair has evolved as a successful technique.
While meniscal repair has become an accepted mode of treatment for selected meniscal injuries, it is not applicable in every instance.\textsuperscript{12} Partial and even total meniscectomies may still be necessary. Because of the degenerative effects of total meniscectomy on the knee joint,\textsuperscript{6} attempts are being made to alter and reverse the joint deterioration that occurs after removal of the menisci. Replacement with either a prosthetic or biologic implant appears to be the only method of restoring normal joint anatomy and preventing the development of joint pathology. Theoretically, the implantation of a substitute that would function and maintain its structure similar to that of the normal meniscus would prevent any further degenerative changes from occurring within the knee joint.

Present surgical attempts of meniscal substitution include the use of allografts, autografts, and synthetic prostheses. Human meniscal allograft transplantation involves the use of harvested menisci from donor cadavers, while meniscal autograft transplantation implants tissues from the patient's body to replace their meniscus. Meniscal synthetic protheses are implants made from synthetic materials which are implanted into the knee joint to replace the absent meniscus. This paper will review the historic evolution of the meniscectomized knee and discuss the current options in meniscal transplant surgery. Although available literature is limited, surgical procedures, results, and considerations of each concept will be reviewed.
CHAPTER II
OVERVIEW OF THE MENISCUS

The menisci serve several important functions in the knee. The ability to perform these functions is based on the intrinsic material properties of the menisci as well as their gross anatomic structure and attachments. This chapter will provide a brief review of the menisci in regard to their anatomy, composition, vascularity, and functions.

Anatomy

The menisci are fibrocartilaginous discs located between the femoral condyles and the tibial plateau. Their inferior surfaces are flat and rest on the tibial articular surface, while their superior surfaces are concave and deepen the articulation of the tibia with the femur. Peripherally, the menisci have a thick convex border which is attached to the joint capsule. The central portion, in contrast, tapers to a thin free edge, making the menisci look somewhat triangular in cross section.

The medial meniscus is C-shaped and is much wider posteriorly than anteriorly. The anterior end, or horn, is attached to the intercondylar eminence of the tibia. This attachment is located anterior to the insertion of the anterior cruciate ligament (ACL). Fibers from the anterior attachment merge with the
transverse ligament, which connects the anterior horns of the medial and lateral menisci. The medial menisci’s posterior end, or horn, is also attached to the intercondylar eminence. This attachment is located anterior to the insertion of the posterior cruciate ligament (PCL) and between the attachments of the lateral meniscus and the PCL. The medial meniscus is attached to the joint capsule all along its periphery. At its midpoint, the meniscus is firmly attached to both the femur and tibia through a thickening in the joint capsule known as the deep medial collateral ligament.

The lateral meniscus is shaped more like an incomplete circle and covers a larger portion of the tibial articular surface than the medial meniscus. It is consistent in width throughout its course. The anterior horn blends with the attachment of the anterior cruciate ligament, whereas the posterior horn attaches just behind the intercondylar eminence. The periphery of the lateral meniscus also attaches to the joint capsule, but has no direct attachment to the lateral collateral ligament due to the hiatus of the popliteus tendon. The lateral meniscus is not attached to the joint capsule as firmly as the medial meniscus and is thus more mobile.

Composition

Meniscal tissue is hydrated, soft, and fibrocartilaginous. Connective tissue attaches the meniscus to the joint capsule. The remaining, more visceral portion of the meniscus (termed the midsubstance) is made up of an avascular, aneural fibrocartilage consisting of cells (fibrochondrocytes)
surrounded by an extracellular matrix. Biochemical collagen typing has shown that the majority of the meniscus consists of type I collagen, which is typical for tissues resisting force.\(^{19}\) Type II collagen, the major type in articular cartilage, is only present in the meniscus in minor amounts. The fibrocartilage of the meniscus has been described as a dense connective tissue with coarse fibrous collagen bundles that have fibrochondrocyte cells lying in between.\(^{20}\) Meniscal fibrocartilage has special mechanical properties concerning tensile strength and compression.

In the superficial layers of the menisci, the collagen fibers are orientated in a transverse fashion.\(^{21}\) In the deep layers, where the bulk of the collagen fibers are found, there tends to be a circumferential orientation. These deep fibers are occasionally interlaced with collagen fibers running transversely and appear to act as "tie rods" to resist longitudinal splitting of the menisci.\(^{22,23}\)

The fibrochondrocyte cells of the meniscus were so named because their appearance is chondrocytic, yet they synthesize a fibrocartilage matrix.\(^{24}\) Articular chondrocytes, in contrast, synthesize their own distinctive hyaline cartilage matrix. The extracellular matrix of the meniscus is composed mainly of collagen, proteoglycans, and water.\(^{13}\) Proteoglycans are large negatively charged molecules that can hold 50 times their weight in free solution. Proteoglycans in the matrix are stiffly extended and provide the tissue of the meniscus with a high capacity to resist large compressive loads.\(^{25}\) This mechanism to resist compressive force is accentuated by the fact that
proteoglycan molecules are compressed to about 20% of their natural solution domain.\textsuperscript{26,27} This creates an osmotic pressure, which further enhances the ability of the tissue to resist compressive load and hold fluid.

Vascularity

The vascular supply to the menisci originates predominately from the superior and inferior medial and lateral geniculate arteries.\textsuperscript{15} These vessels branch to form a perimeniscal capillary plexus within the synovial and capsular tissues of the knee joint. This plexus supplies the periphery of the menisci. At the anterior and posterior horns, the plexus penetrates further into the meniscal substance.\textsuperscript{1,28} Clark and Ogden\textsuperscript{29} have shown that virtually the entire meniscus may be vascularized in children and that this vascularity recedes with age. In adults, the degree of peripheral vascular penetration is 10% to 30% of the width of the medial meniscus and 10% to 25% of the width of the lateral meniscus.\textsuperscript{28,30}

Functions

It has been suggested that the menisci play many roles in normal knee function. Functions attributed to the menisci include load transmission, shock absorption, joint lubrication, joint stability, stress reduction, joint congruity, joint nutrition, and limiting extremes of knee flexion and extension.\textsuperscript{17,31,32} For the purpose of this paper, basic functions of the menisci including load transmission, shock absorption, joint stability, and stress reduction will be reviewed.

It has been indicated that at least 50% of the compressive load of the knee joint is transmitted through the menisci when the knee is in extension.\textsuperscript{4}
With the knee in 90° of flexion, however, the menisci transmit approximately 85% of the compressive load. The remaining load, whether the knee is flexed or extended, is borne directly by the articular surfaces.

Walker and Erkman\textsuperscript{33} have shown that the lateral meniscus carries most of the load in the lateral compartment, while load is shared equally between the medial meniscus and the articular cartilage in the medial compartment. In addition, Seedhom and Wright\textsuperscript{34} found that, with the knee in extension, the lateral meniscus carries 70% of the load in the lateral compartment, while the medial meniscus carries 50% of the load in the medial compartment.

The arrangement of collagen fibers in the meniscus is well-suited for load transmission.\textsuperscript{32} The menisci’s wedge shape, circumferentially oriented collagen fibers, and firm anterior and posterior horn attachments allow it to elongate as the femur compresses down on the tibia. This generates a circumferential tension in the meniscus.

It has been proposed that the menisci play an important role in shock absorption in the knee.\textsuperscript{35} As the femur compresses down onto the tibia, the menisci extrude peripherally and their circumferentially oriented collagen fibers elongate, thus reducing the shock that the underlying cartilage and subchondral bone would otherwise endure.\textsuperscript{36} Documentation has shown that the normal knee has a shock-absorbing capacity 20% higher than a knee that has undergone meniscectomy.\textsuperscript{7}
The menisci also contribute to knee joint stability.\textsuperscript{37} They increase the stability at the knee by deepening the articular surfaces of the tibial plateau and also by filling in gaps along the periphery of the condyles. Levy et al\textsuperscript{9} concluded that the menisci also are important in preventing an increase in anterior laxity in the knee joint when the ACL is deficient. In the intact knee, meniscectomy will have little effect on anteroposterior translation; however, large increases in anterior translation have been observed after sectioning the anterior cruciate ligaments in meniscectomized knees.

Studies suggest that the menisci play an important role in stress reduction.\textsuperscript{4,6,33} Krause et al\textsuperscript{6} found a two-and-one-half-fold increase in load per unit area in human cadaver knees after removal of both menisci. Similar results were noted by Kurosawa et al\textsuperscript{38} who found, under physiological loads, a two- to three-fold increase in average stress across the knee joint following meniscectomy.
CHAPTER III
PATHOLOGY AND TREATMENT OF MENISCAL LESIONS

The prevalence, mechanism of injury, and history of treatments in regard to meniscal pathology will be reviewed. Discussion of treatment options, indications for meniscal substitution, and available rehabilitation protocols following meniscal substitution will also be included.

Pathology

Injuries to the menisci are the most common injury occurring in the knee joint. Although uncommon in children under age ten, meniscal injuries are increasingly prevalent in adolescence and beyond. Meniscal injuries are believed by some to be the most frequently occurring injury among athletes. Sports with the highest incidence of meniscal injuries are soccer, football, basketball, and baseball.

Meniscal injuries usually involve damage due to a rotational force. The common mechanism of injury is a force applied to a flexed knee. A valgus force directed to a flexed knee while the femur is internally rotated tends to cause tears to the medial meniscus. Injuries to the lateral meniscus tend to occur when a varus force is applied to the flexed knee with the femur in external rotation. Since the medial meniscus is more firmly attached to the tibia and, as a result, is
less mobile, the incidence of injuries to the medial meniscus tends to be greater than to the lateral meniscus.¹

History of Treatment

The menisci were once thought to be relatively unimportant structures and were considered expendable.³² The prevailing idea was that meniscal tears were incapable of healing and would produce significant articular damage. It was also thought they would regenerate more completely if removed.³⁷ While it is true that a tissue does replace the excised meniscus, it was later found in an experimental study conducted in dogs that this tissue was not fibrocartilage.⁴¹ It consisted of dispersed collagen fibers and had a proteoglycan content much lower than that found in normal meniscal tissue. The prevailing thought that the menisci were incapable of healing prompted the complete removal of the menisci even when damage was minimal. Meniscectomy was considered a relatively standard procedure that allowed individuals to return to activities soon, with good results in short-term studies.⁴²,⁴³

In the 1960s and 1970s, studies began to document the poor results following meniscectomy.¹¹,⁴⁴ Fairbanks⁴⁵ theorized that the loss of the weight-bearing function of the menisci resulted in osteophyte formation, flattening of the femoral condyles, and narrowing of the joint space. Fahmy et al.⁴⁶ observed fissuring of the articular cartilage at autopsy in individuals who had previously undergone meniscectomy. In a study done on rabbits, articular cartilage damage was observed on the weight-bearing areas of the medial condyles after
medial meniscectomies. In addition, long-term follow-up studies have shown that 20% to 80% of individuals post-meniscectomy were found to have degenerative changes.\textsuperscript{6,11,42,46}

Partial meniscectomy quickly replaced total meniscectomy.\textsuperscript{1} It was found that retention of the meniscus was important in protecting the articular cartilage from further stress and degeneration.\textsuperscript{48,49} Cox et al,\textsuperscript{50} in their study on canines, reported that the amount of meniscal tissue removed was proportional to the amount of degenerative changes seen in the canine knee joint. Even damaged menisci were found to transmit loads as long as part of the circumferential continuity of the collagen fibers remained intact.\textsuperscript{51} Baratz et al\textsuperscript{5} also found that significant loads could be borne by the peripheral rim of the meniscus as long as it remained intact. There were no abnormally high pressures found at the cut edge of the meniscus following partial meniscectomy. For these reasons, partial meniscectomy has been advocated in place of total meniscectomy.\textsuperscript{52}

Arthroscopy plays an important role in the treatment of meniscal pathology today. The use of alternate portals when necessary and an intraarticular probe have been largely responsible for the increasing accuracy and success of diagnostic and pre-operative arthroscopy.\textsuperscript{53} Results from arthroscopic partial meniscectomy are usually good, although unsatisfactory results are often more common than is generally appreciated.\textsuperscript{21} Reports of patients undergoing arthroscopic partial meniscectomy have claimed satisfactory outcomes in 58% to 92% of cases.\textsuperscript{54,55}
Long-term problems with partial or total meniscectomy have led to an increased interest in meniscal repair.\textsuperscript{56} The success of the technique is thought to be dependent on the microvasculature of the meniscus, which exists in its peripheral rim, approximately 2 mm to 3 mm in width.

Early results of meniscal repair are promising. Studies have reported healing rates of 90\% or higher in tears within the vascular zone of the meniscus.\textsuperscript{57,58} Decreased healing rates have been reported with repair of tears of increasing distance from the meniscosynovial junction.\textsuperscript{59} In a five-year follow-up study, DeHaven et al\textsuperscript{57} reported an 89\% survival rate of repaired menisci. In addition, DeHaven and Arnoczky\textsuperscript{60} have documented a 79\% survival rate in a ten-year follow-up study. There was also compelling radiographic evidence for biomechanical function of successful repairs, as 85\% of patients with successful repairs had normal weight-bearing radiographs.

In both meniscal repair and meniscectomy, the surgical goal is to remove loose cartilage and to stabilize the torn meniscal cartilage.\textsuperscript{61} This is done in an effort to decrease destructive enzymatic and pannus formation within the knee joint. Numerous studies have shown that the menisci should be preserved whenever possible.\textsuperscript{32,61} All or part of their substance should be removed only when the ability of the meniscus to function is destroyed and clinical manifestations such as localized pain, locking, and recurrent effusion occur. Due to the degenerative change meniscectomy has imposed on the knee joint, substitutions to replace the absent meniscus are being investigated.\textsuperscript{6,45,50}
There are certain pertinent factors to consider when making decisions regarding treatment for meniscal lesions. The four basic treatment options are total meniscectomy, partial meniscectomy, meniscus repair, and leaving the tear alone. In order to make the most rational decision, precise knowledge of the type, location, and extent of the tear is needed. This information is best determined by direct visualization and palpation during an arthroscopic examination.

After establishing the presence of the tear, a decision needs to be made regarding whether or not to treat the lesion surgically. Partial-thickness split tears and full-thickness short vertical or oblique tears to not require surgical intervention as long as the inner portion of the meniscus is stable with probing. Short radial tears of 5 mm or less also do not require surgical intervention.

When a meniscal lesion requires surgical intervention, the choice between excision and repair needs to be determined. While it has been reported that preserving some of the meniscal tissue (partial meniscectomy) is preferable to total meniscectomy, preserving all of the tissue (meniscal repair) is even better.

It has been established that tears within the vascular zone have healing rates of approximately 90% when repaired. Tears definitely suitable for repair are those occurring within the vascular zone that are greater than 7 mm long, are clearly unstable with probing, and/or have not sustained major
structural damage. Meniscal repair is questionable when the body of the meniscus has been damaged and the vascular supply to the area affected.

The next important assessment involves whether the tear is in the vascular or avascular zone of the meniscus.\textsuperscript{62} If the tear is within 3 mm of the periphery, it is considered vascular and, if 5 mm or more from the periphery, it is considered avascular. Those distances between 3 mm and 5 mm from the periphery should be considered variable. The age of the patient needs to be considered when determining vascularization since vascular penetration has been shown to be greater in the young skeletally immature individual.

Another consideration in determining the suitability of repair is the extent of damage.\textsuperscript{62} Biomechanical functioning of the meniscus may be greatly affected if extensive damage is present, even if successful healing could be achieved. Lesions not suitable for repair because of the extent of damage or because of their location in the avascular zone of the meniscus should be treated by partial meniscectomy. The goal of this option is to excise the mobile fragments and leave a residual meniscus rim that is intact, stable, and reasonably well contoured. Several studies report improved results after partial versus total meniscectomy,\textsuperscript{52,63,64} but a recent study reports no difference between results of the two procedures when performed in the ACL-deficient knee.\textsuperscript{69} Total meniscectomy is reserved for tears in which no other option is suitable.\textsuperscript{62}
Indications for Substitution

Although studies have documented meniscal transplantations, indications for transplantation are not well defined. Patient age, knee stability, alignment, and degree of compartment wear are all factors that need to be considered prior to meniscal substitution. In addition, the patient should have pain and discomfort consistent with early arthrosis of the involved compartment. If compartment wear is present, but no pain associated with it, substitution is not recommended. However, when increasing wear is seen, substitution is indicated. On the other hand, substitution is not suggested for late stage articular wear or when loss of articular cartilage has led to changes in bone alignment. Such changes would be better treated by osteotomy. Meniscal transplantation is avoided in knees with significant malalignment, particularly varus alignments. In these knees, the articular cartilage is often completely worn off and the joint surface is bone on bone.

Instability is commonly present in patients who are candidates for meniscal substitution. In clinical situations, meniscal injuries are often combined with ACL injuries. Furthermore, ACL insufficiency leads to meniscus tears because of disturbed motion patterns and sudden subluxations of the knee joint. In fact, 80% of the patients with ACL insufficiencies were found to have ruptured menisci within two years after their ACL injury. Associated ACL deficiency in the meniscectomized knee with degenerative changes also raises the question as to the need of a meniscal substitute. It is believed that the
substitute will decrease the contact stress in the involved compartment and contribute to stability. This is particularly important when both menisci are absent or when posterolateral instability is present and the lateral meniscus is absent. When the lateral meniscus is absent, the convex lateral femoral condyle is difficult to control on the convex tibial plateau. The cupping effect of a substitute lateral meniscus would act to control rotation and translation.

Age also plays a role in patient selection. A majority of the patients considered for transplantation are in their late 20s to 40s. These individuals are usually years post-meniscectomy, since it takes time for the development of degenerative knee changes, which is one of the indications for substitution. Since patients in this age group are generally not candidates for arthroplasty, salvage of their knees becomes the main goal. In contrast, a patient approaching the age of 60 may be better served by waiting for an osteotomy where more predictable results can be achieved. In summary, meniscal replacement will usually be performed in patients with degenerative changes and accompanying pain who are physiologically too young to be considered for knee arthroplasty.

Rehabilitation

There is very little information regarding rehabilitation following meniscal substitution. Much of the reason can be explained by the fact that a majority of the studies available have used animals as their subjects. According to Siegel and Roberts, the post-operative substitution protocols ought to reflect the
considerations of post-operative meniscal repair protocols. Most of the reports have incorporated early full range of motion and restricted weight bearing (toe-touch to partial weight-bearing) through the first six weeks post-surgery. Garrett and Stevensen\textsuperscript{73} used continuous passive motion (CPM) on the first post-operative day and full weight bearing at six weeks. Milachowski et al\textsuperscript{74} used the CPM post-operatively and allowed full weight bearing 14 weeks after implantation.

Because many meniscal transplants are combined with ACL reconstruction, preservation of motion is considered a primary goal. Cooper et al\textsuperscript{11} believed the potential for compromising the healing meniscus with early motion is outweighed by the risk of stiffness when early motion is limited following ACL reconstruction. In their treatment of meniscal repair in conjunction with ACL reconstruction, Cooper et al used a post-operative brace and allowed range of motion from $0^\circ$ to $90^\circ$. Early weight bearing was permitted with the brace locked in full extension. This resulted in a faster return to activities. At six weeks, weight bearing was allowed out of the brace and the individual returned to athletic participation in four months.

Meniscal substitutions have been proposed as a method of preventing subsequent degenerative changes when no functional meniscal tissue remains. Three different concepts of meniscal substitution have been studied experimentally and will be reviewed in this paper. The following chapters will
concentrate on the concepts of meniscal substitution, including meniscal autograft, allograft, and synthetic prosthesis transplantations.
CHAPTER IV
MENISCAL AUTOGRRAFTS

Autograft tissues have been used in the human body for transplantation for several years. Surgeons have successfully replaced the anterior cruciate ligament in humans with grafts from the patellar tendon. Autograft tissue has also been used experimentally to replace the meniscus. Reports show that two types of autologous tissues have been used as substitutes: tendon tissue and adipose tissue. Studies regarding meniscal autograft substitution are limited with only one source available for the purpose of this paper. Abstracts from additional studies were obtained and will be used as references to provide the reader with additional information regarding meniscal autograft transplantation. This chapter will review the literature regarding meniscal autograft transplantation, the surgical procedures, and results.

Meniscal substitution with autografts has been performed in both human and animal studies. Kohn and Wirth reported in their abstract the use of a fat pad as an autologous substitute for the meniscus in sheep. Between 1986 and 1988, Milachowski et al replaced the absent menisci in seven human subjects using infrapatellar adipose tissue. In an additional study, Milachowski documented the use of infrapatellar fat pads to replace the menisci in human
subjects. Then, in 1992, Kohn et al\textsuperscript{75} published their results of an experiment substituting the menisci in sheep with tendon autografts obtained from the patellar tendon.

Histologically, the collagen fiber orientation in tendon tissue is similar to the collagen fiber orientation in the periphery of the meniscus.\textsuperscript{23} Kohn et al\textsuperscript{75} proposed that a tendon of the appropriate size could be used to replace that part of the meniscus. The purpose of their study was to see if the autograft would eventually change to a meniscus-like tissue and whether it could protect the articular cartilage from the degenerative changes that commonly occur after meniscectomy.

Surgical Procedure

The surgical procedure described in this section is referenced from the study by Kohn et al\textsuperscript{75} in which tendon tissue was used to replace the meniscus in sheep. Procedures using adipose tissues as autografts were not available for review.

Kohn et al\textsuperscript{75} performed their surgical procedure through an arthrotomy. An incision was made medial to the patella, the medial collateral ligament was detached from the femur, and the entire medial meniscus was removed. A portion of the middle third of the patellar tendon corresponding to the peripheral length of the medial meniscus was removed. No attempt was made to shape the graft into a triangular cross-section as is seen in the normal meniscus. Both ends of the autograft were tagged with sutures. Two holes were drilled from the
anterior surface of the tibia, one to the anterior insertion site of the meniscus and one to the posterior insertion site. These sites were located from remnants of the original meniscus. The tag sutures were passed through the drill holes and the tendon was inserted into the joint space. The autograft was then sutured to the joint capsule. The medial collateral ligament was reattached and the sutures were pulled tight and tied.

Results

When using a fat pad to replace the meniscus, the authors observed a transformation of fat cells into a fibrous tissue forming a meniscus-like body.\textsuperscript{76} Although cartilage degeneration observed after one year was less extensive than after meniscectomy, biomechanically, the graft was said to be inferior to the normal meniscus. Milachowski et al\textsuperscript{78} reported a reduction in the size and strength of the grafts in all their subjects when using infrapatellar adipose tissue to replace the meniscus in humans. Milachowski\textsuperscript{77} reported similar results when using the infrapatellar fat pad to replace the meniscus in humans. In this study, the author reported only a weak meniscus-like tissue existing one year post-operatively.

Kohn et al\textsuperscript{75} documented their results following the use of a portion of the patellar tendon to replace the menisci in sheep. Twenty sheep had been randomly assigned to four groups with one group being the control group. In the control group, meniscectomy was the only procedure performed. This group was sacrificed at 12 months and the knee joints examined. The animals in the
remaining groups underwent meniscectomy and replacement using a portion of
the patellar tendon. Animals in these groups were sacrificed at 3, 6, and 12
months and their knee joints examined.

By 12 months, the animals in the control group had regenerated menisci,
but none were of normal size and shape. In contrast, the other group's
implants became progressively more similar in size and shape to a normal
meniscus. At three months, necrosis of the small vessels was detectable. After
six months, highly cellular connective tissue had developed adjacent to the
central edge of the tendon autograft and gave the autograft an appearance
similar to that of the normal meniscus. Also at six months, the autografts were
observed to contain blood vessels. By 12 months, the implants resembled
normal menisci in both size and shape. Two parts of the autograft substitute
could be observed: a peripheral part with strong circumferentially orientated
collagen fibers and a central part with few fibers and more cells. These
appearances at 12 months suggest that a remodeling process had taken place.
Biomechanical testing of the autografts was performed at 3, 6, and 12 months
with the highest values for failure stress and tensile modules being found in the
12th month. These values were still lower than those for a normal meniscus or a
normal patellar tendon. The authors reported results that tendon tissue does not
change into a new meniscus, but only into a somewhat inferior substitute.

The main differences between genuine menisci and the structure resulting
after 12 months implantation were the presence of blood vessels and the
different pattern of the collagen fibers within the substitute. Biomechanically, the differences between patellar tendon, normal meniscus, and the resulting autograft structure were considerable and cast doubt on the suitability of using tendon tissue as an autograft. While transplantations using autograft tissue could possibly eliminate problems related to tissue availability, disease transmission, and immunologic reactions, the results have shown that the ability of the substitute to function like normal meniscal tissue is limited.
CHAPTER V

MENISCAL ALLOGRAFTS

The use of allogenic tissues in orthopedic surgery is relatively common. Studies employing allografts as substitutes for the meniscus in animal models has had promising results. Meniscal substitution with allografts has also been performed in humans but the reported results are only short-term and the available data are limited. This chapter will focus on the concept of allogenic meniscal substitution with review of the different types of allografts available, the surgical procedures used for implantation, and the results of allograft substitution. Considerations regarding meniscal allograft transplantation will also be reviewed.

The first human meniscal allograft transplantation was performed in 1984. Since that time, additional studies have documented the use of allografts in replacing the human meniscus. Wirth et al, in a study published in 1986, reported on 14 patients who had freeze-dried allografts implanted into their knee joints. In 1987, Keene documented a case study using a fresh allograft for substitution. Milachowski et al, in 1989, reported the results of their study using deep-frozen and lyophilized gamma-sterilized allografts in 22 patients. Zukor, in his 1990 study, documented the use of fresh meniscal
allografts in 26 patients. Then, in 1991, DeBoer and Koudstaal reported their results on substitution using a cryopreserved meniscal allograft.

Surgical Procedures

Meniscal allografts can be transplanted arthroscopically or by open technique through an arthrotomy. Milachowski et al performed their procedure through arthrotomy by making a medial incision through which they either split the medial collateral ligament longitudinally or detached it from its tibial insertion, depending on the amount of instability present in the knee joint. Meniscal remnants were trimmed back, leaving a thin rim around the periphery. The posterior part of the allograft was then attached either to the remnant or the intercondylar ridge of the tibia. Another allograft attachment was made to the posterior cruciate ligament (PCL). The allograft was then sutured to the peripheral rim of the original meniscus. Anterior cruciate ligament reconstruction was then performed using the middle third of the patellar tendon.

Garrett and Stevensen used arthrotomy in their procedure which involved removing the ipsilateral collateral ligament from its femoral attachment. The original meniscal remnant was resected back to the vascular periphery and the allograft was trimmed to fit. The allograft was sutured to the rim of the original meniscus and a cancellous screw inserted to reattach the collateral ligament. Garrett and Stevensen eventually included in their procedure both anterior and posterior horn attachments using a bone block from the donor tibia.
A trough was created in the recipient tibia and the bone block secured using a cancellous screw.

Other surgical procedures employing arthrootomy have been used in meniscal allograft transplantation. One procedure involves using individual circular bone blocks at the anterior and posterior horn attachments. The blocks are then fit into tunnels drilled in the recipient tibia. Although the surgical technique was not described, another procedure transplanted menisci with their attached tibial plateaus.

Meniscal allograft transplantations have also been performed arthroscopically. Shelton and Dukes implanted 14 meniscal allografts using an arthroscopic technique. The procedure involved trimming the original meniscus back to a thin rim and drilling tunnels in the recipient tibia for replacement of bone plugs. The allograft with its bone plugs was then inserted into the recipient without detachment of the collateral ligaments. The bone plugs were secured into the tunnels and the allograft was sutured to the peripheral rim of the meniscal remnant.

Results

Results of experimental meniscal allograft transplantations in the animal model have been documented. Arnoczky et al. replaced the medial meniscus of 14 adult dogs with cryopreserved meniscal allografts. Two weeks following transplantation, the allograft appeared grossly normal and had begun to heal to the periphery. At one month, some specimens showed a disruption of the
posterior horn attachment which had healed with a gap. By six months, all allografts had completely healed to the periphery. Allograft cellularity had decreased two weeks after transplantation, but by six months, cellularity and metabolic activity had returned to normal. Also at six months, the periphery of the allografts were revascularized with small vessels originating from the joint capsule and synovial tissue. The authors stated the results proved that cryopreserved meniscal allografts could heal into the knee joint. The tibial cartilage left uncovered by the allograft showed signs of fissuring and degeneration. While the healing did not preserve all the cartilage from degeneration, it was significantly better than the cartilage in meniscectomized knees.

Arnoczky et al. studied cellular repopulation of deep-frozen meniscal autografts in the canine model. Menisci were deep frozen by immersion in liquid nitrogen. After transplantation in the same dog, the menisci were repopulated with host cells presumably from the synovium. All implants showed complete healing to the periphery. By three months, all but the center of the implant was repopulated with host cells. At six months, polarized microscopy showed a loss of normal collagen orientation in the superficial and subsuperficial layers of the implant. While this was a study of deep-frozen meniscal autograft transplantation, it does demonstrate that all donor cells in the implant are killed by the deep-freezing technique. The authors suggested that it was also likely that deep-frozen meniscal allografts are completely repopulated by host cells.
Milachowski et al transplanted lyophilized gamma-sterilized and deep frozen allografts into the knees of sheep. The lyophilized allografts healed at six weeks and were fully remodeled by 48 weeks. In contrast, the deep-frozen allografts were healed at 48 weeks, but showed little remodeling or revascularization.

Clinical results of meniscal allograft transplantation in humans have also been documented. Milachowski et al, after successful transplantation in sheep, performed meniscal allograft transplantations in 22 patients. In their study, they used lyophilized gamma-sterilized allografts in 16 patients and deep-frozen allografts in six patients. All transplantations were performed in conjunction with ACL reconstruction through an arthrotomy. Arthroscopy was performed post-operatively on five patients with deep-frozen implants. All allografts had healed, but in one case, it had decreased in size by two-thirds. Ten patients receiving the lyophilized allografts were arthroscoped post-operatively. Only one patient demonstrated a normal meniscus. A reduction in size was noted in all others, with four grafts being reduced in size by two-thirds and four being reduced by one-third. In one case, the implant was completely destroyed. Synovial reaction was more pronounced in the lyophilized transplants with four cases of intense synovitis. The authors concluded that meniscal transplantation is a reasonable procedure when using deep-frozen allografts.
Garrett and Stevensen\textsuperscript{73} transplanted fresh meniscal allografts into six patients through arthrotomy. Three of the patients had ACL reconstruction in conjunction with meniscal allograft transplantation, two had osteochondral allografts for lateral femoral condylar defects, and one had ACL reconstruction and an osteochondral allograft for a lateral femoral condylar defect. Four of the patients underwent post-operative arthroscopy. All demonstrated complete healing of the allograft with no shrinkage. Results of this study showed that fresh allografts could heal to the peripheral rim and contribute to knee stability.

Keene et al\textsuperscript{82} arthroscopically transplanted a fresh meniscal allograft into a stable knee four years after meniscectomy. An arthroscopy at six months showed healing of the implant to the periphery, but not at the anterior and posterior horns.

DeBoer and Koudstaal\textsuperscript{83} implanted a cryopreserved lateral meniscal allograft, also into a stable knee. At six months, arthroscopy showed a normal-sized meniscus firmly healed to the capsule. Biopsy showed viable, metabolically active chondrocytes. The authors reported clinically that fresh and cryopreserved menisci can heal to the periphery, but their ability to forestall degenerative arthritis needs to be determined.

Types of Allografts

Meniscal replacements have been performed using fresh, deep-frozen, lyophilized (freeze-dried), and cryopreserved (controlled rate freezing) allografts.\textsuperscript{85} In theory, transplantation of fresh meniscal allografts allows the
cells to maintain their viability and function. Arnoczky and Milachowski noted that the rationale for maintaining cell viability in meniscal tissue was based on studies involving articular cartilage, where changes in material properties have been noted. It has been suggested that a viable cell population at the time of transplantation might be beneficial to the material properties of the meniscal allograft.

Meniscal substitutions employing fresh allografts have produced variable results. Jackson et al. noted normal appearing menisci six months after transplantation. While a normal vascular distribution was also noted, a decrease in cellularity was observed. Biochemical analysis revealed increased water and decreased proteoglycan content in the transplanted menisci. Conversely, Keating described allograft degeneration with associated articular cartilage destruction seven months after implantation of fresh allograft menisci in goats. Their observation of an inflammatory cell infiltrate at three months following surgery may have been due to a subtle immune response.

Menisci, like other cartilaginous structures, have generally been considered "immunologically privileged" tissues. This view has been supported by the apparent absence of graft rejection in animal models. It was suggested that antigens present on the surface of meniscal chondrocytes were shielded from the host immune system by the nature and abundance of extracellular matrix. Arnoczky, however, has shown that fresh tendon allografts are capable of eliciting a potent inflammatory response. Vasseur et al. reported
finding anti-donor leukocytes in the synovial fluid of dogs receiving patellar
tendon allografts for reconstruction of the ACL. These observations, when
combined with Keating’s, suggest that a subtle immune response may develop
against implanted menisci.

The use of fresh allografts presents numerous logistical problems such as
harvesting, graft transportation, and operative timing. In a study of patellar and
ACL allografts, Jackson et al\textsuperscript{91} noted that fresh allograft cell DNA was completed
replaced by host DNA four weeks after transplantation in goats. This suggests
that the cells of fresh allografts do not survive. Fresh meniscal allografts may
also undergo a similar repopulation by host cells. If all donor cells of fresh
allografts are replaced by host cells, then the additional difficulties created by
fresh allograft transplantation may not be warranted.

The remaining types of allografts used for transplantation have been
subjected to preservation techniques and include lyophilized, deep-frozen, and
cryopreserved allografts.\textsuperscript{92} Clinical impressions vary as to which preservation
 technique is preferable.

Freezing can reduce the immune response evoked by allografts.\textsuperscript{88}
Milachowski et al\textsuperscript{93} observed that the outer one-third of deep-frozen meniscal
allografts in sheep became vascularized in a fashion similar to the normal
meniscus. They also observed a repopulation by cells derived from the host. A
subtle remodeling of the superficial collagenous network was reported by
Arnoczky in the canine model.\textsuperscript{85} This raises concerns regarding the
biomechanical functions of the graft. Bylski-Austrow et al., demonstrating only partial restoration of meniscal load-bearing function six months after transplanting deep-frozen menisci. Whether such a small change in joint load is clinically significant remained to be determined.

Lyophilizing (freeze-drying) offers the advantage of easy handling and prolonged storage at room temperature. However, the results of implanting lyophilized menisci in animal models have not been encouraging. Significant gross and histological alterations have been noted in the morphology of lyophilized meniscal allografts following implantation. Articular cartilage degeneration, as well as increased synovitis, are present in animals receiving these grafts.

Cryopreservation of transplanted cells and tissues is usually accomplished with dimethyl sulfoxide (DMSO) or glycerol. These agents prevent cell membrane disruption by crystal formation during the freezing process. It has been suggested that chondrocyte viability in cartilage ranges from 10% to 40% when using this technique. Arnoczky et al. examined graft incorporation following the transplantation of cryopreserved meniscal allografts in the canine model. They described a nearly normal histologic appearance of the meniscal allograft at three months. In addition, the proteoglycan content and tensile strength of the allografts were similar to control menisci six months following transplantation.
Considerations

Selecting an allograft of the appropriate size is an important consideration when performing meniscal transplantations. Magnetic resonance imaging (MRI), computed tomography (CT) arthrograms, and standard anteroposterior films of the knee have been used to predict the appropriate allograft size. A technique for matching donor menisci with recipients using standard anteroposterior films of the knee was described in a study done by Garrett and Stevensen. Matching to within 5% was achieved in every case. The ability of MRI and CT arthrogram in determining the size of allograft needed for individual meniscal transplantation has been examined. Magnetic resonance imaging and CT arthrograms were performed on cadaver knees. Measurements were taken and compared to measurements of the menisci after dissection. It was found that MRIs and CT arthrograms tend to either over or under-estimate meniscal size in 93% and 88% of cases respectively. The medial and lateral menisci of contralateral knees were measured and found to be near mirror images of each other. This suggests that the contralateral meniscus could be used for sizing purposes in meniscal transplantation.

Once selected, if the meniscal allograft is too large, the periphery can be trimmed, but care should be taken not to disrupt the circumferential orientation of the collagen fibers. If too small, the allograft should not be used, as it would have to be cut or stretched to make it fit. This would disrupt the fiber orientation and render the allograft functionless.
Disease transmission resulting from tissue transplantation is a significant concern. Because of the risk of contaminated tissue bypassing current screening methods, certain tissue banks are providing sterilization.\textsuperscript{72} Lyophilization has been shown to kill the AIDS virus and prevent disease transmission. This method is used less often in meniscal transplantation as the technique distorts and dries the tissue. A reconstitution is then necessary which may cause tissue hydration, swelling, and size changes that are critical to meniscal transplant success. Irradiation of tissue has been a popular technique for sterilization.\textsuperscript{95} It has been shown to sterilize all but the most virulent bacterial and viral pathogens at a dose that does not distort the tissue size.

Currently, much of the meniscus transplant surgery involves Cryopreservation.\textsuperscript{72} This technique involves an easily reproducible method of preserving harvested meniscal tissue while maintaining active DNA and cell viability over a period of prolonged storage. Cryopreservation does not sterilize the meniscal allograft as sterilization would render all cells and DNA biologically inert. With the increased concern of AIDS transmission, many surgeons are demanding the serialization of meniscal allografts. If Jackson’s data are correct (indicating that all allogenic DNA is nonviable four weeks after implantation), it may not matter if the allograft is cryopreserved and viable or sterilized and non-viable.\textsuperscript{91} Sterilized allografts may produce results equal to cryopreserved allografts.
In summary, after an initial impairment, the allograft’s metabolic activity and material properties returned to normal. Long-term performance of the substitute was questioned, however, due to the decreased cellularity and alterations in collagen structure of the superficial layers that were noted six months after implantation. With all substitutes, gross inspection suggested that the tibial cartilage was better preserved than after meniscectomy.
CHAPTER VI
MENISCAL PROSTHESIS

Meniscal replacements using artificial prostheses have been performed since 1983 and have been limited solely to animal studies.\textsuperscript{98} This chapter will review the concept of substituting the meniscus with an artificial prosthesis, the surgical procedures used, the results obtained, and considerations surrounding the use of meniscal prostheses.

Over the years, different materials have been tried in an attempt to find a design similar to the normal meniscus in terms of its mechanical properties. A Teflon net prosthesis was used in a study on dogs in 1983.\textsuperscript{98} Also in 1983, results of a siliastic meniscus prosthesis were published.\textsuperscript{99} In 1990, meniscal substitutes made of polyester-carbon fiber were used in a rabbit experiment.\textsuperscript{100} Dacron prostheses with polyurethane coatings were used to replace the menisci in rabbit knees in a 1992 study.\textsuperscript{101} Three different substitutes were used in an experiment published in 1993; polyurethane-coated Dacron, polyurethane-coated Teflon, and uncoated Teflon prostheses.\textsuperscript{102} In 1993, a Teflon prosthesis coated with an autologous periosteal flap was used experimentally to replace the meniscus in rabbits.\textsuperscript{103}
Surgical Procedures

Surgical procedures to implant the synthetic prosthesis have been performed solely through arthrotomy.\textsuperscript{98-103} The techniques used have been described and vary somewhat between studies. In a study published in 1990, the authors implanted polyester-carbon fiber bioprostheses into the knee joints of rabbits.\textsuperscript{100} The implants were comprised of concentrically stacked hoops of carbon fibers ensheathed by woven high-tenacity polyester fibers. On either end, the prosthesis continued as braided threads for transosseous anchorage of their anterior and posterior ends. Through a medial parapatellar incision at the inferior pole of the patella, the medial collateral ligament was divided transversely and a medial meniscectomy was performed. A 2 mm transosseous tunnel was created from the subcutaneous border of the tibia to the posterior horn insertion and the posterior thread of the implant was passed through. The implant was then sutured to the joint capsule and the anterior thread of the implant was passed through the patellar tendon. The anterior and posterior threads were tied and the medial collateral ligament repaired.

A variation of the previous procedure was described by Sommerlath and Gillquist\textsuperscript{101} in their study on rabbits in 1992. In their study, the synthetic prosthesis used was made of dense woven Dacron felt with polyurethane coating on both the upper and lower surfaces, while the peripheral margin remained uncoated. Incisions were made anterior and posterior to the medial collateral ligament and a medial meniscectomy performed. Two 1 mm holes
were drilled beginning anterior to the tibial portion of the medial collateral ligament and aimed at the areas of the anterior and posterior horn attachments of the meniscus. Anchoring sutures attached to the anterior and posterior horns of the prosthesis were passed through the drill holes and tied. The prosthesis was then sutured to the medial collateral ligament and the joint capsule.

In 1994, Kessner\textsuperscript{103} described a surgical procedure that was used to implant Teflon prostheses coated with autologous periosteal flaps into the knees of rabbits. Incisions were made anterior and posterior to the medial collateral ligament and the medial meniscus was excised. The incisions were enlarged to gain access to the proximal tibia. A round periosteal flap was cut out of the tibia and removed. The flap was folded over the prosthesis with the free edge along the peripheral border of the implant. Sutures were used to hold the free ends of the flap together. Additional sutures were placed to hold the flap to the prosthesis. The cambium layer of the periosteal flap was faced inward in order to enhance ingrowth into the artificial matrix. This composite meniscus was then inserted and fixed into the joint by passing sutures through drill holes, similar to the procedure described by Sommerlath and Gillquist.\textsuperscript{101}

Results

Studies on artificial meniscal prostheses have shown varying degrees of success. Toyonaga et al.\textsuperscript{98} used a Teflon net as a matrix for tissue ingrowth. After a slight adverse reaction to the Teflon during the first months, they observed ingrowth of fibrocartilage cells into the net. Although osteophyte
formation and degenerative cartilage changes were present, the prosthesis appeared to slow the processes down. According to their results, the authors suggest that the substitute needs to be closer to the normal meniscus in size, shape, and material properties in order to restore meniscal function.

The results of a study on rabbits using prostheses of Dacron with polyurethane coatings on both the upper and lower surfaces showed good ingrowth and stabilization by the surrounding tissues. Compared to one group in their study which had undergone meniscectomy with no prosthetic replacement, the group with the implants had a lower frequency of cartilage changes on the tibia, but not on the femur. Biomechanical assessments were performed by first disarticulating the limb to be tested at the hip. All soft tissues were removed, leaving the ligaments and joint capsule intact. The femur and tibia were cut proximal and distal to the knee joint. The joint was then mounted into a testing machine (Alwetron, Loventzon, & Wettre, Stockholm, Sweden) and secured with screws. Loads were applied and the joint was cycled several times followed by periods of relaxation. It was shown in this study that the meniscal prosthesis could not restore the load-relaxation behavior of a normal knee joint. The authors concluded that improper sizing of the prosthesis together with inferior biomechanics led to excessive osteophyte formation and chronic synovitis.

Messner and Gillquist reported results of their study in 1993. Three different implants were used to substitute the menisci in rabbit knees; one
comprised of Dacron with a polyurethane-coating on the upper surface, one of Teflon with a polyurethane-coating on the upper surface, and one of Teflon with polyurethane-coating only at its suture sites. Biomechanical testing was performed in a manner similar to the method described in the previous study. Results were similar for both prostheses coated on their upper surfaces. Both types of coated prostheses kept their original size and shape, while the Teflon prosthesis with coating at its suture sites had decreased in size. The Teflon implants with coating only at their suture sites were less compliant and had a higher load-relaxation than the knees with the other protheses. Ingrowth of fibrous tissue into the prosthesis rim tended to be more efficient in both Teflon prostheses. In most subjects, implantation of a synthetic prosthesis led to synovitis. Overall, the authors determined the coated Teflon prosthesis gave the best results.

In another of Messner’s studies, the author used a Teflon prosthesis coated with an autologous periosteal flap. This study was based on the idea that the artificial part (Teflon) would provide material properties similar to the normal meniscus. The biological part (periosteal flap) was supposed to facilitate the integration of the prosthesis, prevent wear, and thus improve long-term function. Results of this study showed that the prosthesis lost its shape once implanted and was not able to function as a normal meniscus. The cartilage in the knee joint showed osteoarthritic changes similar to those seen after meniscectomy. Moderate synovitis was also observed in the knee joints.
Elongation of the prosthesis was observed at both the anterior and posterior attachments. Biomechanical testing revealed normal values for joint compression compliance and joint load relaxation despite a non-functioning prosthesis and the presence of osteoarthritis. In all cases except one, the periosteal graft provided for cellular immigration throughout the artificial matrix; however, the graft only regenerated fibrocytes, instead of fibrochondrocytes, which are typical of the normal meniscus.

Considerations

An important consideration for any artificial substitute is the biocompatibility of its components. The synthetic materials used in the studies mentioned in this chapter have proven their biocompatibility and have been routinely used for human implantation. Unfortunately, the requirement for biocompatibility limits the access to other synthetic materials which may better match the complex material properties of the normal meniscus. Knee joint synovitis has been reported as a common reaction to the particle debris from the different materials being used. This fact may limit the use of these materials as meniscal substitutions.

Ideally, the prosthesis should be of the correct size and shape for implantation. This poses considerable difficulties since in vivo measurements require complicated and expensive evaluations. Shaping and sizing the prosthesis at the time of surgery is not recommended due to the resulting loss of tissue quality. Since contralateral menisci are said to be near mirror images of
each other, MRI of the contralateral menisci appears to be an excellent solution to attaining the correct measurements. Nevertheless, the use of MRI for this purpose does require the presence of a healthy contralateral meniscus. To further complicate the sizing process, in patients with post-meniscectomy arthrosis, remodeling of the tibial and femoral condyles may have already taken place which influences the fit of any substance.\textsuperscript{45} Even if the exact measurements could be obtained, it may be difficult to find a prosthesis with these same measurements. Kessner's study showed that the results of improper prosthesis sizing are synovitis and formation of large osteophytes.\textsuperscript{104} A perfectly sized and shaped substitute seems to be more important in prosthetic replacement than in replacements using biological substitutes where a certain amount of remodeling can take place. When using a prosthesis of improper size, either a remodeling of the synthetic material resulting in wear and dysfunction will occur or a remodeling of the knee joint with resulting synovitis, arthrosis, and osteophyte formation occurs.\textsuperscript{101-103}

The material properties of normal meniscus tissue are complex and vary throughout the meniscus.\textsuperscript{17} The nature of these properties makes matching of its material properties very difficult.\textsuperscript{104} The normal meniscus undergoes gross changes during dynamic motion.\textsuperscript{108} The polyurethane-coated Teflon prosthesis, which proved to be the best prosthesis in Kessner's study, seemed too inflexible to carry out these changes.\textsuperscript{102} However, the uncoated Teflon prosthesis, which was more flexible and had the best mechanics, failed in its ability to resist wear
and retain its shape.\textsuperscript{102,103} The Teflon prosthesis with a periosteal flap was then tried with the idea that the synthetic material would provide for cellular ingrowth which would improve the material properties of the implant.\textsuperscript{103} It was suggested that the biological cover may prevent long-term wear and give the implant some potential for remodeling and healing. This idea failed due to the deformation of the substitute and elongation of the anterior and posterior attachments.

Determining the attachment sites of the anterior and posterior horns of the original meniscus is important when implanting a prosthesis. In meniscectomized knees, it may be difficult to find these anatomical attachment sites and may result in malalignment of the prosthesis.\textsuperscript{104} In Kessner's series of experiments, part of the osteophyte formation and cartilage degeneration found after three months of implantation was felt to have been caused by poor placement of the prosthetic attachments.\textsuperscript{102,103}

Strong and elastic attachments of the anterior and posterior horns of the prosthesis are needed to guarantee the transfer of vertical loads.\textsuperscript{109,110} During flexion and extension of the knee joint, the normal meniscus undergoes changes in its shape at both its body and attachment sites.\textsuperscript{108} Without the elastic component, the constant elongation these sites undergo during flexion and extension will result in permanent changes in the prosthesis and lead to dysfunction.\textsuperscript{109,110} In a study that implanted uncoated Teflon prostheses, the failure as felt to be a result of both elongation of their attachments and changes in the shape of the prostheses which eventually caused displacement of the
prostheses. Furthermore, in vitro loading of a knee joint with damage to its attachments showed corresponding load increases on the tibia. This finding is similar to the load increases seen in the meniscectomized knee.

Decreases in contact area between the femoral condyles and the tibial plateaus that occur following meniscectomy tend to result in increased peak stresses. In contrast to newly meniscectomized knees, decreases in peak stress were found in a study on goats four and eight months post-meniscectomy. The decrease in peak stresses resulted from an increase in the contact area which occurred following joint remodeling with irreversible cartilage changes. This indicates the importance of substituting the meniscus immediately following meniscectomy.

Meniscectomy tends to cause an increase in stiffness in the knee joint. This is felt to be a result from the cartilage destruction, soft-tissue swelling, or pannus formation on the tibia. In knees with synthetic prostheses implanted, joint stiffness was decreased. Sommerlath and Gillquist felt this was caused by the high compressibility of the implant used in their study. The authors suggest the difference in joint stiffness between knees with prostheses and meniscectomized knees may also be due to differences in the degree of cartilage changes.

Ingrowth into the synthetic prosthesis is needed to provide a stable fixation of the implant. Toyonaga et al reported good integration of the Teflon net prosthesis used in their experiment. Sommerlath and Gillquist also
had good ingrowth using Dacron prostheses. In Messner's\textsuperscript{103,104} series of studies, the rim of the Dacron and Teflon prostheses was firmly incorporated into the joint capsule with minimal invasion of fibrous tissue into the matrix. In contrast, Messner and Gillquist's\textsuperscript{102} Dacron prosthesis showed little ingrowth. The authors felt a probable cause for this was that after adaptation of the implant to the measurements of a normal rabbit meniscus, the peripheral uncoated rim of the implant could have become too small to allow sufficient ingrowth. Conditions for good ingrowth are reported to be knee joint stability with intact ligaments and the presence of a porous uncoated material at the rim of the prosthesis.\textsuperscript{102,112} In studies implanting synthetic meniscal prostheses into knee joint with resected ACLs, the Dacron prostheses became initially fixed by fibrous ingrowth at six weeks.\textsuperscript{112} Longer observation showed most prostheses to be loose and subluxed anteriorly.\textsuperscript{71} Joint alterations became so advanced after three months of ACL deficiency that even intact menisci ruptured and became displaced. This indicated the importance of joint stability when considering meniscal substitution.

Synovitis and osteophyte formation are common after meniscal substitution.\textsuperscript{74,98,101} Osteophyte formation, synovitis, cartilage softening, and arthrosis have all been reported following prosthetic implantation.\textsuperscript{102} In prosthetic surgery, these changes reflect a combination of disturbed movement patterns and adverse reactions.\textsuperscript{113} Because meniscectomy has led to similar changes, disturbed movement patterns are of predominant concern. Cartilage softening is usually associated with clefts in the superficial cartilage layers and
reflects definite cartilage damage. Cartilage softening has also been reported soon after ligament or meniscus resection as the first signs of osteoarthritis. Synovitis following disturbed motion patterns was observed by Garcia et al. After implantation of a sterile sheet of polyethylene into the rabbit knee, the authors observed formation of fibrocartilage and chondrocytes, leading to ossification adjacent to bone. By three months, complete osteophyte had formed. The synovitis seemed to be proliferative, destructive, and proceeded the arthrosis. This type of synovitis was common in subjects with either biological minuscule substitutes or artificial prosthesis and in subjects following meniscectomy or ACT resection.

To summarize the concept of minuscule substitution using synthetic prostheses, studies have found that the requirement of biocompatibility severely limits access to materials which may possess properties more similar to the normal meniscus. The possible advantages of a synthetic minuscule substitute, such as availability and freedom from disease transmission, are overshadowed by factors such as sizing problems, inferior materials, and wear. Normal attachments of the anterior and posterior horns of the prosthesis could not be reconstructed with the synthetic materials and this may be one of the main causes of insufficient cartilage preservation after substitution. It was shown that synthetic implants without a polyurethane coating may fail due to wear and changes in shape while the coated prostheses, which are more inflexible, often caused osteophyte formation and synovitis. Knee joint stability
with intact cruciate ligaments seems to be a basic requirement for incorporation and fixation of the prosthesis into the knee joint.\textsuperscript{102,112}
CHAPTER VII

CONCLUSION

Some parts of the body can be removed without ill effect and some parts regenerate completely; however, neither of these statements is true regarding the meniscus in the human knee. With acknowledgment of their vital role in normal knee biomechanics came the understanding of the significance in preserving the menisci. The structure and composition of the menisci allow them to be effective in performing their many functions. Following meniscectomy, a loss of these functions occur and the common result is a knee joint with progressive degenerative arthritis. Meniscal substitution is currently being researched in an effort to substitute the absent meniscus and prevent further degenerative changes from occurring. Three different concepts of meniscal substitution have been proposed as replacements for the absent meniscus, meniscal autografts, meniscal allografts, and synthetic prostheses.

According to available literature, autograft substitutions for the meniscus have been used in a limited number of experiments. Autologous tissues have the advantage of avoiding the problems of disease transmission, immunologic reactions, and tissue availability. While able to heal with good
integration into the joint, the grafts were described as "weak" and biomechanically "inferior to the normal meniscus."

Artificial synthetic prostheses to replace the meniscus have the advantages of availability and freedom from disease transmission, but these advantages are overshadowed by sizing problems, inferior material properties, and wear. With the use of available materials, such as Dacron and Teflon, knee joint stability with intact cruciate ligaments seem to be a basic requirement for the incorporation and fixation of the synthetic material into the biological environment. Similar to using allografts or autografts, normal anterior and posterior attachment sites could not be reconstructed with the synthetic material, which may be one of the main causes of insufficient cartilage preservation after meniscal substitution. Furthermore, it was shown that synthetic implants without a polyurethane coating failed because of wear and changes in shape, while the coated more flexible implants often caused osteophyte formation and synovitis. To develop a more successful design for a prosthetic meniscal replacement, further investigations are needed to create a prosthesis that possesses the structural and material properties needed to simulate normal meniscal function.

Both human and animal studies have shown early success in restoring meniscal function by transplantation of whole menisci. Menisci from cadaver donors have been used to replace the absent menisci in human knees. It is presumed that the successful transplantation of a meniscal allograft may protect the joint from some of the degenerative changes seen after a total
meniscectomy.\textsuperscript{85,86,97} This presumption requires that the material properties of the transplanted meniscus can be maintained on a long-term basis. At six months, implants showed changes suggesting degeneration; however, clinically, the menisci looked good grossly as did the adjacent articular cartilage.\textsuperscript{85,86} If the biochemical parameters do not return to a more normal level, the breakdown of the transplanted meniscus may follow. Since many unanswered questions remain regarding preservation of grafts, immune response to grafts, and technical considerations involving implantation, further studies are needed.

Although transplant surgery for the meniscus remains an exciting and encouraging procedure to minimize knee problems in individual who have undergone total meniscectomy, long-term follow-up currently is limited or nonexistent. Meniscal substitution remains a cautiously optimistic treatment for the future.
REFERENCES


34. Seedhom BB, Wright V. Functions of the menisci. J Bone Joints Surg. 1974;56B:381.


