

Knee Meniscus Replacement

An Essay

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Abbreviations

MAT	Meniscus allograft transplantation
CMI	Collagen meniscus implant
bFGF	Basic fibroblast growth factor
BMP	Bone Morphogenic Protein
BMSCs	Bone marrow derived stem cells
C ABC	Chondroitinase ABC
DNA	Deoxyribonucleic acid
ECM	Extracellular matrix
FGF	Fibroblast growth factor
GAGs	Glycosaminoglycans
IGF	Insulin-like growth factor
IL-1	Interleukin-1
kPa	Kilopascal
MMP 2	Matrix metalloproteinase 2
MSCs	Mesenchymal stem cells
PCL	Polycaprolactone
PDGF bb	Platelet Derived Growth Factor bb
PGA	Polyglycolic acid
PLA	Polylactic acid
PLGA	Polylactic co-glycolic acid
PNIPAAm	Poly N isopropyl acrylamide
PU	Polyurethane
PTFE	Polytetrafluorethylene
PVA-H	Poly (vinyl alcohol) hydrogel
PRP	Platelet rich plasma
TGF-β	Transforming Growth Factor- β
VEGF	Vascular endothelial growth factor

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Aim of the work

Meniscus plays an important role in protecting the health and function of the knee joint, this study aims to review the alternatives of meniscal replacement like meniscus transplantation and meniscus implants.

Introduction

Introduction

Meniscus is a greek word meniskos (crescent) which points to semi lunar discs of fibro cartilage tissue that play an important role in knee biomechanics. Meniscus is composed of a network of collagen fibers (predominantly type 1 collagen) interposed with cells and extracellular matrix of proteoglycans and glycoproteins. Menisci are placed between medial and lateral femoral condyle and tibial plateau. Anatomical studies have shown that the degree of vascular penetration is 10% - 30% of the width of medial meniscus and 10%-25% of the width of lateral meniscus, so the majority of the meniscus is a vascular and must therefore derive nutrition from synovial fluid diffusion.(1)

Menisci play an important role within knee joint. Their functions include load bearing, shock absorption, joint stability, joint lubrication and proprioception. Biomechanical properties of menisci depend on the anatomical characteristics and material properties of this tissue. (2)

Meniscus injuries most commonly occur through rotational movement of the loaded knee. A deficient meniscus implies a decrease of surface contact area with a subsequent increase of contact pressure, leading to wear and gradual disappearance of cartilage. (4)

Meniscus transplantation aims to restore knee joint anatomy. The allograft is aimed to serve and perform in a similar fashion as the original one. An allograft should delay or better still prevent osteoarthritis of the knee. An allograft is indicated in young patient with history of menisectomy and in ACL deficient patient who had medial menisectomy with ACL reconstruction to increase knee stability. The success of allograft needs normal or normalized knee alignment, stability, size matched and non irradiated graft with secure fixation of meniscal horn. (10)

Collagen scaffolds are implanted into the knee to support the regeneration of new meniscal tissue. These resorbable implants have been moulded to approximate the shape of a normal human knee meniscus. Collagen meniscus

implants are made from purified type 1 collagen fibers isolated from bovine achilles tendon. (25)

The paradigm of tissue engineering has traditionally been defined as the combination of replacement cells, cell signaling stimuli (mechanical or chemical/biochemical), and supporting scaffolds. Although the use of these three elements in combination comprises the classical approach to engineering replacement tissue, in recent years cell self assembly has begun to gain recognition and support in generation of functional cartilage, fibro cartilage, vasculature and retina. (25)

Implants are placed using an arthroscopic or open surgical procedure. When menisectomy is indicated, the damaged meniscus tissue is removed by debridement until healthy vascularized tissue is reached. In those cases where debridement doesn't reach vascularized tissue, a bleeding bed is created by perforating the rim of the meniscus. An implant of suitable dimension is then sutured to meniscal rim. (28)

The collagen meniscus implantation indication includes irreparable injury or partial loss of menisci in a normally aligned knee. The involved knee should be stable or able to be stabilized at the time of surgery. Collagen meniscus implant shouldn't be performed in patient with full thickness complete meniscal defects, inflammatory disease, systemic disease (gouty), known collagen allergies and autoimmune disease. (28)

Experience with polycarbonate urethane as a scaffold for tissue engineering was obtained during the search for vascular prosthesis in cardiovascular surgery. Studies had already demonstrated its biodegradability, biocompatibility, micro porous structure and elasticity related to its porosity. (30)

Chiari developed a biomaterial consisting of hyaluronic acid and polycaprolactone to serve either as a partial or total meniscus substitute and tested in sheep. The former is prepared by ring opening polymerization of caprolactone and is subjected to biodegradation via hydrolysis. (31)

Chapter I

Basic science

- Anatomy of Knee Meniscus
- Biochemical Content
- Biomechanical and Functional Properties
- Meniscus tear Pathophysiology
- Meniscal Cells

Anatomy of knee meniscus

The meniscus is a c- shape fibrocartilaginous tissue. The peripheral border of each meniscus is thick and attached to the capsule of the joint, while the inner border tapers to a thin free edge. **(1)**

The anterior and posterior horns of both menisci directly attach to bone. The medial meniscus is firmly attached to peripheral joint capsule and less mobile than the lateral meniscus. The lateral meniscus covers a larger percentage of the articular surface than the medial meniscus. **Fig. 1 (1)**

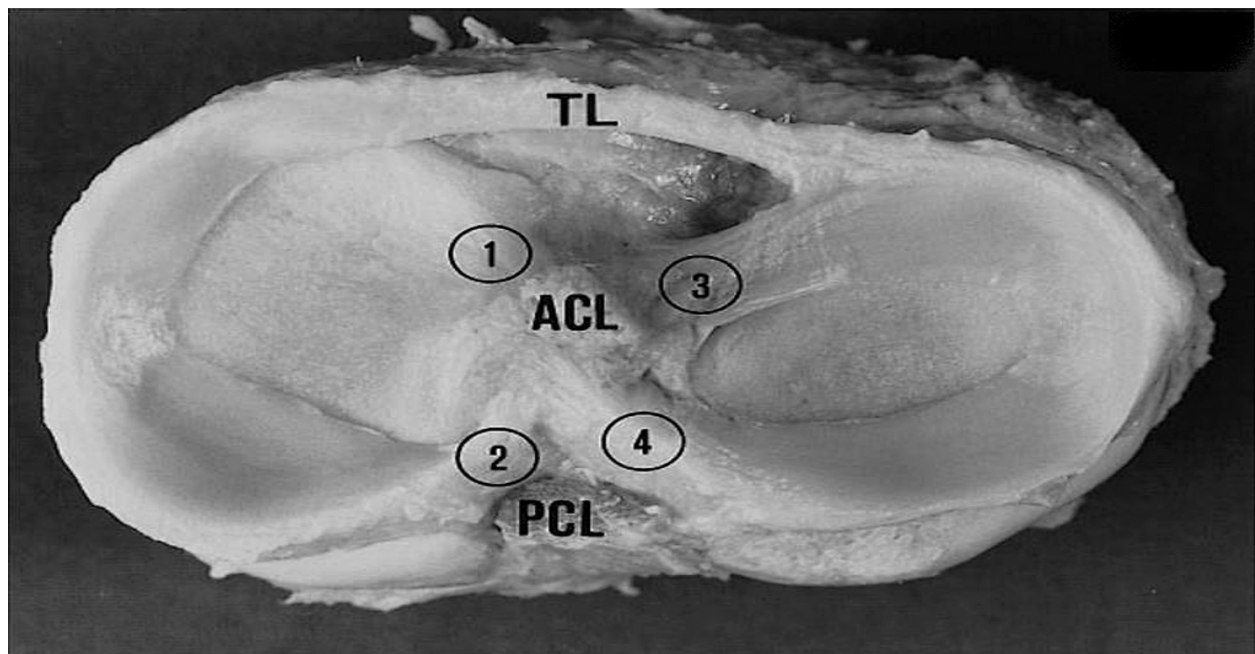


Fig. 1. Right human knee joint viewed from above (the femur has been removed); the tibial tuberosity is on top. The medial (left hand side of figure) and lateral (right hand side of figure) menisci are connected by a transverse ligament. 1, anterior insertional ligament of the medial meniscus; 2, posterior insertional ligament of the medial meniscus; 3, anterior insertional ligament of the lateral meniscus; 4, posterior insertional ligament of the lateral meniscus; ACL, cross section of the anterior cruciate ligament; PCL, cross section of the posterior cruciate ligament. **(1)**

The peripheral portion of the lateral meniscus has a loose attachment to the joint capsule. The two meniscomfemoral ligaments (the ligaments of Humphrey and Wrisberg) run from the posterior attachment of the lateral meniscus to the medial femoral condyle, adjacent to the posterior cruciate. There are two cell types in the meniscus: fibroblastic cells on the meniscus surface and ovoid cells in the deeper layer. **(1)**

This latter cell has been called a fibrochondrocyte because, while it can synthesize a fibrous matrix, it has the rounded appearance of a chondrocyte. These cells are responsible for synthesizing and maintaining the extracellular matrix. **(1)**

The extracellular matrix contains water (70% total weight), type I, II, III, V and VI collagen (60-70% of the dry weight with type I collagen predominant) and proteoglycan (1-2% of dry weight). **(2)**

Proteoglycans are composed of polypeptides to which one or more specialized polysaccharides, called glycosaminoglycans (GAGs) are covalently attached. The meniscus has a unique collagen structure orientation that is related to its function and consists of three different layers that can be distinguished microscopically. **(2)**

The superficial layer consists of a thin layer of fine fibrils. Just below the superficial layer is a layer of irregular aligned collagen bundles. The middle layer consists of larger, circumferentially oriented fibers anchored by a small number of radially oriented fibers. **Fig .2. (2)**

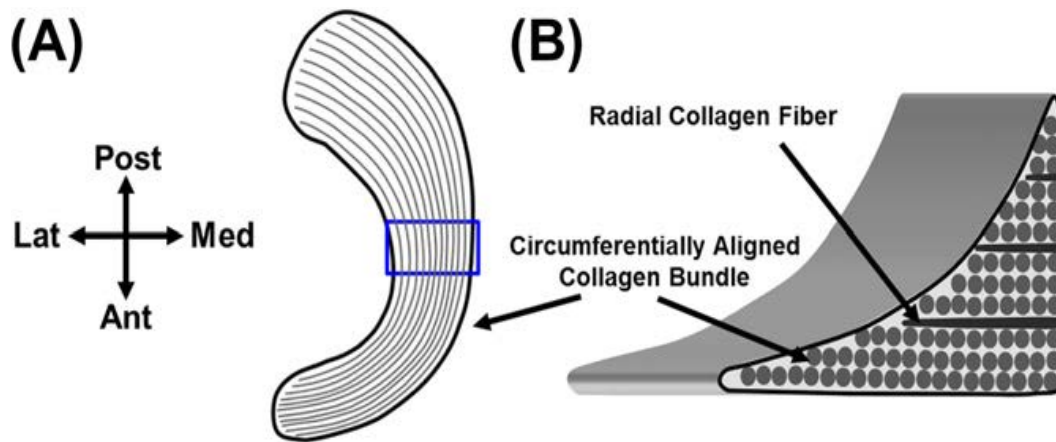


Fig. 2. Illustration of a meniscus showing (A) the generalized anatomic macrostructure and (B) a wedge-like cross-section displaying a simplified collagen fiber organization, with the majority of fiber bundles in the circumferential direction with occasional radial “tie” fibers. **(2)**

The principal GAG is chondroitin sulfate (40%) with lesser amounts of dermatan sulfate and keratan sulfate. GAGs function to bind water molecules and thus provide the compressive properties of the tissue. Several adhesion molecules, including type VI collagen, fibronectin and thrombospondin, facilitate cell matrix interactions. **(2)**

Biochemical content

Regarding composition by wet weight, the meniscus is highly hydrated (72%water), with the remaining 28% comprised of organic matter, mostly ECM and cells. In general, collagens make up the majority (75%) of this organic matter, followed by glycosaminoglycans (GAGs) (17%), DNA (2%), adhesion glycoproteins (<1%), and elastin (<1%). The above proportions might vary depending on age, injuries, and other pathological conditions. **(3)**

Although collagen is the main fibrillar component of the meniscus, different collagen types exist in varying quantities in each region of the tissue. In the red zone, collagen type I is predominant, at approximately 80% composition by dry weight, with other collagen variants (type II,

III, IV, VI, and VIII) present at less than 1%. In the white zone, collagen makes up 70% of the tissue by dry weight, of which 60% is collagen type II and 40% is collagen type I. (3)

Aside from collagen, another fibrillar component is elastin: a combination of mature and immature elastin fibers has been found in very low concentrations (less than 0.6%) in the adult meniscus. Elastin's exact biochemical and functional importance in the meniscus has yet to be determined. (3)

Proteoglycans are heavily glycosylated molecules that constitute a major component of the meniscus ECM. These molecules are comprised of a core protein which is decorated with GAGs. The main types of GAGs found in normal human meniscal tissue are chondroitin 6 sulfate (60%), dermatan sulfate (20-30%), chondroitin 4 sulfate (10-20%), and keratan sulfate (15%). Aggrecan is the major large proteoglycan of the meniscus while biglycan and decorin are the main small proteoglycans. (3)

Regional variation of these molecules has also been observed, with the inner two thirds containing a relatively higher proportion of proteoglycans than the outer one third. Their main function is to enable the meniscus to absorb water, whose confinement supports the tissue under compression. Adhesion glycoproteins are also indispensable components of the meniscus matrix, as they serve as a link between ECM components and cells. The main adhesion glycoproteins present in the human meniscus are fibronectin, thrombospondin, and collagen VI. (3)