

**“ MORPHOMETRIC ANALYSIS OF MENISCI OF
THE KNEE JOINT IN ADULT HUMAN CADAVERS
OF NORTH KARNATAKA - A CROSS SECTIONAL
STUDY”**

REG. NO. BB 0111002

Dissertation

Submitted to the
KLE University, Belgaum, Karnataka

In partial fulfillment
of the requirements for the degree of

DOCTOR OF MEDICINE

IN

ANATOMY

**DEPARTMENT OF ANATOMY,
JAWAHARLAL NEHRU MEDICAL COLLEGE,
NEHRU NAGAR, BELGAUM – 590 010, KARNATAKA**

APRIL - 2014

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ENDORSEMENT BY THE HOD, PRINCIPAL / HEAD OF
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This is to certify that the DISSERTATION entitled
**“MORPHOMETRIC ANALYSIS OF MENISCI OF THE KNEE
JOINT IN ADULT HUMAN CADAVERS OF NORTH
KARNATAKA - A CROSS SECTIONAL STUDY”** is a bonafide
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LIST OF ABBREVIATIONS

OA	-	Osteoarthritis
ECM	-	Extracellular matrix
MM	-	Medial meniscus
LM	-	Lateral meniscus
PCL	-	Posterior cruciate ligament
ACL	-	Anterior cruciate ligament
MFL	-	Menisofemoral ligament
aMFL	-	Anterior Menisofemoral ligament
pMFL	-	Posterior Menisofemoral ligament
CNS	-	Central nervous system
DNA	-	Deoxyribonucleic acid
GAG	-	Glycosaminoglycans
MRI	-	Magnetic resonance imaging
AIMM	-	Anamolous insertion of medial meniscus
MAT	-	Meniscal allograft transplantation
PL	-	Peripheral length
IBL	-	Inner border length
ANT	-	Anterior
MID	-	Middle
POST	-	Posterior
b/w	-	Between
AH	-	Anterior horn
PH	-	Posterior horn

Rt	-	Right
Lt	-	Left
mm	-	Millimeters
SD	-	Standard deviation
%	-	Percentage
&	-	And

ABSTRACT

Background and Objectives:

The menisci of the knee have been described as 'C' shaped wedges of fibrocartilage located between the condyles of the tibia and the femur. Meniscal function is essential to normal functioning of knee joint and acts as joint filler compensating for gross incongruity between femoral and tibial articulating surfaces. Since the size of the meniscus is related to its function, any procedure to replace the cartilage must be accompanied by measurement techniques to determine meniscal size. Hence this study was conducted to analyze morphometric parameters of menisci and its variations in cadavers of North Karnataka.

Methods:

This study was done on 120 menisci from 60 human knees, 29 right and 31 left. Morphological variants of the shape of the menisci were macroscopically noted and classified. The thickness, the width, peripheral and inner border length, distance between anterior and posterior horns of the adult menisci were measured using standard techniques. Students unpaired 't' test was employed for statistical analysis.

Results:

It was observed that 96.66% of medial menisci were crescentic in shape, 1.66% were sided V shaped and 1.66% showed sickle shaped. Among the lateral menisci 88.33% were C shaped, 6.66% showed sided U shape and 5% showed incomplete discoid. Peripheral length (99.8mm) and inner border length (60.3mm) of medial menisci were higher than those of lateral menisci and statistically significant. Posterior third of medial menisci was the widest portion. No significant difference

was observed in thickness of the medial and lateral menisci. Distance between anterior horn and posterior horn was more for medial menisci. Significant differences were not observed in various morphometric parameters of the menisci between the right and left knees except for the peripheral length which was greater for left sided medial menisci.

Interpretation and Conclusion:

The results of this study with respect to the morphometric analysis of menisci are consistent with the results of various studies mentioned in the literature. The study has provided additional information on different shapes and measurements of the medial and lateral menisci of North Karnataka population with contribution to a better delineation of meniscal anatomy and implications in regard to allograft meniscus transplantation.

Keywords:

Menisci, Morphometry, Meniscal transplantation, Width, Thickness, Peripheral length

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INTRODUCTION

Menisci are semicircular shaped fibrocartilagenous structures with bony attachments at the anterior and posterior aspects of tibial plateau and are wedged between the femoral condyles and the tibial plateau on the medial and lateral sides of the knee.¹ The knee joint is considered the largest articulation in the body. It is a double condyloid joint with 20° of freedom of motion. The condyles of the femur rest in unequal manner on the shallow concave surface of the tibia, therefore the knee joint depends on other structures to provide both static and dynamic stability which are achieved by a variety of soft tissue structures such as the medial and lateral collateral ligaments, anterior and posterior cruciate ligaments, the menisci, the capsule and the muscles crossing the joint.^{2,3}

The medial meniscus is C-shaped and it is wider posteriorly than anteriorly.⁴ Its anterior insertion is fan-shaped and it is attached above to the tibial plateau and to the intercondylar notch, about 6 to 7 mm anterior to the fixation of the anterior crossed ligament.⁵ Its posterior insertion attaches to the posterior intercondylar area of the tibia between the posterior insertion of the lateral meniscus and anteriorly to the fixation of the posterior crossed ligament.⁶

The lateral meniscus is nearly circular in shape, smaller and more freely mobile than the medial meniscus. The anterior insertion of the lateral meniscus is attached to the anterior intercondylar fossa of the tibia, anteriorly to the lateral eminence of the tibia and parts of its fibers blend with the anterior crossed ligament.⁶ The insertion of the posterior lateral meniscus is fixed in the tibia anteriorly to the insertion of the medial meniscus. In 50% of cases, the anterior fibers of the posterior insertion of the lateral meniscus are set out in the intercondylar notch of the medial

condyle of the femur anteriorly to the origin of the posterior crossed ligament forming the posterior crossed meniscofemoral ligament.⁵

The inner non fixed edges of the menisci in the inner part of joint are sharp and free, whereas outer edges are thick fixed. On transverse section they are cuneiform in shape. The menisci are firmly attached to the intercondylar area of tibia and their outer edges are attached to the fibrous capsule of the knee joint. The coronary ligaments are capsular fibers clinging to the margins of the menisci to the tibial condyles.⁷

Menisci consist of cells like chondrocytes and fibroblasts. Collagen, proteoglycans, glycoproteins and elastin constitutes the extracellular matrix.⁸ The meniscus is anchored at the anterior and posterior horns by insertional ligaments which are primarily composed of type I collagen fibrils extending from the main body of the meniscus into the tibial plateau.⁶

The prime function of menisci of the knee joint is to enhance joint congruence and load distribution, thus reducing the stress on the knee joint. This function assists to protect the articular cartilage and prevent osteoarthritis.⁶ There are noticeable differences in the contour and insertion between the lateral and the medial menisci which are important in relation to the injury mechanisms.⁹ Variations of form and in particular, the thickness and width of the menisci can determine the possibility and kind of injury.¹⁰ The firm bony insertion of the anterior and posterior horns is considered vital to the meniscus function of loads distribution.⁶

The functions of the meniscus include load transmission, shock absorption, stress reduction, improve joint stability, limit to extreme flexion and extension, proprioception, joint lubrication and nutrition.⁸ A meniscus protects the adjacent articular cartilage by keeping the congruency of the femorotibial articulation and

distributing axial load properly on the surface of femorotibial articular cartilage. By distributing loads and reducing the knee joint contact stress, the menisci keep the forces encountered by the cartilage and subchondral bone tissue in reasonable limits¹¹ and thus protect the joint from developing osteoarthritis(OA).¹²

With the advent of new techniques such as arthroscopy, computed tomography and magnetic resonance imaging, the anatomical abnormalities and variations of the intraarticular structures of the knee joint have become important.⁴ Long term complications of removal of a meniscus include cartilage degeneration and bone remodeling, this discovery changed considerably the therapeutic approach to this common work or sports injury.¹³ Hence, today a ruptured meniscus is repaired rather than removed, but this treatment is only feasible when the meniscus tissue is otherwise of good quality.⁶

The most common congenital abnormality of the meniscus in man is a discoid meniscus the incidence of discoid meniscus ranges from 0.4% to 17% for the lateral and 0.06% to 0.3% for the medial side.¹⁴ Blood vessels and lymphatics can be found throughout the menisci from the time of birth to a child's first birthday.¹⁵

Many studies show that meniscectomy leads to progressive degenerative osteoarthritis and to slow the process of knee degeneration after meniscectomy, meniscal allograft transplantation has been considered as a possible choice.¹⁶ In the past, medical professionals have routinely underappreciated the menisci and failed to give them the respect they so richly deserve. In 1897 Sutton described the menisci of the knee as "functionless and the vestigial remnants of leg muscle."¹⁷ This led surgeons to believe they could completely remove a meniscus without any adverse sequelae. In 1909, total meniscectomy for a torn or degenerated meniscus was common. In 1948, authors described the knee joint changes following a total

meniscectomy which include a narrowing of the joint space, a flattening of the femoral articular surface and an osteophyte formation on the femoral condyle of the involved side.¹³ Subsequent studies demonstrated long-term adverse sequelae such as progressive meniscal pathology, articular cartilage damage, degenerative changes and ligamentous instability. Different approaches to meniscus replacement were undertaken, such as allografts, autografts, biodegradable collagenous scaffolds and permanent prosthesis.⁵ Appropriate material, adequate size and anatomically correct position must be recognized as crucial factors influencing the outcome of meniscus replacement procedures and as preventive measures for degenerative arthritis developing after total meniscectomy.⁵ Knowledge of meniscal horn bony insertion-site anatomy is essential when planning meniscal surgery, particularly meniscal transplantation. Each meniscal horn was found to have a distinct bony insertion site with characteristic and consistent landmarks defining its margins.¹⁸

The important role of the width in determining the contact pressure distribution is well recognized. A study demonstrates that the intact meniscus transmits the majority of the compressive force. When a portion of the meniscus is removed, the contact stress increases in proportion to the amount of meniscus removed. So, width of the meniscus within the normal limits of variation is an important determinant of the contact pressure distribution.¹⁹

Since the size of the meniscus is related to its function, any procedure to replace the cartilage must be accompanied by measurement techniques to determine meniscal size. Accurate measurement would be helpful as a clinical evaluation tool for meniscal replacement and regeneration techniques adopted in orthosurgeries. Hence there is a need for more knowledge about morphometric variations of menisci in people of North Karnataka.

OBJECTIVES

Primary: To analyze the thickness, the width, peripheral and inner border lengths, distance between anterior and posterior horns and shape of the adult menisci and to compare with that of meniscal parameters which are available in the literature.

Secondary: To gather information about anomalies and variations encountered, if any which may prove valuable in clinical and orthopaedic procedures.

REVIEW OF LITERATURE

Brief historical review:

The word Meniscus is derivative of the Greek word meniskos, meaning the diminutive of mene (moon). Each knee joint is occupied by two semi-lunar cartilages. They were described as muscle remnants and were credited very few functions before, now menisci are known to transmit tibio-femoral load, prevent synovial impingement, act as shock absorbers, lubricators of joint and also in assisting in smooth gliding of surfaces over one another.²⁰

Thomas Annandale, a Scottish surgeon in 1885 was the first to repair meniscus. Later, in 1908 the first clinical study on menisci was published in a German medical journal by Moritz Katzenstein, he is considered as the father of meniscus repair surgery. His study was a series of seven meniscal repairs with a seven years follow up.²¹ Understanding the functional importance of menisci has been evolutionary. In 1897, Bland-Sutton characterized the menisci as “functionless remnants of intra-articular leg muscles”.²² In 1948 Fairbank gave the importance of the meniscus in the human knee. He explained degenerative changes following meniscectomy with radiographic evidence and named them as “Fairbank’s Changes” which included:

- 1- Formation of an AP ridge on the femoral condyle (osteophyte)
- 2- Flattening of the femoral condyle (squaring)
- 3- Narrowing of the joint space¹³

Smillie believed that there was a failure of resorption of the central area of the cartilage plate during the fetal stages of normal development, proposed the first theory on the development of the discoid meniscus.⁹ In 1918, Professor Kenji Takagi of Tokyo University inspected the knee of a cadaver using a cystoscope. He used a

7.3 mm cystoscope for his first arthroscopies. After several attempts to refine the cystoscope, in 1931 he developed a 3.5mm instrument, the No. 1 arthroscope which became the model for present-day arthroscopes. The first accurate functional arthroscope was developed by Dr. Masaki Watanabe, who carried out first surgery of arthroscopic partial meniscectomy in 1962 in Japan.²³ He is called as the father of modern arthroscopy. In 1969, 1st arthroscopic meniscus repair was performed by Hiroshi Ikeuchi. In 1970, open meniscus repair was popularized by Ken DeHaven and team. In 1984 Milachowski completed the first meniscal transplant.²⁴



Fig.1 Masaki Watanabe, the “Father of modern Arthroscopy”²³

Normal anatomy of the menisci:

The menisci are crescentic, intracapsular, fibrocartilaginous laminae deepening the articulation of the tibial surfaces that receive the femoral condyles. In cross section, the menisci are triangular being thicker at the periphery and tapering to a thin free edge centrally. The peripheral edges of the menisci are convex, fixed and attached to the inner surface of the knee joint capsule, except where the popliteus is interposed laterally, these peripheral edges also are attached loosely to the borders of the tibial plateaus by the coronary ligaments. The inner edges are concave, thin and unattached.²⁵

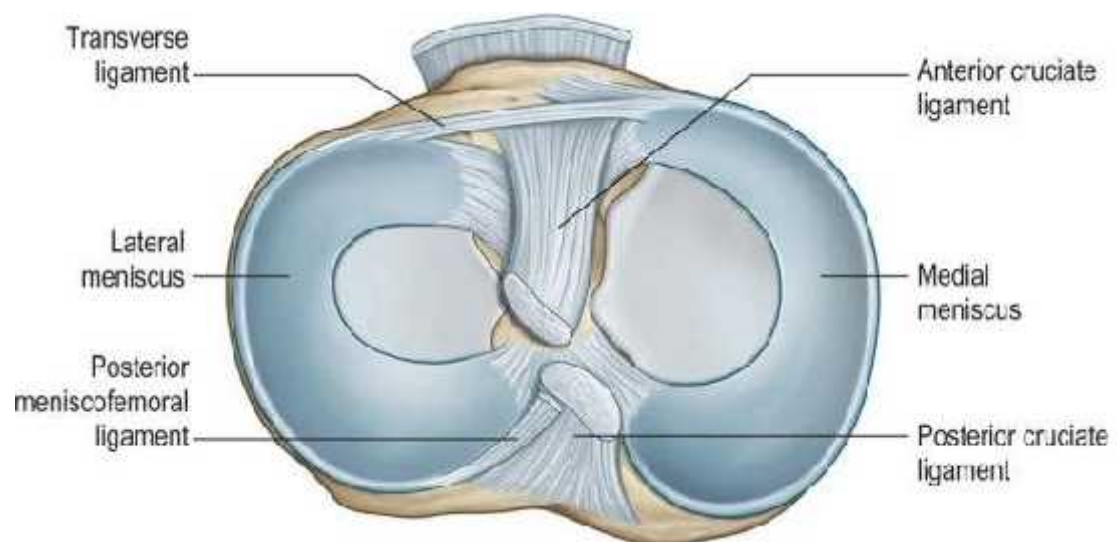


Fig. 2 Superior aspect of the left tibia, showing the menisci and the attachments of the cruciate ligaments.²⁵

The superior surfaces are concave to lodge the convexity of the femoral condyles and the inferior surfaces are flat to fit to the tibial plateaus. The menisci extend the superior tibial surface, improving its congruency with the femoral condyles. Anterior and posterior meniscal horns attach to the intercondylar area of the tibial plateau.²⁵

Menisci are a pair of wedge shaped semilunar cartilages with diameter approximately 35 mm and their thick convex shaped peripheral rim, measuring approximately 110 mm including the length of the insertional ligament is attached to the joint capsule.⁵ The anterior and posterior meniscal horns are firmly attached to bone through insertional ligaments. Marked differences in dimensions have been noticed in human medial and lateral menisci. Medial menisci are 40.5- 45.5mm long and 27mm wide, while lateral menisci are approximately 32.4 - 35.7mm in length and 26.6 - 29.3mm wide. Though both menisci are roughly wedge shaped and semilunar, lateral menisci display high diversity in size, shape, thickness and mobility than medial menisci.²⁶ Each meniscus is glossy white complex tissue consists of cells, specialized extracellular matrix (ECM) molecules, zone specific innervation and vascularization. Both menisci are essential components of a healthy knee joint.^{5,27,28}

Medial meniscus (MM)

The medial meniscus is C-shaped in structure and its posterior horn larger in anterior-posterior width than the anterior horn. The medial meniscus covers roughly 50% of the medial tibial plateau and is fixed steadily to the medial joint capsule via the meniscotibial and coronary ligaments. The deep medial collateral ligament is characterized by a discrete midpoint capsular thickening. To maintain the congruency between meniscal surfaces and tibial and femoral articulations, the medial meniscus translates 2.5 mm posteriorly as the femoral condyle rolls backward during knee flexion.^{17,29,30}

Anterior horn of the medial meniscus is fixed to the anterior tibial intercondylar area in front of the anterior cruciate ligament, while few posterior fibres of the anterior horn are continuous with the transverse ligament. The posterior horn of the medial meniscus is inserted to the posterior tibial intercondylar area between the

attachments of posterior cruciate ligament and lateral meniscus. Its peripheral border is attached to the fibrous capsule and the deep surface of the medial collateral ligament. The tibial attachment of the meniscus is known as the 'coronary ligament'. Collectively these attachments ensure that the medial meniscus is relatively fixed and moves much less than the lateral meniscus.²⁵ A cadaveric study demonstrated that the radial tear of posterior horn in the elderly was associated with the severe grade of cartilage degradation.³¹

Lateral meniscus (LM)

The lateral meniscus is circular and more uniform in width. It covers 70% of the lateral tibial plateau. The anterior horns of the medial and lateral menisci are attached to each other by means of the transverse (intermeniscal) ligament. The posterior horn of the lateral meniscus is attached to the posterior cruciate ligament (PCL) and medial femoral condyle through the menisiofemoral ligaments of Wrisberg (the posterior menisiofemoral ligament) and Humphrey (the anterior menisiofemoral ligament). It is also attached to the popliteus tendon.^{3,32}

The lateral meniscus is more mobile and is not attached to the lateral collateral ligament. During rotational movements the lateral meniscus attachment to the femur and the popliteal tendon pairs its motion with that of the femoral condyle. So, there are very few chances of injuries than the relatively immobile medial meniscus. Entrapment of lateral meniscus in between tibia and femur is prevented by the popliteal tendon, which retracts the posterior horn of the lateral meniscus during flexion and internal rotation.³ Due to lack of restriction during knee flexion the lateral meniscus translates 9 to 11 mm on the tibia, accounting for the lower incidence of lateral meniscal tears.^{17,29,30}

The tendon of the popliteus muscle separates the posterolateral periphery of the lateral meniscus from the joint capsule and the fibular collateral ligament. The tendon of the popliteus is enveloped in a synovial membrane and forms an oblique groove on the lateral border of the meniscus.²⁵ Reports on the proportions of the insertional areas of the lateral meniscus are more controversial. One study found the area of the anterior enthesis of the lateral meniscus to be 1.2 times smaller than the posterior,⁵ which was in contrast to another study that found it 1.5 times larger than the posterior one.¹⁸ Due to the close relationship of the lateral meniscal horn insertion sites with the tibial attachment of anterior cruciate ligament (ACL) along with their nearness to one another (6 to 10 mm separation) has important inference with regard to meniscal reconstruction using meniscal allograft with attached bone plugs. Thus, when creating osseous tunnels for the anterior and posterior horn bone plugs great care should be taken.¹⁸

Menisconfemoral ligaments (MFL)

The posterior horn of the lateral meniscus is connected to the inner (lateral) aspect of the medial femoral condyle by the two menisconfemoral ligaments (MFLs). The anterior MFL (aMFL; ligament of Humphry) passes anterior to the posterior cruciate ligament. The posterior MFL (pMFL; ligament of Wrisberg) passes behind the posterior cruciate ligament and attaches proximal to the margin of attachment of the posterior cruciate ligament. Anatomical studies found that at least one menisconfemoral ligament was present in 92% of cadaveric knees examined, whilst both coexisted in 32%. Biomechanical studies have revealed the cross-sectional area and strength of the menisconfemoral ligaments to be comparable to those of the posterior fibre bundle of the posterior cruciate ligament. The menisconfemoral ligaments are believed to act as secondary restraints supporting the posterior cruciate

ligament in minimizing displacement caused by posteriorly directed forces on the tibia. These ligaments are also involved in controlling the motion of the lateral meniscus in conjunction with the tendon of popliteus during flexion.²⁵

Transverse [intermeniscal] ligament

The anterior horn of the medial meniscus is connected to the anterior convex margin of the lateral meniscus through the transverse ligament, which varies in thickness and is often absent. Its exact role is hypothetical, but when the knee is subjected to load this ligament is supposed to help decrease tension generated in the longitudinal circumferential fibres of the menisci.²⁵

Vascular anatomy of menisci

Vascular supply is crucial to meniscal healing. The blood supply to the medial and lateral menisci arises mainly from the medial and lateral inferior genicular arteries and middle geniculate artery. A premeniscal capillary network arising from branches of these arteries originates within the synovial and capsular tissues of the knee along the periphery of the menisci. The anterior and posterior horns of medial and lateral menisci are more vascular than the bodies of the menisci.³³ Only 10% to 30% of the peripheral medial meniscus border and 10% to 25% of the lateral meniscus border receive direct blood supply.³⁴ The remaining portion of each meniscus (65% to 75%) receives nourishment only from the synovial fluid via diffusion.³⁵

Blood vessels and lymphatics can be found throughout the meniscus from the time of birth to a child's first birthday. At 18 months soon after the menisci become weight-bearing structures the blood and lymph supply is reduced to the outer 25% to 33% of the body of the menisci.^{8,15} The peripheral portion of adult menisci receives nutrition through blood vessels and the central portions of the menisci get from the synovial fluid by diffusion. Research has suggested that the diffusion of nutrients

from the synovial fluid requires the intermittent loading and release of stress on the menisci via body weight and muscular force. Considerable amount of weight-bearing or muscular force, is not experienced during the first year of an infant's life, hence the inner portion of the menisci cannot depend on diffusion from the synovial fluid for nutrition. Before the human infant starts standing erectly and walks its essential that the whole meniscus has direct blood supply. After the infant learns the skills of bipedal gait pattern, the resultant stress from body weight and muscular forces is too much for the blood vessels in the inner portion of the menisci and this region then becomes avascular. Beyond the age of 50, the blood and lymph supply to the outer portion of the menisci is reduced to the outer 10% to 33%.^{8,15} Age changes in the menisci include an increase in keratan sulfate interfering with the nutrition of the cells and an increase in hyaluronic acid inhibiting the movement of water within the menisci, both of which may play a role in the reduction of the peripheral blood supply to the menisci.⁸

At the insertion of the menisci on the bony tibial plateau, the fibrocartilage inside the inserting structures was avascular.¹⁵ Difference in vascular pattern exist between medial and lateral side of the menisci, the most significant being the relative avascular zone in the area of lateral meniscus adjacent to the popliteus tendon.³³ The location of a meniscal tear is of paramount importance because tears in the vascular portion of the meniscus, termed the “red zone,” are far more likely to heal than tears in the avascular portion or “white zone” of the meniscus.⁶

Lymphatic drainage of the menisci

Histochemical analysis demonstrated that lymphatics usually accompany the blood vessels. The lymphatic circulation inside the meniscus also shows same age dependency as the blood vessels. Lymphatics reached the inner meniscal

circumference in the first year of life, while lymphatic supply to the outer third of the menisci was witnessed only in adults.¹⁵ Lymphatics carry away interstitial fluid, macromolecules and cells. Apart from a nourishing function, structured water inside the menisci also serves a biomechanical purpose. Meniscal deformation due to stress causes a shift of fluids inside the tissue. A part of the interstitial fluid is pressed into the joint cavity and lubricates the joint. Due to the wedge form of the meniscus, compression causes a decrease in resistance and a shift of fluids to the meniscal base. In this area a transportation of fluids via the lymphatics is possible.³⁵

Neural anatomy of menisci

Each menisci shows free nerve endings (nociceptors) and 3 different mechanoreceptors (Ruffini corpuscles, Pacinian corpuscles and Golgi tendon organ) in the horns and in the outer two-thirds of the body.^{8,33} Menisci are innervated by posterior articular branch of posterior tibial nerve and the terminal branches of obturator and femoral nerves. Along with the blood vessels after piercing the joint capsule they end within the substance of menisci.³⁶ There is general agreement that the nerve supply to menisci is more extensive in the horns than the body.³³ but anterior and posterior horns are richly innervated throughout. The outer third of the body of the menisci is more densely innervated than the middle third. The inner third of the menisci is thin and has a hyaline quality to it lacks neural innervations.^{8,37} Posterior horns of the medial and lateral meniscus have a higher density of nerves than the anterior horns.⁸ Studies demonstrated the presence of type I, II and III mechanoreceptors and nociceptor fibers throughout the anterior and posterior horns and outer two-thirds of the body of the human menisci.^{8,37,33}

Sensory function

The menisci of the knee not only function as passive stabilizers, due to presence of mechanoreceptors within the menisci they also function as transducers converting the physical stimulus of tension or compression into a specific electrical nerve impulse.⁸ Based on presence of mechanoreceptor in menisci, studies have attributed various functions to menisci which include transmission of proprioceptive information to help the central nervous system control muscular tone and coordinate movement, provide information regarding damage (pain), aid in initiating protective muscular reflexes, provide the CNS with information regarding joint position and contribute to protective and postural reflexes.³³

Histological structure of the menisci:

The histological structural details of menisci influence their mechanical properties. Normal human menisci contained 0.10 - 0.12% DNA, 70-75% water, 20 - 22% collagen and 0.6 – 0.8% total glycosaminoglycans. The glycosaminoglycans consisted of about 40% chondroitin 6-sulphate, 20% chondroitin 4-sulphate, 20% dermatan sulphate, 15% keratan sulphate and 3% hyaluronate.³⁸ Collagen is the main fibrillar component of the meniscus which exist in different types and in varying quantities. Collagen type I is predominant in red zone, accounting to 80% of its dry weight, with other collagen variants (type II, III, IV, VI, and XVIII) present at less than 1%. The white zone consist of 60% of collagen type II and 40% of collagen type I. Another fibrillar component present is elastin, in adult meniscus mixture of mature and immature elastin fibers has been seen in very low concentrations (<0.6%).^{26,39} The menisci exhibits three collagen fiber layers which are specifically assembled to convert compressive loads into circumferential or “hoop” stresses. The superficial layer shows radially arranged fibres acting as “ties” that resist shearing or splitting.

The middle layer fibers run parallel or circumferentially to withstand hoop stress during weight bearing. Lastly, there is a deep layer of collagen bundles that are arranged parallel to the periphery.⁴⁰

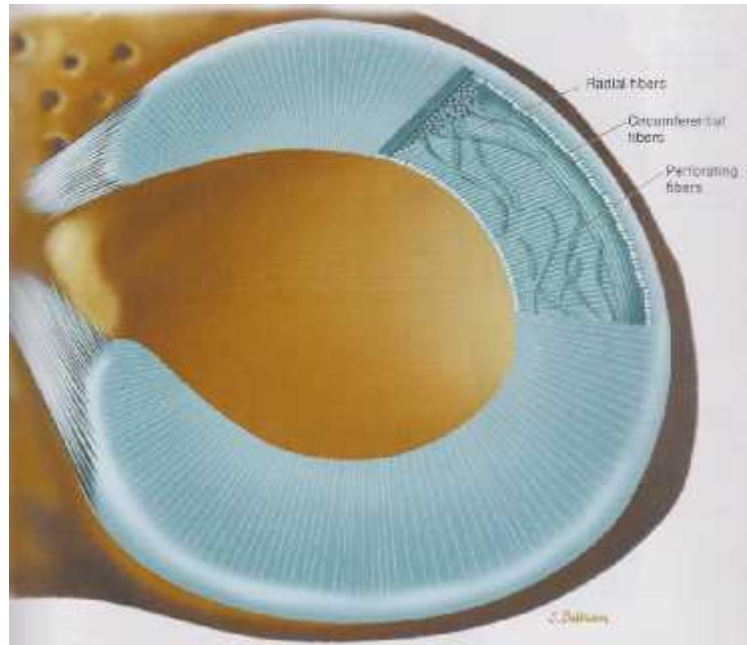


Fig. 3 showing idealized structure of meniscal fibrocartilage with peripheral circumferential fibres, radial fibres and perforating fibres.⁴¹

The extracellular matrix is composed of proteoglycans. 1% of the wet weight of the meniscus is by glycosaminoglycans (GAGs) which contributes to its material properties, such as tissue hydration, compressive stiffness and elasticity.³⁵ The compressive stiffness of the menisci depends upon the size of the proteoglycan macromolecules with water-retention and electrostatic-repulsion properties. Meniscal shock absorption is time dependent due to the exudation of water out of the extracellular matrix. This exudation also provides joint lubrication as water is forced into the joint space. The meniscal horns and the inner half of the menisci have highest GAG concentrations corresponding with the primary weight-bearing areas.³⁸ The proteoglycans have very little role in meniscal tensile properties. Rather, elastin which

constitutes less than 0.06% of meniscal tissue is supposed to help in the recovery of shape after load deformation.³⁵

Each meniscus shows have different cell types at different regions. The chief cell in the inner third are named fibrochondrocytes.^{42, 43} The major cell in the middle third is fibrocytic and in the outer third of the meniscus the cells are fibroblastic (active fibrocytes). The distinctive cell type in the outer periphery of the meniscus as compared to the central portion of the meniscus helps justify some of the healing properties of the different regions.³

Development of menisci

Knowledge of the basic embryological and vascular features of the meniscus is essential to understand meniscal pathology. The typical shape of the medial and lateral meniscus is determined early in prenatal development. The meniscus is identifiable about seven and half weeks after ovulation.⁴⁴

An embryo of eight weeks presents with organised menisco-ligamentous complex in the knee. During prenatal period the meniscus is prominently cellular with a high nuclear/cytoplasmic ratio. Vascular supply to the attachment sites namely tibial and capsular is abundant and can be seen all over the fetal meniscus. The key modifications occurring postnatally are diminished blood supply, increase in adequate growth of proximal tibia and distal femur to lodge changing femorotibial communication.⁴⁴

O'Rahilly in his study analysed the development and established the morphogenetic time table of the knee joint under various stages. In stage 18 chondrification starts as a result mesenchymal tissue in the form of a band is formed between the lower end of femur and upper end of tibia. This articular interzone band differentiated into two eccentric bands and a medial band which appears more lax in

contrast to the eccentric bands. During O’Rahilly Stage 22, the knee joint cavity appears and the eccentric bands now adapt to the shape of the femoral and tibial condyles, resulting in a dense band of perichondrial connective tissue which marks the first sign of organization of the articular cartilage. Initiation of formation of menisci occurs as the lateral parts of the interzone become densified. The joint capsule begins to attach peripherally to the menisci. At the level of the medial layer small cavities begin to appear between the meniscus and the lateral condyles of the femur and tibia. ⁴⁵

In O’Rahilly stage 23, the lateral margins of the patella and the articular capsule surround the femoral condyles and become attached to the eccentric surface of the menisci. The femoropatellar, femoromeniscal and meniscotibial joint cavities are distinguishable. In week 9, development of the menisci proceeds giving rise to the femoromeniscal and meniscotibial joint cavities in which a few tracts of connective tissue are still visible. Peripherally, the menisci will be attached by the coronary ligaments to the capsule. In 10th & 11th week, Development of the medial meniscus continues and brings the organization of the internal femoral meniscal and meniscotibial joints. The anterior horn of the medial meniscus will attach to the anterior aspect of the upper surface of the tibia. The lateral meniscus will be clearly evident and its formation will bring about the organization of the lateral femoromeniscal and meniscotibial joints. ⁴⁵

Postnatal development

Gradual transition from the prenatal stage was observed at birth with no rapid changes. At 3 months in all the specimens studied anterior expansions from both menisci to the anterior cruciate ligament and to each other were noted. Presence of significant attachments like thickened medial capsular ligament and posteromedial

capsular complex the medial meniscus is less mobile or fixed. In contrast due to lack of attachment posterolaterally, mainly in the area of the popliteus tendon recess the lateral meniscus is more mobile. The size and presence of menisco-femoral ligaments of Humphrey and Wrisberg were variable. Histologically, the meniscus is less cellular, reduced nuclear size and with an increase in collagen content. Cartilage matrix was not identified. Entire substance of the meniscus showed blood vessels, more predominantly in the external and intermediate regions.⁴⁴

At 9 months stage the knee joint now resembles the adult. Growth continues with less nuclear/cytoplasmic ratio of the meniscal cells and with increase in the collagen content. The internal zone appeared comparatively avascular. During 3-9 years, significant morphologic growth is observed. Vascularity further decreases. Microscopically, highly organized alignment of collagen fibers is seen, which are arranged in a circumferential fashion in the long axis of the meniscus with few fibers traversing in a radial direction. These radial fibers are placed on the surface more on the tibial side than the femoral. Weight-bearing portions of the meniscus showed thin synovium and at the inner edge of the meniscus it was completely absent.⁴⁴ At 11 years, prominent vessels were found along capsular and coronary ligament attachment sites. Synovial covering was now lacking in the weight bearing regions of the meniscus. Internal region of menisci is avascular. No evidence of cartilage matrix was present.⁴⁴

Functional role of menisci

The meniscus resist many different forces such as shear, tension and compression. It also plays a critical role in load bearing, load transmission, shock absorption, lubrication and nutrition of articular cartilage. Because of the particular

wedge shape, it helps to stabilize the curved femoral condyle during articulation with the flat tibial plateau.²⁶

Shock absorption

Meniscus is considered as biphasic medium consisting of solid and fluid medium. Solid matrix comprises of collagen network and GAGs. Meniscus act as viscoelastic material during loading due to presence of solid matrix and interstitial fluid flow. The creep and stress relaxation behavior of the meniscus is decided by the viscoelasticity. This blend of reduced compressive stiffness and permeability suggest that the menisci play a role in shock absorption.⁴²

Load bearing

The meniscus encounters tensile and compressive stress during loading. The medial meniscus transmits 50% of the joint load in the medial compartment and 70% of the load in the lateral compartment is conducted by the lateral meniscus. When the knee joint is extended the menisci transmit 50% of the load and 85 to 90% of the joint load when the knee is in flexion.^{42,46} Study have observed that contact stresses are increased by 65%, when one-third of the inner meniscus is lost.⁴⁷ Articular cartilage damage and eventual degeneration is commonly caused by such significantly increased compression stress across the joint. Hence, even partial meniscectomy can influence the ability of the meniscus to function in load transmission across the knee.¹³ Axial tibiofemoral forces compress the menisci during routine activities. The wedge shape of the meniscus and its horn attachments operate to convert the vertical compressive forces to horizontal hoop stresses.²⁶ Study showed that the meniscus is much stronger and stiffer in the circumferential direction than the radial direction and the radial shear strength is thought to be at least partly responsible for the occurrence of longitudinal tears.⁴²

Joint stability

It is accepted that wedge shape of the meniscus contributes to its function in joint stabilization. In the anterior cruciate ligament intact knee removal of medial meniscus has little effect on anteroposterior motion, whereas in the ACL-deficient knee, medial meniscectomy results in an increase in anterior tibial translation up to 58% at 90° of flexion.⁴² Posterior horn of the medial meniscus resists an applied anterior tibial force in an ACL-deficient knee.⁴⁸ A biomechanical study done on cadavers revealed that knees with an absent ACL and deficient medial meniscus displayed greater varus-valgus laxity than did those with intact medial meniscus and an absent ACL.⁴⁹

Joint lubrication

It has been suggested that joint conformity contributed by meniscus promotes the viscous hydrodynamic action required for fluid film lubrication and this function assists in the overall lubrication of the articular surfaces of the knee joint. During compressive loading water extruded out into joint space aids in joint lubrication. Meniscus helps in maintaining synovial fluid film over the articular surface thereby providing nutrition to articular cartilage.⁴²

Proprioception

Menisci also gives proprioceptive feedback for joint position sense. Outer portion of the meniscus is rich in neural elements, particularly type-I and type II nerve fibers. Both the horns of the meniscus are innervated with mechanoreceptors, which provide feedback during extremes of motion. These neural elements are thought to be part of a proprioceptive reflex arc that may contribute to the functional stability of the knee.⁵⁰

Morphological variants of the menisci

Normal variants of the meniscus are relatively uncommon and are frequently asymptomatic, although there is a greater propensity for discoid menisci to tear. However, recognizing these variants is important, as they can be misinterpreted for more significant pathology on MRI. The most common of these meniscal variants is the discoid lateral meniscus and the least common is complete congenital absence of the menisci.⁵¹

Normal variants of the meniscus include hypoplastic menisci, absent menisci, anomalous insertion of the medial meniscus, discoid lateral meniscus, including the Wrisberg variant and discoid medial meniscus.⁵¹ Anomalies of the meniscal shape have been reported in man and are classified as hypoplasia or hyperplasia. The meniscal hyperplasias or discoid menisci, have been the object of many studies, because they are frequently the source of symptoms.⁹

Of the several reported congenital meniscal abnormalities anomalous attachments of the meniscal horns and discoid menisci are the most frequent. They most frequently affect the lateral side of the knee. In 1967 first case of medial meniscal hypoplasia was reported. The association of simultaneous anomalies in the knee, in some cases is likely due to the common mesenchymal origin of some of these structures.⁵²

There are reported cases of complete absence of the medial meniscus as described in thrombocytopenia absent radius syndrome (TAR syndrome). The congenitally absent meniscus appears to influence the development of the distal femur and proximal tibia, the proximal medial tibia was convex and the distal medial femoral condyle was saddle shaped in these cases.^{51,53} A new case was reported of bilateral hypoplasia of the medial meniscus not in association with other knee

anomalies in a young woman as a consequence almost all the medial tibial plateau surface was uncovered.⁵⁴

Anomalous insertion of the medial meniscus (AIMM) has been illustrated and it is into the anterior cruciate ligament. The anomalous insertion passes from the anterior horn of the medial meniscus to either the mid or base of ACL or the intercondylar notch. The insertion site of the AIMM into the ACL is classified as Type 1 (inferior third), Type 2 (middle third), or Type 3 (superior third; intercondylar notch). The incidence AIMM with discoid MM is greater than with discoid LM.^{51,55}

A study reported a rare anatomical aberration case of double-layered lateral meniscus, where an accessory proximal hemimeniscus was overlying the body and posterior horn of the lateral meniscus in a male of Indian origin.⁵⁶ Although both menisci have been reported to have discoid shape, lateral tends to be more common than the medial meniscus. Bilateral lateral meniscus involvement is rare and co-existence of both medial and lateral discoid menisci in the same knee has been reported only twice.⁵⁷ One documented instance of familial transmission (father and two of his four children) of discoid meniscus was reported.⁵⁸ A case reported in Scotland where the discoid meniscus patient's daughter also had an abnormality of knee suggesting the inheritance playing a part in its transmission.⁵⁹

Two cases with abnormal band of lateral meniscus, which were serpentine shaped and narrower than the accessory meniscus were reported.⁶⁰ A case gives description of a ring-shaped meniscus on the lateral side of the human knee without any other associated malformation. The rounded uniform rim with no evidence of a tear of that meniscus suggests that this finding is congenital in origin.⁶¹

Meniscal ossicle is mature lamellar and cancellous bone containing fatty bone marrow enveloped by hyaline cartilage within the substance of meniscus. It is a rare

entity and must be differentiated from conditions like chondrocalcinosis, avulsion at the site of attachment of posterior cruciate ligament, avulsions of the semimembranosus tendon and loose body, as the mode of management will differ in each case.⁶² Most of the reported cases were located in the posterior horn of the medial meniscus. Many theories have been put forward regarding the etiology of meniscal ossicles. They are considered as vestigial structures and are common in rodents, domestic cats and Bengal tigers, or they may represent a degenerative phenomenon due to the ossification of mucoid degeneration. A traumatic etiology has also been put forth suggesting that the ossicles represent heterotopic ossification or they may represent bone fragments arising from the tibial attachment of the meniscal root insertion. This theory is supported by the fact that the most common location for meniscal ossicles is in the posterior horn of the medial meniscus.^{63,64}

Discoid meniscus

The most frequently encountered abnormal meniscal variant in children is discoid meniscus.¹⁷ Discoid lateral meniscus is more common among Asians than that among Caucasians. The incidence of discoid meniscus ranges from 0.4% to 17% for the lateral and 0.06% to 0.3% for the medial side.¹⁴ It is still debatable whether this anatomic derangement necessarily leads to abnormal function or susceptibility to injury. The issue is complicated by the fact that several variants of the discoid meniscus have been described and that there is a continuous range of variation between normal, C-shaped menisci and those that extend completely across the lateral or medial joint space.

Stable discoid meniscus is often an incidental finding in asymptomatic patients, which can become symptomatic in the presence of a tear. The most common tear pattern is the degenerative horizontal cleavage, that can result in pain, swelling

and snapping of the affected knee. The abrupt change in the rapport between the meniscus and the femoral and tibial condyles leads to a snap sound.¹⁴

Etiology of discoid menisci

Etiology of a discoid lateral meniscus is still a topic of argument. There are no embryological studies in the human foetus showing this initial discoid stage, but instead the lateral meniscus shows the adult crescent shape from its inception.⁵² Smillie hypothesized that discoid morphology represented an arrest in embryologic development with failure of central meniscal resorption. He states that the meniscus exists as a cartilaginous disc at an early stage of development and that a congenital discoid meniscus is caused by an occasional persistence of the foetal state.⁶⁵ This theory has been disproven because during no stage of meniscal development is the meniscus found to be discoid. Early studies show that discoid menisci are more prone to mechanical stresses because they are thicker, less vascular and often lack peripheral capsular attachments.⁵² Most authors now consider a discoid meniscus as an anatomical variant with a propensity for tearing caused by increased mechanical stresses and hypermobility from meniscocapsular separation secondary to increased shear stress at meniscal capsular junction.⁶⁶ A developmental theory hypothesized that the discoid meniscus developed because of the absence of the posterior tibial attachments of a normal meniscus. It was noted that in a case series of six patients with discoid menisci at surgery, the posterior menisocofemoral ligament (ligament of Wrisberg) was the only posterior attachment. Due to deficiency of sufficient posterior attachments the meniscus unusually subluxates into the notch during extension and during flexion it is pulled laterally by the coronary ligaments and the popliteal tendon. This abnormal movement caused repetitive micro trauma and produced the increased size and shape of the discoid meniscus.⁶⁷

Discoid lateral meniscus

A discoid lateral meniscus is a relatively uncommon developmental variant of the meniscus. It affects 4% to 5% of the patient population.⁶⁸ The frequency of discoid lateral menisci in man varies, according to the series between 1.4% and 15.5%.⁶⁹ These series are based either on meniscectomies⁵² or on arthrograms.⁶⁸ Of 10,000 meniscectomies reported in a study 467 had a discoid LM.⁵² The condition is classically asymptomatic and so, is rarely diagnosed. Commonest symptom is pain that begins with a minor trauma yet, other symptoms include clicking, snapping and locking during movement and less commonly joint-line tenderness, reduced mobility and a giving way sensation. A high percentage of cases present with an associated meniscal tear and peripheral rim instability.⁷⁰

In a study based on 1643 knee arthroscopies done between the years 1993 & 1999, 87 patients with discoid lateral menisci were encountered with regard to clinical presentation and radiographic features.⁷⁰

Classification of the Discoid Lateral Meniscus:

Watanabe's classification developed in 1967 is the most accepted classification for discoid lateral meniscus which is based upon their shape and tibial attachments. This classification which was developed from arthroscopic observations divides discoid lateral menisci into three types, Complete, incomplete and Wrisberg type.⁷¹

Type 1: A complete slab of meniscal tissue with complete tibial coverage. Discoid menisci with intact peripheral attachments are complete (type I) and cover the entire tibial plateau. The Wrisberg ligament may also be thick and high in patients with a complete discoid lateral meniscus.

Type 2: An incomplete slab of meniscal tissue with less than 80% coverage of the lateral tibial plateau.

Type 3: The Wrisberg variant, where meniscus has a normal morphology but lacks its posterior attachment, the meniscotibial ligament and meniscal fascicles.^{51,71}

Wrisberg variant may present with a snapping knee due to hypermobility.⁶⁸

Type 1 is most common and type 3 is least common. Monllau et al in 1998 proposed adding a fourth type, the rare ring-shaped meniscus to the classification.⁶¹ Cadaver studies have reported the prevalence of lateral discoid menisci to be between 0 and 7%, whereas arthroscopic studies have demonstrated ranges from 0.4 to 16.6%. The proportion of the Wrisberg variant has been reported between 0 and 33% of discoid menisci.^{52, 69}

Another classification proposed that there are three types of discoid lateral meniscus; primitive, intermediate and infantile and explains the cause of the anomaly as the persistence of a disc-shaped meniscus arrested at varying stages of embryological development.⁵²

Jordan suggests a classification based on peripheral stability, type of discoid meniscus (complete or incomplete), presence of a meniscal tear and presence or lack of symptoms as stable, unstable with discoid shape and unstable with normal shape. In this classification system both the complete and incomplete discoid menisci are considered stable because they have the same firm anterior and posterior tibial attachments, regardless of the presence of a menisiofemoral ligament attachment. The stable types are further sub classified as symptomatic or asymptomatic and as torn or not torn. The unstable types in this system are classified as either unstable with a discoid shape or unstable with a normal shape. Again these are further subdivided as symptomatic or asymptomatic and as torn or not torn.^{17, 66}

Hall, in 1977, devised a classification of discoid lateral menisci based on arthrographic appearance. He described six types of discoid lateral meniscus, including a slab type and a biconcave type, both of which resemble the complete type. Interestingly, one third of the knees with a discoid lateral meniscus in his series had medial side symptoms only and did not require lateral meniscectomy. Author did not indicate specifically which types of discoid lateral meniscus were prone to be symptomatic.⁷²

A partially duplicated discoid lateral meniscus with a peripheral tear was reported where, the medial one-third portion of the discoid meniscus was duplicated with the same thickness of 4 mm. The inner surfaces between the duplicate portions were smooth and glistening contrary to the torn surface of the discoid meniscus.⁷³

Associated anomalies of discoid lateral meniscus:

Discoid lateral meniscus is linked with other anomalies like; lateral femoral condyle hypoplasia, fibular muscular defects, high fibular head, lateral joint widening, abnormally shaped lateral meniscus and vertical septum type of infrapatella plica.⁷³

Discoid medial meniscus

The vast majority of discoid menisci are lateral and the discoid medial meniscus is extremely rare. A discoid meniscus on the medial side of the knee was described by Watson-Jones in 1930. The literature reviews by an author describe the male dominance for unilateral cases of discoid medial menisci.⁷⁴

The frequency of a discoid medial meniscus is differently estimated out of a total of 16895 subjects recorded in the literature 15 cases of discoid medial menisci are mentioned, i.e. in 0.09% of cases.⁷⁵ Of 10,000 meniscectomies reported by Smillie, 3467 had a discoid lateral meniscus and only 7 had a discoid medial meniscus.⁵² In 14,731 menisci examined 410, (0.12%) of 8,040 medial menisci and

102 (1.5%) of 6,691 lateral menisci were discoid.⁷⁴ Problems encountered in a discoid medial meniscus are the same as a discoid lateral meniscus, including a propensity for tears to occur and with mechanical features of clicking and locking.⁵¹

A study showed MRI findings of discoid medial menisci as widening of the medial compartment and the medial meniscus covered the width of medial plateau extending through out the entire medial compartment extending into the intercondylar notch with radial tear. It also showed a big tie configuration of the meniscus.⁷⁶ Associated anomalies in a discoid medial meniscus also exist which include; an anomalous insertion of the anterior horn of the medial meniscus into the anterior cruciate ligament, meniscal cyst, discoid lateral meniscus in the same knee and pathologic medial patella plica.⁷⁷

Bilateral discoid menisci

A case report showing bilateral medial and lateral discoid menisci where arthroscopic examination of the right knee confirmed the presence of discoid medial and lateral menisci. The medial meniscus was incomplete discoid conformation and had a horizontal tear, whereas the lateral meniscus was completely discoid and had no tear. The discoid medial meniscus had an anomalous insertion to the anterior cruciate ligament (ACL).⁷⁸

Ring-shaped medial meniscus:

It was reported that Watson-Jones made the first description of a ring-shaped menisci. It was an internal meniscus that blocked extension. However, the same author doubted that his finding corresponded to a congenital abnormality or an old bucket-handle tear. Noble (1975), reported the first true congenital ring meniscus. It was a lateral ring-shaped meniscus, which was found by chance during an autopsy, associated with congenital absence of the anterior cruciate ligament. The rounded

uniform rim with no evidence of a tear of that meniscus suggests that this finding is congenital in origin.⁷⁹

Tears of the menisci

Menisci tear in different ways. Tears are noted by how they look, as well as where the tear occurs in the meniscus. 'Traumatic tears' is a term used to describe tears that are considered to arise mainly as a result of a specific, traumatic injury which include vertical, bucket handle and radial tears. Traumatic tears normally occur in younger sports-active people. Degenerative tears are due to degenerative processes and include horizontal, flap and complex tears as well as meniscal degeneration and destruction. Their appearance at arthroscopy is highly variable and includes fraying of the free edge, central degeneration, centrally located horizontal tears, fringe tags, degenerative flap tears and extensive fibrillation of the entire meniscus.^{80,81}

O'Connor described classification of meniscal tear patterns. He classified meniscal tears into Longitudinal tears, Horizontal tears, Oblique tears, Radial tears, Flap tears, Complex tears, Degenerative tears and Interstitial tears. The altered shape, increased thickness and weak structure, along with poor vascularity and abnormal mobility of the discoid meniscus, makes it bio mechanically weak to resist normal stresses and thus, more prone to tears. Compared with the normal semilunar meniscus, the discoid lateral meniscus has a higher frequency of meniscal tears, more so the solitary tears are more common in discoid variant.⁸²

Longitudinal tear is when the tear is parallel to the edge of meniscus. Complete tears usually displace and if it is displaced over the intercondylar notch it is called bucket handle tear. Medial menisci are three times more prone than the lateral and may be associated with acute ACL tears. Bucket handle tears are commonly seen

in young adults with a history of locking, extension block or slipping of the joint. Tear near the capsular attachment of meniscus is known as peripheral tear which can be sutured.⁸¹

Horizontal tears are frequently seen in the posterior half of the medial meniscus or middle of lateral meniscus. Horizontal, cleavage or fish-mouth tears are common in older people and extend from the inner free margin to the intrameniscal substance where myxoid degeneration may be present. These tears divide the meniscus into superior and inferior flaps. They have little or no healing capacity.^{80,81}

Oblique (parrot beak) tears pass obliquely from the inner edge to the body of the meniscus. They are full thickness tears which may be anterior or posterior. Usually occur at the junction of the posterior and middle thirds of the meniscus. Radial tear runs from inner edge to the outer edge of the meniscus. They are more common in the lateral meniscus and associated with ACL tears. If they reach the periphery it transects the entire meniscus. Radial tears in the avascular inner one-third of the meniscus have little potential for healing. Displaced tears are fragments of a torn meniscus partially attached to the meniscus and migrating to any position within the joint. Other variations include flap tears which are antero- inferior flaps arising from inferior surface of the anterior third of the meniscus and created a nodule palpable on the anterolateral joint line.⁸⁰

Medial menisci tears are vertical, horizontal and cystic and are relatively more frequently found in men than women. Vertical tears are more common than horizontal. Lateral menisci tears are vertical, oblique, flaps, radial and cystic and vertical tears being more common. Discoid menisci showed central tears, flap, horizontal within the substance of meniscus, peripheral detachment and central thickening causing mechanical symptoms. Cystic menisci has a swollen appearance

and a soft texture with loss of normal architecture and are associated with aching pain at night and swelling. Meniscal cysts are encountered about the knee and can be in contact to menisci or remote. The pattern of meniscal tear vary with age, older people had flap tears and myxoid.^{80,81}

Comparative anatomy of meniscus

In a sample of 316 nonhuman primates, representative of 43 genera the lateral meniscus morphology was studied. The lateral meniscus has a crescentic shape in Prosimii, in Platyrrhini (New World monkeys) and in *Pongo pygmaeus*. The lateral meniscus is disc-shaped, with a central foramen, in Catarrhini (Old World monkeys), in *Hylobates*, in *Gorilla* and in *Pan troglodytes*. In man, the lateral meniscus has a crescentic shape. Discoid lateral menisci are reported as meniscal variants in man; their source has given rise to much discussion, but the comparative data favour a phylogenetic origin. The posterior fasciculus (Wrisberg's ligament) of the posterior menisco-femoral ligament is constantly present and large in all non-human primates, but in man, it may be absent and seems to be a regressive structure. On the other hand, the anterior fasciculus (Humphry's ligament) exists only in man and seems to be a progressive structure. The posterior menisco-tibial attachments are weak or non-existent in nonhuman primates, but they are well-developed in man. The evolutionary development of these characters can be related to human bipedal locomotion. The lateral meniscus in some Prosimii contains one or two intrameniscal ossicles. These structures are absent or very rare in all other primate groups. In man, intrameniscal ossicles are extremely unusual, their origin phylogenetic or posttraumatic, is controversial, but comparative data favour, at least in some cases, the persistence of an ancestral character.⁷⁵

A study was conducted on animal species like sheep and rabbit where the menisci were compared with human menisci. Results disclosed a similarity in cell and tissue properties and matrix composition for these three species. But, some features of the human meniscus are essential for meniscus repair, which include vascularization pattern, cellularity and ECM collagen ultrastructure which were similar in human and sheep but not in rabbit, suggesting sheep to be advantageous as an animal model for meniscus repair.⁸³

Meniscal transplantation

Meniscal transplantation has been developed to prevent the expected joint worsening that occurs after meniscectomy. Much remains to be learned about the biological behavior of the meniscal transplant, as well as its expected longevity.⁸⁴ The menisci of the knee joint plays a critical role in conserving normal knee function. Knowledge about meniscal function provides a basis to retain these structures whenever possible. Improvement in the surgical repairs of meniscal tears have modified the techniques from complete excision to arthroscopic meniscal repairs. Meniscal allograft transplantation (MAT) was developed to check the unpleasant effects observed with meniscectomy and subsequently proven to be effective in animal trials. In 1989 the first clinical trial was published and reported the experimental and short-term results of the technique as a possible treatment option in a painful meniscectomized knee.⁸⁵

There is widespread agreement that graft selection should be specific for the compartment being transplanted (right or left, medial or lateral). Careful selection of the perfect candidate is important step for success of meniscal transplantation. Typically, patients should be less than 50 years and must have underwent a total or subtotal meniscectomy with persistent pain localized to the meniscus deficient

compartment. The knee joint must be stable and have normal alignment with intact articular surfaces. Contraindications include inflammatory arthritis, synovial diseases, infection of the knee joint, immunodeficiency, obesity, systemic metabolic diseases and skeletal immaturity.⁸⁶

Careful size-matching of the meniscal allograft to the native meniscus is the criteria for success. Meniscal allografts are compartment and size specific. Allograft sizing has a major importance, as oversized meniscal allografts lead to greater forces across the articular cartilage and undersized allografts result in greater forces seen by the meniscal tissue.²⁴

Meniscal size is based on the characteristics of the patient. Gender, height and weight should be considered as fast and cost-effective variables to predict meniscal dimensions.⁸⁷ Cadaver tissue was used to assess the anatomic positions of the insertion sites for the anterior and posterior horns for both the medial and lateral menisci and compared the relative measurements with standard anteroposterior and lateral radiographs.²⁴

Different types of meniscal substitutes

1. Meniscal prostheses - Teflon and Dacron prostheses have demonstrated some chondroprotective effect in the rabbit knee.
2. Tissue engineered menisci have been under investigation as an implant.
3. Collagen scaffolds have been implanted, serving as a template to regenerate meniscal cartilage which help the host chondrocytes migrate into the new tissue.
4. In sheep the transplanted pediculated infrapatellar fat-pad results in the development of a meniscus- like structure within 6 months.
5. Tendon autografts

6. Meniscal allografts- The experiments have shown that the allografts generally heal to the capsule and are revascularized and repopulated with host cells.⁸⁸

The allograft risk include a possibility for immune reactions and the danger of disease transmission. Meniscal allografts have been demonstrated to express Class I and II histocompatibility antigens.⁸⁹

The tests to assess meniscal disorders

Palpation of the medial and lateral joint lines is the most basic procedure of the meniscal assessment. Flexing the knee and adding tibial rotation either internally or externally allows for easier palpation of the periphery of the medial and lateral meniscus respectively. It is estimated that sixty to eight percent of patients with meniscal lesions will have a joint line that is painful upon palpation. Few tests which are employed to assess meniscal disorders are: Apley compression test, Anderson medial-lateral grind test, Thessaly test, McMurray's test and Ege's test. With newer surgical advancements, arthroscopy has become the gold standard for the accurate diagnosis of internal derangements of the knee including cruciate ligament tears and tears of the menisci.⁸¹

Morphometric study of menisci

Cadaveric study was done on 22 pairs of human tibial plateaus with both menisci attached intact. They measured the peripheral length of the menisci with a thin steel wire moulded around the peripheral rim of each meniscus. They also measured the width of the body of the medial and lateral menisci using the digital vernier caliper. They found that the peripheral length of medial and lateral menisci were 99 ± 9.3 mm and 91.7 ± 9.6 mm respectively. The widths of the body of the medial and lateral menisci were 9.3 ± 1.3 mm and 10.9 ± 1.3 mm.²⁷

Erbagci et al (2004) performed 174 MRI examinations of the knee with a IT imager. They measured the width and thickness of the menisci at three zones anterior horn, mid-body and posterior horn. For the medial meniscus, the thickness and width of anterior horn were 5.32 ± 0.95 mm and 7.78 ± 1.86 mm, the thickness and width of the midbody were 5.03 ± 0.92 mm and 7.37 ± 2.65 mm, and the thickness & width of the posterior horn were 5.53 ± 0.99 mm and 11.71 ± 2.63 mm, respectively. For the lateral meniscus, the thickness and width of the anterior horn were 4.33 ± 0.98 mm and 8.88 ± 2.3 mm, the thickness and width of the midbody were 4.94 ± 0.99 mm and 8.37 ± 0.83 mm, and the thickness and width of the posterior horn were 5.36 ± 1.03 mm and 9.70 ± 1.69 mm respectively. Also they encountered 3 cases (1.7%) of discoid lateral meniscus.⁹⁰

Kale et al (2006) studied on 22 knee joints of 11 foetal cadavers (7 females & 4 males). 8 cadavers (73 %) had the same shape of menisci on each side. They found that 77.27% of lateral menisci were discoid. 54.54 % of the LM were incomplete discoid, and 22.72 % of the LM were complete discoid. They found that 22.72 % of the LM were nondiscoid among them, 13.63 % of the LM had a crescentic shape and 9.09 % of the LM were C shaped. They did not find any discoid medial menisci. 36.36 % of the MM were sickle shaped, 22.72 % of the MM were sided V shaped, 18.18 % of the MM had a crescentic shape, 13.63 % of the MM were C shaped and 9.09 % of the MM were sided U shaped. They also measured the mean width of the midpoint of the anterior horn, posterior horn and lateral side of the menisci. They were 0.29, 0.34 and 0.37 cms for the lateral meniscus and 0.28, 0.29 and 0.26 cms for the medial meniscus.⁹¹

Almeida et al (2004) analyzed the morphometric aspects of the menisci of the knee joint. They analyzed 44 menisci of the 22 adult knees. According to them, the

thickness and width of MM at anterior 1/3 were $5.92 \pm 1.37\text{mm}$ and $9.02 \pm 1.59\text{mm}$, middle 1/3 were $5.31 \pm 1.06\text{mm}$ and $12.16 \pm 2.58\text{mm}$ and posterior 1/3 were $5.91 \pm 1.13\text{mm}$ and $17.37 \pm 2.22\text{mm}$ respectively. Similarly thickness and width for the lateral menisci at ant 1/3 were $3.71 \pm 1.15\text{mm}$ and $11.86 \pm 1.81\text{mm}$, middle 1/3 were $6.10 \pm 1.04\text{mm}$ & $11.97 \pm 2.56\text{mm}$ and post 1/3 were $5.29 \pm 0.78\text{mm}$ & $11.44 \pm 1.07\text{mm}$ respectively. The distance between the anterior & posterior horn of medial meniscus was $29.70 \pm 4.12\text{ mm}$ and for lateral meniscus, it was $12.71 \pm 1.84\text{ mm}$.¹⁰

Dieter Kohn & B. Moreno (1995) measured the peripheral length of the menisci, including their insertion ligaments. The study was done on 92 knee joints and the values were $111 \pm 14\text{mm}$ for the medial & $111 \pm 10\text{ mm}$ for the lateral meniscus.⁵

Braz and Silva (2010) in their study on 40 menisci from 20 human knees, 7 right and 13 left reported the peripheral length of MM was $91.85 \pm 11.21\text{mm}$ and for LM was $92.80 \pm 9.36\text{mm}$. The distance between the anterior and posterior horn of the medial meniscus ($25.88 \pm 3.33\text{ mm}$) was significantly higher than that of the lateral meniscus ($12.55 \pm 1.98\text{ mm}$). With regard to the width of the lateral meniscus, there was no significant difference between the anterior ($11.32 \pm 1.46\text{ mm}$), medium ($11.16 \pm 1.64\text{ mm}$), and posterior thirds ($11.67 \pm 1.54\text{ mm}$). However, in the medial meniscus, the posterior third was the widest part ($14.96 \pm 2.66\text{ mm}$) followed by the mid ($9.32 \pm 2.24\text{ mm}$) and anterior third ($7.68 \pm 1.36\text{ mm}$). The average thickness of MM was 5.88mm and for LM was 5.46mm .⁹²

Muralimanju et al (2010) studied on 106 foetal knee joints and reported that the peripheral and inner border length of MM were significantly more than LM. The average thickness of medial and lateral menisci were ($1.52 \pm 0.37\text{mm}$) and ($1.53 \pm$

0.38mm) respectively. The posterior one third was the widest part of MM, whereas middle one third was the widest for LM.⁹³

Kapandji (2000) reports that the distance between the horns of the lateral meniscus are closer together than those of the medial meniscus. Hence the LM looks like a ring and MM represents half moon shape.⁹⁴

METHODOLOGY

Material:

To carry out this study, embalmed human adult cadaveric limbs available in the Department of Anatomy, Jawaharlal Nehru Medical College, Belgaum were used. For this study, 120 menisci from 60 human knees, 29 right and 31 left, previously dissected and preserved with a solution of 10% formalin were used. Since the pieces were removed from the cadavers thus presenting an isolated knee joint, it was not possible to determine whether the knees were from the same or different cadavers nor to determine other aspects related to weight, sex and height, even though these factors may influence certain anatomical variations .

Study design: Cross sectional study.

Duration of study: 2 years.

Sample size :

120 menisci from 60 adult human lower limbs. Sample size is based on number of cadaveric limbs available during the course of study period.

Inclusion criteria :

All cadaveric limbs available in the Department of Anatomy of J. N. Medical College during the study period.

Exclusion criteria:

1. Cadaveric lower limbs with abnormal knee joints such as deformity, exostosis, fractures or traumatic injury.
2. All menisci that showed any structural change which prevent its morphometric analysis such as injuries or advanced degenerative changes were excluded.

The following instruments were used for the study:

1. Dissection kit
2. Vernier caliper (of accuracy 0.10 mm)
3. Cotton thread
4. Pins
5. Measuring tape
6. Magnifying lens
7. Coloured marker pens

Method:

After the dissection of skin and muscles, the approach to the menisci was performed. The joint cavity was opened, anteriorly by a longitudinal incision on each side of the joint capsule and cutting the patellar ligament and the collateral ligaments transversely. In order to expose the menisci clearly, the joint capsule and the intraarticular ligaments were cut, and the condyles were circumferentially detached from their soft tissue attachments and removed, exposing the tibial plateau. The anterior intermeniscal ligament, if present, was then identified, either within or overhung by the retropatellar fat pad. All dissections were performed in a systematic fashion and data were recorded on a standardized collection sheet.⁹¹

Morphological variants of the shapes of the menisci were macroscopically noted and classified.

The lateral menisci (LM) and medial menisci (MM) were classified as discoid and nondiscoid menisci. Further, the discoid menisci were divided into subgroups as the complete and incomplete discoid menisci. The nondiscoid menisci were subgrouped as crescentic (semilunar) shaped, C shaped, sickle shaped, sided U shaped and sided V shaped.

When the meniscus covers the tibial plateau circularly, the meniscus is said to be discoid type. The incomplete discoid menisci had an opened area at the centre of the menisci and they were all horse shoe shaped.⁹¹ The menisci which did not have any opened area at the centre of the menisci were defined as the complete discoid menisci.

The menisci, which had thin anterior and posterior horns and a thin body, were defined as the crescentic (semilunar) type. The menisci, which had thick anterior and posterior horns and a thick body, were named as the thick horse shoe shaped type.

The menisci, which had thin anterior and posterior horns and a thick body, were defined as the sickle shaped type. The menisci which resembled like sided U, sided V and C were named as sided U, sided V and C shaped, respectively.

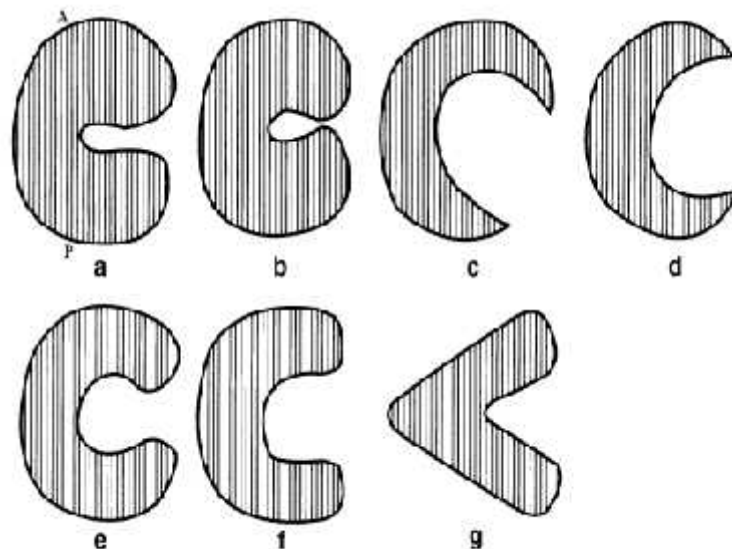


Fig. 4 showing the shapes of menisci a) incomplete discoid, b) complete discoid, c)crescentic shaped, d) sickle shaped, e) C shaped, f) sided U shaped, g) sided V shaped.⁹¹

To measure the thickness of outer circumference of menisci, the peripheral length was determined first. A nonelastic cotton thread was placed along the periphery of the meniscus and the meniscus tibial insertion ligaments were held in place with small pins. The length of this thread from the most anterior part of the anterior insertion area to the most posterior part of the posterior insertion area was measured and was called “peripheral length.” In the same way, the inner free border length was measured by keeping the thread at the inner free edge.

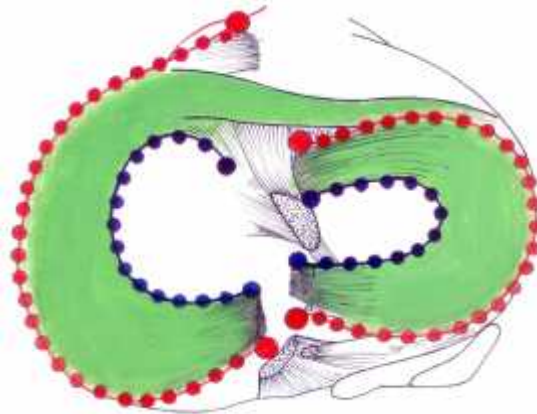


Fig. 5 Measurements of the peripheral length & inner border length of the meniscus along the dotted lines. ⁹³

Then the thread with peripheral circumference length is divided into 3 equal parts by using scale & colour marker pens. The thread is placed again over the meniscus and the meniscus were divided into 3 equal parts anterior 1/3(ant 1/3), middle 1/3(mid 1/3) and posterior 1/3(post 1/3) respectively. Then the width and the thickness of the meniscus was measured at the above mentioned parts at their midpoint. The distance between (b/w) the anterior horn (AH) & posterior horn (PH) was also measured. A Vernier caliper of 0.10 mm accuracy was used for taking

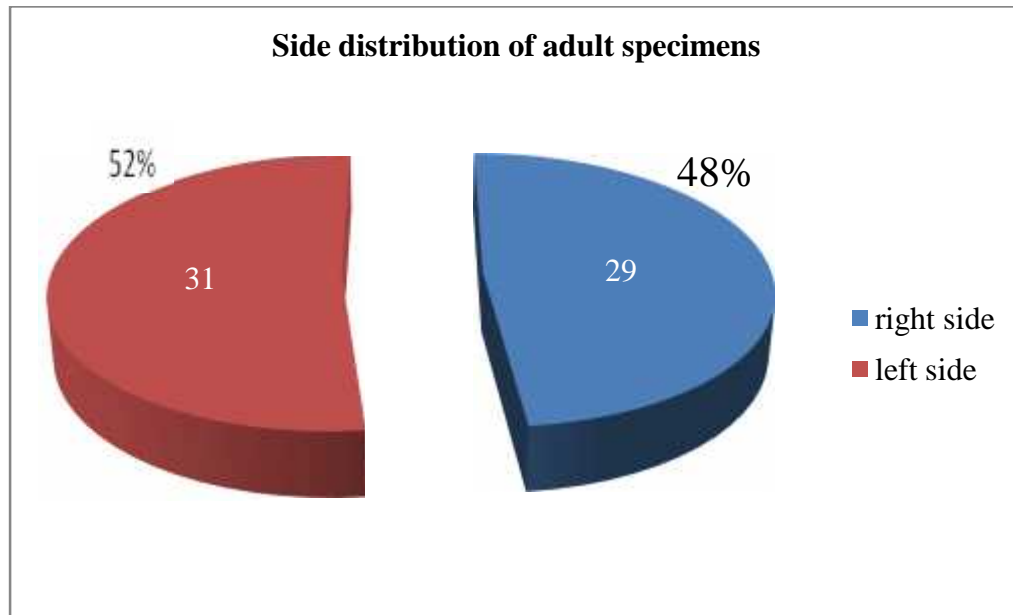
measurements. These parameters were used to determine dimensions of the normal menisci.

Statistical analysis included mean and standard variations of each variable calculated and their difference between medial and lateral menisci was compared by using Student's unpaired t-test, where significance value was $p < 0.05$.

RESULTS

Study was done on 60 knee joints. In which 29 (48%) belonged to right knee joint and 31 (52%) were of left knee joint.

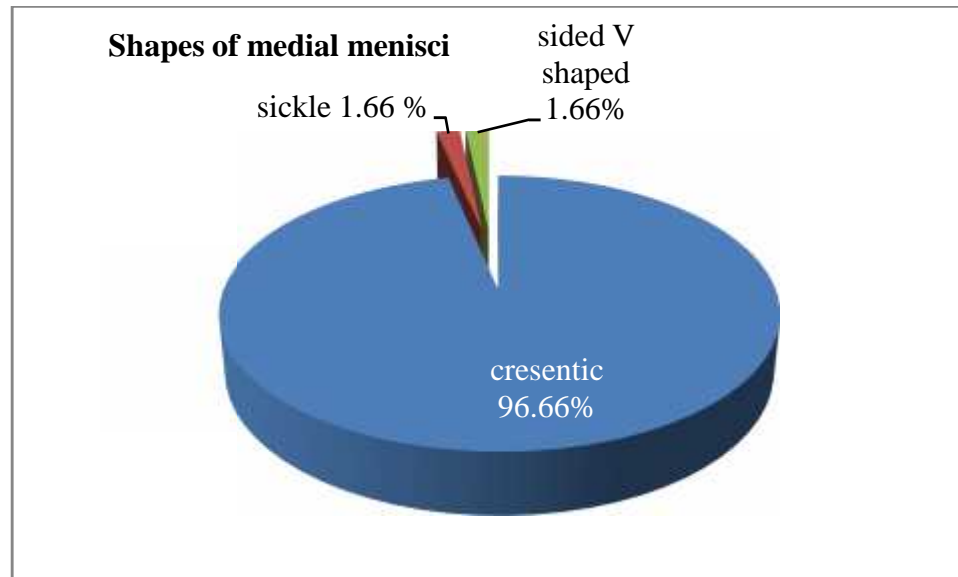
Graph 1. Side distribution of adult specimens (n= 60).



Morphological shapes of menisci

In our study six morphological types of the shape of menisci were determined. It was observed that 96.66% of medial menisci were crescentic in shaped, 1.66% showed sided V shaped and 1.66% showed sickle shape (Graph 2). Among the lateral menisci 88.33% were C shaped, 6.66% sided U shaped and 5% showed incomplete discoid (Graph 3).

Graph 2. Incidence of different shapes of medial menisci in adults (n = 60).



Graph 3. Incidence of different shapes of lateral menisci in adults (n = 60)

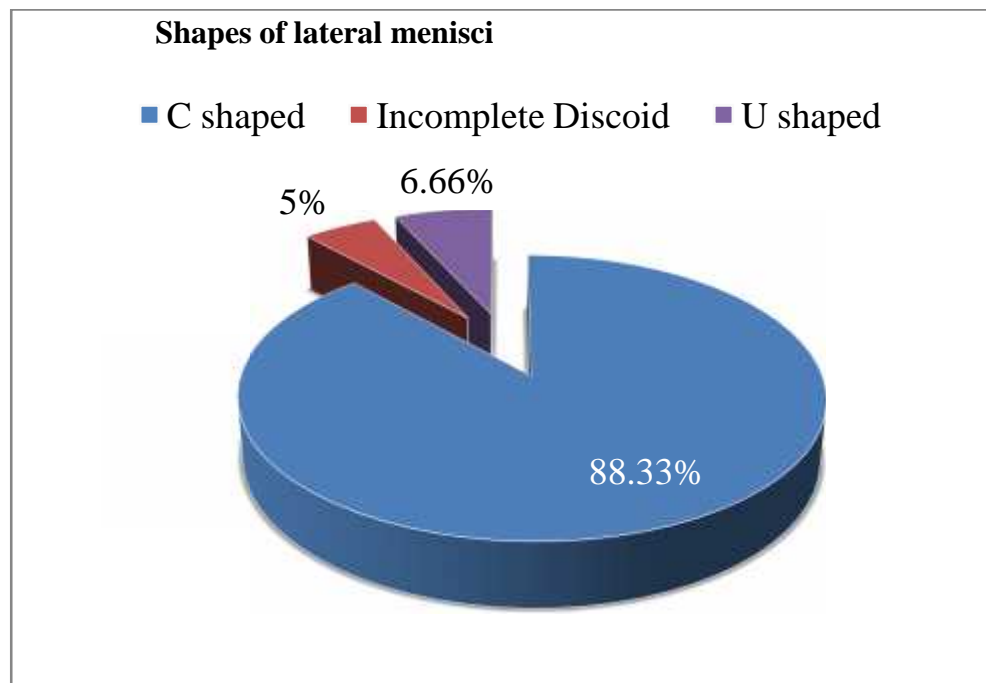


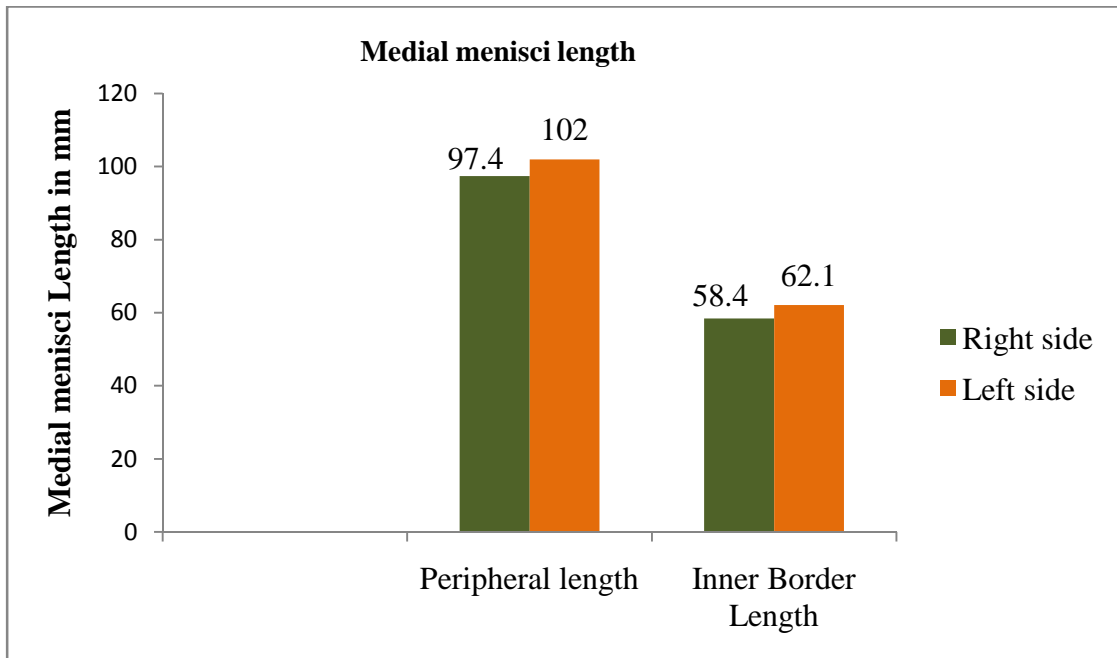
Table 1. Medial meniscal parameters in adults (n = 60).

PARAMETERS		RIGHT SIDE (mm)	LEFT SIDE(mm)	t value	p value
Peripheral Length		97.4 ± 8.53	102.1 ± 8.56	2.136	0.037 *
Inner Border Length		58.4 ± 8.59	62.1 ± 8.04	1.753	0.085
Width	Ant 1/3	6.9 ± 1.24	7.3 ± 1.70	1.012	0.311
	Mid 1/3	7.2 ± 1.53	7.4 ± 1.58	0.707	0.482
	Post 1/3	12.1 ± 2.20	12.2 ± 2.65	0.186	0.853
Thickness	Ant 1/3	4 ± 0.69	4.2 ± 0.80	0.730	0.469
	Mid 1/3	4.2 ± 1.08	4.2 ± 0.94	0.149	0.882
	Post 1/3	4.4 ± 0.73	4.6 ± 0.71	0.703	0.485
Distance b/w AH & PH		27.8 ± 5.65	28.7 ± 5.31	0.647	0.520

Values are Mean ± SD, Statistical significance (Paired t-test) *p<0.05

Table 1 and Graph 4 & 5 showed comparison of medial menisci parameters on left and right side, mean peripheral length of left sided medial menisci were higher with statistically significant difference (p <0.05). Mean inner border length was also high on left medial menisci but the difference was not significant. Mean values of width and thickness of medial menisci at anterior1/3, middle1/3 and posterior 1/3 were more in left sided menisci with no significant difference. Mean of distance between anterior and posterior horns of menisci were high on left side.

Graph 4. Comparison of length of medial menisci in adults (n = 60).



Graph 5. Medial menisci parameters in adults (n = 60).

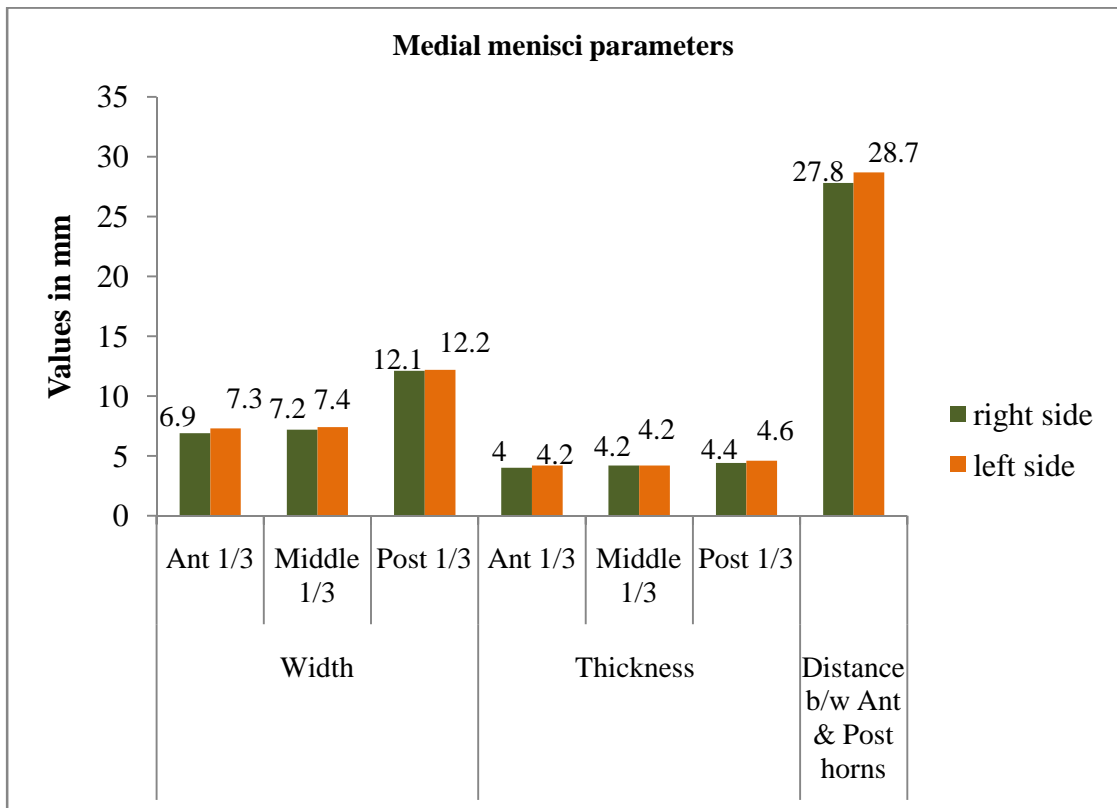


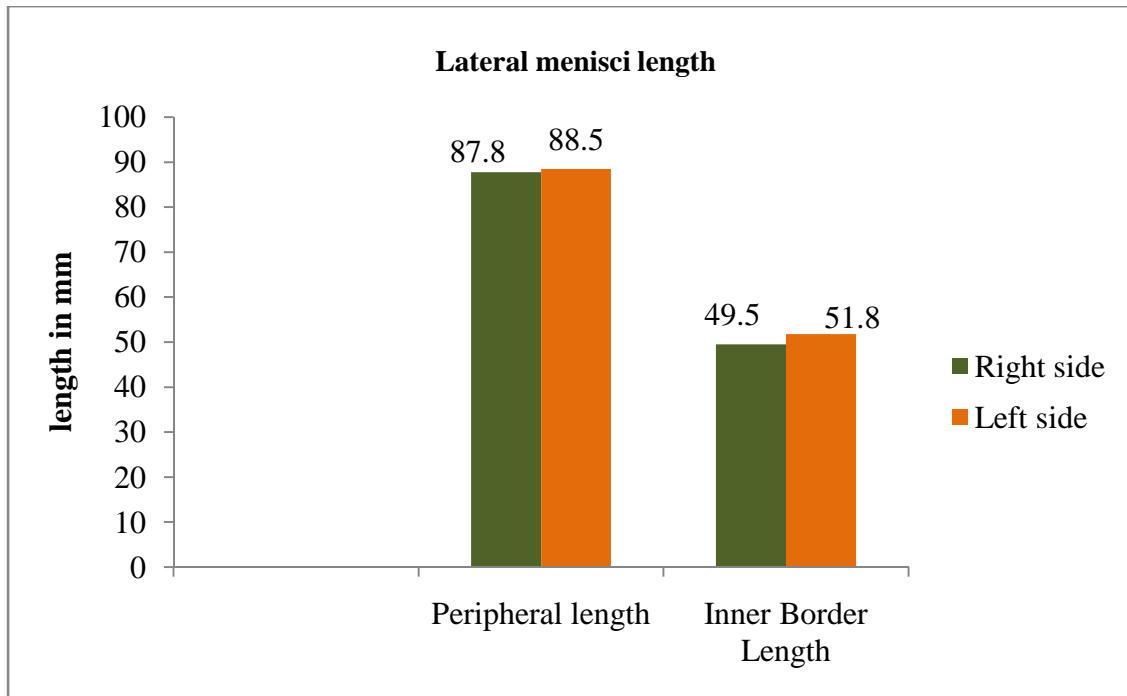
Table 2. Lateral meniscal parameters in adults (n =60).

PARAMETERS		RIGHT SIDE (mm)	LEFT SIDE(mm)	t value	p value
Peripheral Length		87.8 ± 8.39	88.5 ± 7.36	0.371	0.712
Inner Border Length		49.5 ± 8.88	51.8 ± 5.87	1.202	0.234
Width	Ant 1/3	8.4 ± 2.21	8.8 ± 1.97	0.571	0.570
	Mid 1/3	9.2 ± 2.31	9.3 ± 2.61	0.128	0.899
	Post 1/3	9.6 ± 1.93	9.5 ± 2.16	0.088	0.930
Thickness	Ant 1/3	3.8 ± 1.26	3.9 ± 0.87	0.235	0.815
	Mid 1/3	4.4 ± 1.58	4.3 ± 1.05	0.425	0.672
	Post 1/3	4.7 ± 1.43	4.9 ± 2.25	0.546	0.587
Distance b/w AH & PH		11.4 ± 2.89	12.5 ± 2.62	1.502	0.139

Values are Mean ± SD, Statistical significance (paired t-test) *p<0.05

Table 2 and Graph 6 and 7 shows the lateral menisci parameters of right and left side, it was observed that all the parameters like peripheral length, inner border length, width and thickness at anterior 1/3, middle1/3, and posterior 1/3, distance between anterior and posterior horns were higher in left sided lateral menisci, but the difference was not statistically significant (p>0.05).

Graph 6. Lateral menisci length (n = 60)



Graph 7. Lateral menisci parameters (n = 60)

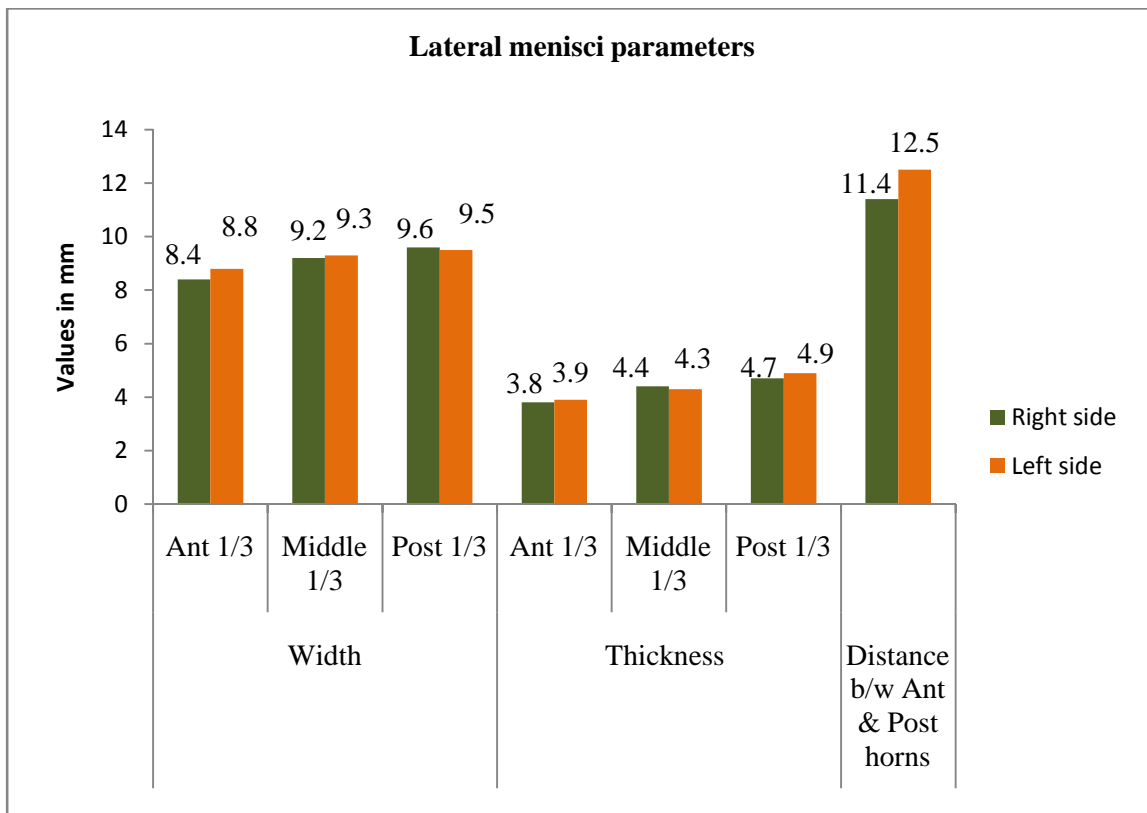


Table 3. Length of menisci in adults (n =60).

Length in mm	Medial Meniscus	Lateral Meniscus	t value	p value
Peripheral Length	99.8 ± 8.80	88.2 ± 7.82	7.676	< 0.001*
Inner Border Length	60.3 ± 8.46	50.7 ± 7.50	6.593	< 0.001*

Values are Mean mm ± SD, Statistical significance (Paired t-test) *p<0.05

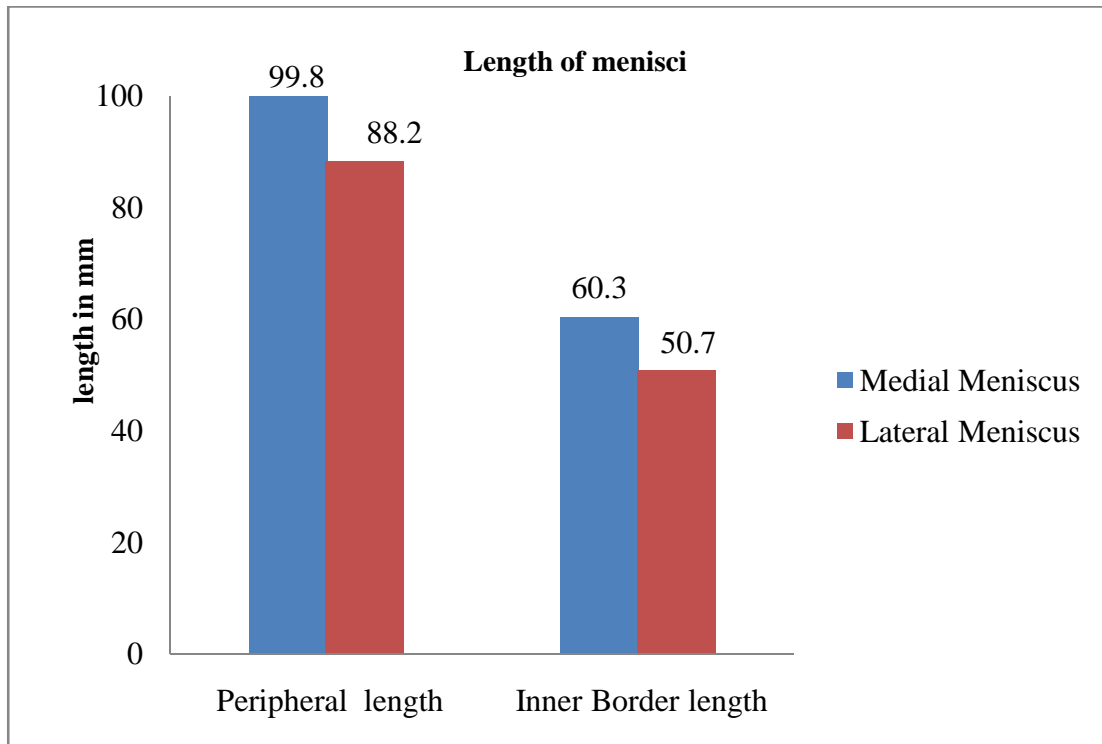
Table 4. Width of menisci in adults (n =60).

Width in mm	Medial Meniscus	Lateral Meniscus	t Value	p value
Ant 1/3	7.1 ± 1.49	8.6 ± 2.08	4.507	< 0.001*
Mid 1/3	7.3 ± 1.55	9.2 ± 2.45	5.088	< 0.001*
Post1/3	12.2 ± 2.42	9.5 ± 2.04	6.444	< 0.001*

Values are Mean mm ± SD, Statistical significance (Paired t-test) *p<0.05

It was observed that the values in mm for peripheral and inner border length of medial menisci were high and was statistically significant($p < 0.05$)(Table 3, Graph 8). Table 4 shows the width at ant1/3 and middle 1/3 of lateral menisci were significantly higher than the medial menisci, but the width at posterior 1/3 of medial menisci were high and the difference was statistically significant (Graph 9).

Graph 8. Length of menisci (n = 60)



Graph 9. Width of menisci (n = 60)

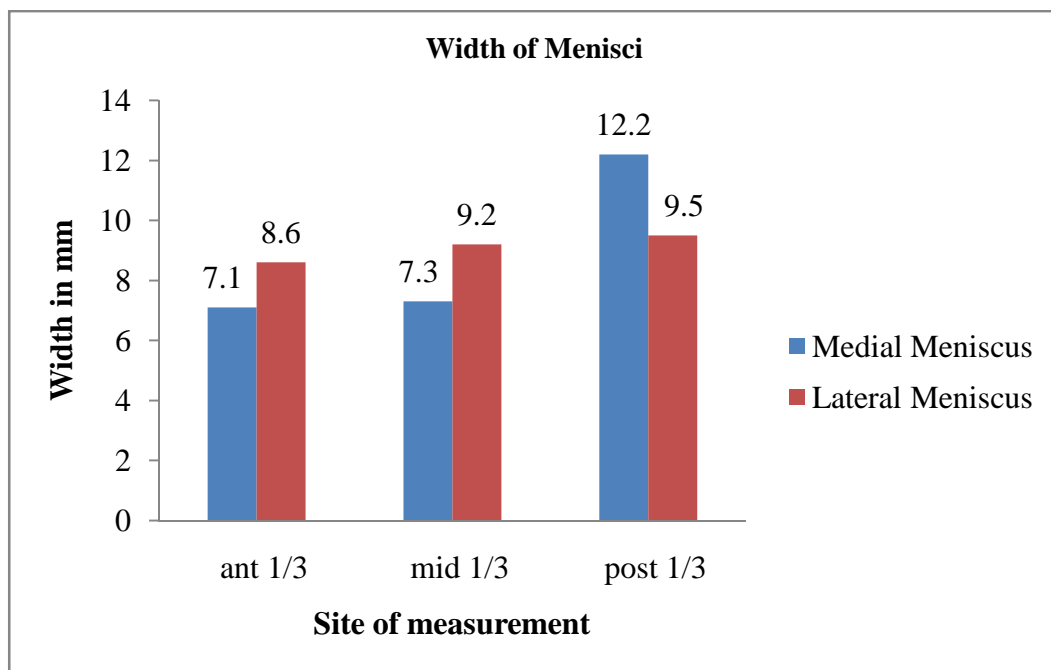


Table 5. Thickness of menisci in adults (n =60).

Thickness in mm	Medial Meniscus	Lateral Meniscus	t Value	p value
Ant 1/3	4.1 ± 0.75	3.9 ± 1.07	1.483	0.141
Mid 1/3	4.2 ± 1.01	4.3 ± 1.32	0.613	0.541
Post 1/3	4.5 ± 0.72	4.8 ± 1.89	1.116	0.268

Values are Mean mm ± SD, Statistical significance (Paired t-test) *p<0.05

Table 6. Distance between the anterior & posterior horns of the menisci in adult (n = 60)

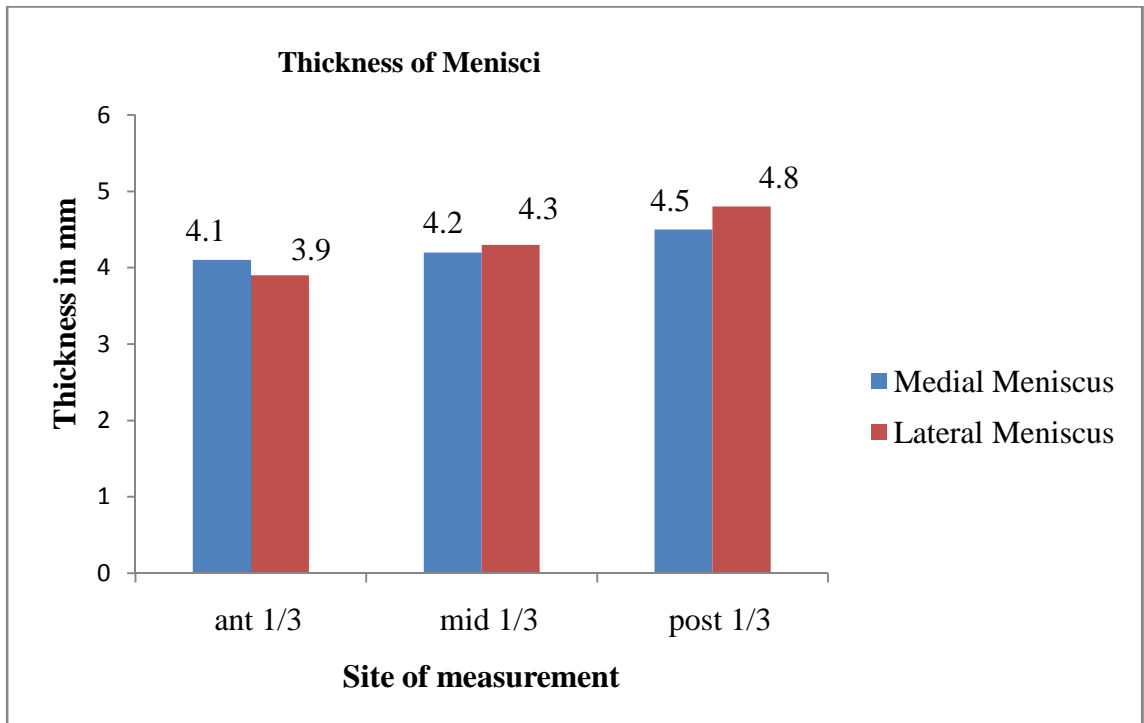
	Medial Meniscus	Lateral Meniscus	t Value	p value
Distance b/w AH & PH	28.2 ± 5.45	11.9 ± 2.78	20.610	0.001*

Values are Mean mm ± SD, Statistical significance (Paired t-test) *p<0.05

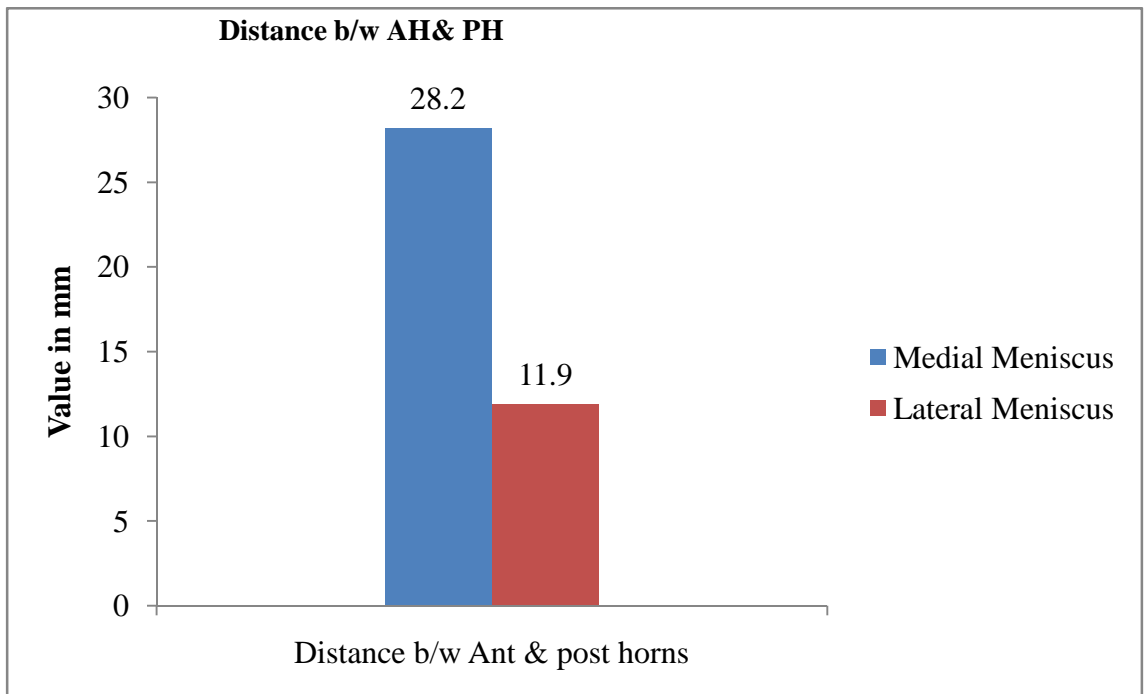
It was observed in table 5 that the thickness at ant1/3 were high for medial menisci but the difference was not significant. Thickness at middle 1/3 and posterior 1/3 were more in lateral menisci with insignificant difference (Graph 10).

The mean of distance between anterior and posterior horn of menisci were high in medial menisci than lateral menisci and the difference was statistically significant (Table 6, Graph 11).

Graph 10. Thickness of menisci



Graph 11. Distance between anterior and posterior horns



DISCUSSION

This study was conducted on 120 menisci from 60 adult knee joints which included 29 right and 31 left side isolated specimens of knees (Graph 1). Different studies have quoted different facts and figures which have led to spectrum of findings.

The lateral menisci (LM) and medial menisci (MM) were classified as discoid and nondiscoid menisci. Further, the discoid menisci were divided into subgroups as the complete and incomplete discoid menisci. The nondiscoid menisci were subgrouped as crescentic (semilunar) shaped, C shaped, sickle shaped, sided U shaped and sided V shaped.

In this present study of 60 knee joints, 96.66% of the MM were crescentic shaped, 1.66% of the MM were sided V shaped and 1.66% of the MM were sickle shaped. No discoid medial menisci were seen (Graph 2). 88.33% of LM were C shaped, 6.66% were sided U shaped and 5% of them were incomplete discoid shaped. No complete discoid lateral meniscus was observed (Graph 3).

The differences of the shape of meniscus may be due to the mesenchymal differentiation or to the development of the vasculature early in embryonic life.⁹¹

Study on 22 fetal knee joints, reported that 73% of the cadavers they studied had the same shape of meniscus on each side. According to their observations, medial menisci showed 18.18% (crescent-shaped), 22.72% (sided V-shaped), 9.09% (sided U-shaped), 36.36% (sickle-shaped) and 13.63% (C- shaped). Discoid medial meniscus was not observed. In the same study, 13.63% of the LMs were crescent-shaped, 9.09% (C-

shaped) and 77.27% (discoid-shaped). Among the discoid shaped 54.54% of the LMs were incomplete discoid and 22.72% were completely discoid.⁹¹

The meniscus arises from the differentiation of mesenchymal tissue within the limb bud and becomes a clearly defined structure by the eighth week of fetal development.⁶⁷ Variations of morphological differences of menisci in particular in the thickness and width of menisci can determine the possibility of an injury, but also the location and the kind of injury. However, the data related to the morphometric parameters of these structures are scarce.¹⁰ There are marked differences in the contour and insertion between the lateral and the medial menisci which are important in relation to the injury mechanisms.⁹

Length of the menisci

From the results obtained, it was observed that there was statistically significant difference in the mean peripheral length of the menisci ($p < 0.05$) between the medial (99.8 ± 8.80 mm) and lateral menisci (88.2 ± 7.82 mm) and mean inner border length for medial (60.3 ± 8.46 mm) and lateral menisci (50.7 ± 7.50 mm) with statistically significant difference (Table 3, Graph 8).

In the study done on fetal menisci also, the peripheral and inner border lengths were more in the medial meniscus than the lateral.⁹³ In contrast a study done in Brazil the average length of the outer circumference was 91.85 mm for the medial meniscus and 92.8 mm for the lateral meniscus. There was no statistically significant difference.⁹²

Comparison of peripheral length (mm \pm SD) with data from the literature.

Authors	Medial Meniscus	Lateral Meniscus
Dieter Kohn & B. Moreno (1995) ⁵	111 \pm 14	111 \pm 10
McDermott, F.Sharifi et al (2004) ²⁷	99 \pm 9.3	91.7 \pm 9.6
Braz et al (2010) ⁹²	91.85 \pm 11.21	92.80 \pm 9.36
Present study (2013)	99.8 \pm 8.80	88.2 \pm 7.82

When compared within the group among the medial menisci mean peripheral length of left sided menisci (102.1 \pm 8.56 mm) were higher than right (97.4 \pm 8.53 mm) with statistically significant difference. Within the lateral menisci also left side showed higher values than right side. Inner border length for both MM and LM were greater for left sided menisci than right sided with no significant difference (Table 1 &2). These findings were consistent with a study done in Germany on 92 knees with left sided values for length being higher.⁵

Report of the study suggests that if bony fixation of a meniscal substitute is attempted, the entire circumferential length of the meniscus plus both the insertion ligaments must be known.⁵

Width of the menisci

Each meniscus was divided into 3 equal parts anterior 1/3, middle 1/3 and posterior 1/3. Width was measured at the midpoint of the three mentioned parts. The individual analysis of each meniscus showed that the posterior third (12.2 ± 2.42 mm) was the widest part of the medial menisci followed by the middle third (7.3 ± 1.55 mm) than the anterior third (7.1 ± 1.49 mm). All the values were statistically significant when compared with the lateral menisci which showed widest post 1/3 (9.5 ± 2.04 mm), followed by mid 1/3 (9.2 ± 2.45 mm) then ant 1/3 (8.6 ± 2.08 mm) (Table 4, Graph 9). The posterior third region was the widest followed by the middle third region and the anterior third region for both lateral and medial menisci. This finding was in correlation with other studies.^{10,92}

When we compare the width of MM with the LM, the width at post 1/3 of MM was greater than LM, but the width at ant1/3 and mid1/3 was greater in LM than MM. These differences are statistically significant in our study.

In another study done on 44 menisci reports the width at post 1/3 and mid 1/3 of MM was greater than LM, but width at ant 1/3 of LM is greater than MM.¹⁰

It is assumed that the wider the meniscus, the more susceptible it is to meniscal injuries. Such assumption could be justified by the fact that the greater the width of the meniscus, the more it is exposed to the actions of the femoral condyles. The anterior third of the MM presented with narrow width explains the lower incidence of injuries at this region due to the weaker action of the femoral condyle.⁹²

Comparison of the widths of the medial & lateral menisci with data from literature

Parameters in mm	Almeida et al ¹⁰	Braz et al ⁹²	Present Study
Width of MM at ant 1/3	9.02 ± 1.59	7.68 ± 1.36	7.1 ± 1.49
Width of MM at mid 1/3	12.16 ± 2.58	9.32 ± 2.24	7.3 ± 1.55
Width of MM at post 1/3	17.37 ± 2.22	14.96 ± 2.66	12.2 ± 2.42
Width of LM at ant 1/3	11.86 ± 1.81	11.32 ± 1.46	8.6 ± 2.08
Width of LM at mid 1/3	11.97 ± 2.56	11.16 ± 1.64	9.2 ± 2.45
Width of LM at post 1/3	11.44 ± 1.07	11.67 ± 1.54	9.5 ± 2.04

Within group comparison between left and right sided medial menisci it was observed that the values for width at the three regions were higher in left side than right side but the difference was not statistically significant. Similarly left sided lateral menisci showed more width than the right sided LM (Table 1 & 2).

In a study done on fetal menisci it was observed that the highest width of LM was at mid1/3 (3.7mm), followed by the post1/3 (3.4mm) and ant1/3 (2.9mm). For the MM post1/3 (2.9mm) was the highest, followed by ant1/3 (2.8mm) and mid 1/3 (2.6mm).⁹¹

Another study on foetal menisci suggests that the posterior third of MM was widest (3.28 ±0.62mm) followed by anterior third (2.94 ± 0.61mm) and middle third (2.88 ± 0.61mm). For the LM the middle third was widest (3.53 ± 0.75mm) followed by posterior third (3.44 ± 0.63mm) and anterior third (3.26 ± 0.60).⁹³

A study done to determine dimensions of the normal menisci in 174 healthy subjects by using MRI in vivo the measurements of width for the medial meniscus were (7.78 mm) anterior horn, (7.37 mm) mid-body and the (11.71 mm) posterior horn. For the

lateral meniscus, width of the anterior horn were (8.88 mm), mid-body (8.37 mm) and posterior horn was (9.70 mm).⁹⁰ These findings correlate with our present cadaveric study.

Thickness of the menisci

In our study the thickness measured along the outer circumference of meniscus at the post 1/3 (4.5 ± 0.72 mm) of the MM was the greatest followed by mid1/3 (4.2 ± 1.01 mm) and ant1/3 (4.1 ± 0.75 mm). Similarly thickness of the LM was greatest at post 1/3 (4.8 ± 1.89), followed by mid 1/3 (4.3 ± 1.32) and ant 1/3 (3.9 ± 1.07) (Table 5, Graph 10). Posterior 1/3 was thicker for both MM and LM. Comparing the values of medial meniscus with the values of lateral meniscus, statistically significant difference was not observed.

When the thickness of right and left side MM were compared, it was seen that the values were approximately similar with no significant difference. Right and left side LM also did not show any statistically significant difference in the thickness at all the three regions (Table 1 &2).

Another study reports that the posterior third of the medial meniscus was the thinnest (5.18 mm) followed by anterior third (6.17 mm) and middle third (6.31 mm). On the other hand, in the lateral meniscus the anterior third was the thinnest (4.40 mm) followed by the posterior third (5.46 mm) and middle third (6.52 mm).⁹²

A study related to the thickness of menisci, the middle third of medial meniscus was the least (5.31mm) followed by the posterior third (5.91mm) and anterior third (5.92mm). The lateral meniscus showed a statistically significant difference among the

anterior third (3.71mm), middle third (6.10mm) and posterior third (5.29mm), with the middle third as the thickest point of the meniscus.¹⁰

It can be said that the width and thickness were inversely related, the greater the width of meniscus the smaller the thickness, while the opposite was also true.⁹²

A clinical study done to measure thickness using MRI suggests that the medial meniscus thickness at anterior horn, mid body and posterior horn were 5.32 mm, 5.03 mm and 5.53 mm respectively. For the lateral meniscus, thickness at anterior horn, mid body and posterior horn were 4.33 mm, 4.94 mm and 5.36 mm respectively indicating the posterior horn of both MM and LM were thickest.⁹⁰

A study on fetus menisci reports the anterior third of the medial meniscus was the thickest part compared to posterior and middle thirds. No statistically significant difference was observed in relation to the thickness of the anterior, middle and posterior thirds of lateral meniscus.⁹³

Comparison of the thickness of the MM and LM with data from literature

Parameters in mm	Almeida et al ¹⁰	Braz et al ⁹²	Present Study
Thickness of MM at ant 1/3	5.92 ± 1.37	6.31 ± 1.73	4.1 ± 0.75
Thickness of MM at mid 1/3	5.31 ± 1.06	6.17 ± 1.68	4.2 ± 1.01
Thickness of MM at post 1/3	5.91 ± 1.13	5.18 ± 1.55	4.5 ± 0.72
Thickness of LM at ant 1/3	3.71 ± 1.15	4.40 ± 0.83	3.9 ± 1.07
Thickness of LM at mid 1/3	6.10 ± 1.04	6.52 ± 1.81	4.3 ± 1.32
Thickness of LM at post 1/3	5.29 ± 0.78	5.46 ± 1.19	4.8 ± 1.89

Distance between anterior and posterior horns

In our study the distance between anterior and posterior horns was greater for MM ($28.2 \pm 5.45\text{mm}$) than LM ($11.9 \pm 2.78\text{mm}$) and the difference was statistically significant ($p < 0.05$) (Table 6, Graph 11). Within the group comparison of distance between AH and PH of right and left side MM and right and left side LM did not show any significant difference (Table 1 & 2).

Results of our study and the other two studies also suggest that the distance between the anterior and posterior horns of the lateral meniscus is less than medial meniscus.^{10, 92} Study done on fetus also correlates with our findings showing the distance between the anterior and posterior horns of the medial meniscus ($3.79 \pm 0.89 \text{ mm}$) which was significantly more than the lateral meniscus ($1.56 \pm 0.61\text{mm}$).⁹³

Literature reports that the horns of the lateral meniscus are closer together than those of the medial meniscus, due to the fact that the lateral meniscus has the form of an almost complete ring, whereas the medial is more like a half-moon. This high proximity between the insertions of the horns of LM would be one of the reasons for the lateral meniscus to be less prone for lacerations.⁹⁴

Comparison of the distance b/w AH and PH of menisci with data from literature

	Medial Meniscus	Lateral Meniscus
Almeida et al ¹⁰	29.70 ± 4.12	12.71 ± 1.84
Braz et al ⁹²	25.88 ± 3.33	12.55 ± 1.98
Present study	28.2 ± 5.45	11.9 ± 2.78

CONCLUSION

After studying 120 specimens of adult menisci from 60 knee joints the following conclusions were drawn.

1. In most of the specimens the medial meniscus was crescentic in shape (96.66%).
2. The most common shape of the lateral meniscus was 'C' shape (88.33%).
3. Incomplete lateral discoid menisci were observed in 5% of lateral meniscus. No complete discoid medial or lateral menisci were observed in specimens.
4. The peripheral length of the medial meniscus was greater than the lateral meniscus ($p < 0.05$).
5. The inner border length of the medial meniscus was greater than the lateral meniscus ($p < 0.05$).
6. In anterior and middle thirds, lateral meniscus was wider than the medial meniscus ($p < 0.05$), but in posterior third region medial meniscus was wider than lateral meniscus ($p < 0.05$).
7. Statistically significant difference was not observed among the thicknesses of anterior, middle and posterior thirds of lateral and medial menisci ($p > 0.05$).
8. The distance between the anterior and posterior horns of medial meniscus was greater than that of the lateral meniscus ($p < 0.05$).
9. Statistically significant differences were not found for the various morphometric parameters of the menisci between right and left knees ($p > 0.05$), except for the peripheral length of the medial menisci which was more on the left side ($p < 0.05$).
10. The present study provides additional information on different shapes and measurements of the medial and lateral menisci with contribution to a better

description of meniscal anatomy and implications in regard to allograft meniscus transplantation.

11. This study is useful for the health professionals who work with the treatment of meniscal injuries to create an awareness of the anatomical variations that may exist in the menisci facilitating the rehabilitation process.
12. With the above findings, present study proposes that future studies should be undertaken involving the measurement of volume of the meniscus and to assess any gender differences in the morphometry of menisci.

SUMMARY

The primary objective of this cross sectional study was to analyze the thickness, the width, peripheral and inner border lengths, distance between anterior and posterior horns and shape of the adult menisci and to compare with that of meniscal parameters which are available in the literature. The secondary objective was to gather information about anomalies and variations encountered, if any which may prove valuable in clinical and orthopaedic procedures.

The morphometric study was conducted on 120 specimens of menisci from 60 adult knee joints. After dissecting individual knee joint meticulously the shape of the menisci and variations were observed and all the other parameters were analysed.

The obtained results of the study were tabulated and compared with the available literature. 96.66% of the medial menisci were crescentic shaped, 1.66% of the medial menisci were sided V shaped and 1.66% of the medial menisci were sickle shaped. No discoid medial menisci were seen. 88.33% of lateral menisci were C shaped, 6.66% were sided U shaped and 5% of them were incomplete discoid shaped. No complete discoid lateral meniscus was observed. The peripheral and inner border length of medial menisci were higher than lateral menisci. In anterior and middle thirds, lateral meniscus was wider than the medial meniscus but in posterior third region medial meniscus was wider than lateral menisci. No significant difference in thicknesses of anterior, middle and posterior thirds of lateral and medial menisci was found. The distance between the anterior and posterior horns of medial meniscus was greater than that of the lateral meniscus. All the above findings correlated with the available data from the literature.

These findings are of clinical significance to orthopedic surgeons as the clinical treatment of meniscal tear needs a prior basic knowledge about its anatomy and its variations. Since the size of the meniscus is related to its function, any procedure to replace the cartilage must be accompanied by measurement techniques to determine meniscal size. Accurate measurement would be helpful as a clinical evaluation tool for meniscal replacement and regeneration techniques adopted in orthopedic surgeries. Hence our study adds to the knowledge about morphometric variations of menisci in people of North Karnataka.

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Proforma of the Study

1. Specimen Number:
2. Side of the Joint:
3. Meniscal Parameters (measurements taken in mm):

		Medial Meniscus	Lateral Meniscus
a. Shape		Crescentic	Crescentic
		Sided V	Sided V
		Sided U	Sided U
		Sickle	Sickle
		C shaped	C shaped
		Discoid	Discoid
		Incomplete Discoid	Incomplete Discoid
b. Peripheral length			
c. Inner border length			
d. Width at the midpoint of	Ant 1/3		
	Mid 1/3		
	Post 1/3		
e. Thickness at the midpoint of	Ant 1/3		
	Mid 1/3		
	Post 1/3		
f. Distance b/w anterior & posterior horns			

MASTER CHART

ANNEXURE I

Adult Specimens		Side	Menisci Shape	length (mm)		Width (mm) at			Thickness (mm) at			Dist. b/w AH & PH(mm)
Sl.No	Specimen No			PL	IBL	Ant 1/3	Mid 1/3	Post 1/3	Ant 1/3	Mid 1/3	Post 1/3	
1	1	Lt	Crescentic	100	62	9	11	18	5	7	4.5	33
2	2	Lt	Crescentic	100	70	8	9	16	7	6	5	31
3	3	Rt	Crescentic	104	61	6	6	8	4	3	3	30
4	4	Lt	Crescentic	130	56	10	11	9	5	4	5	25
5	5	Rt	Crescentic	128	58	9	12	10	6	4	5	26
6	6	Rt	Crescentic	106	64	7	5	13	5	4	3	34
7	7	Lt	Crescentic	98	58	5	7	8	4	5	6	28
8	8	Lt	Crescentic	120	70	4	5	13	4	5	4.5	40
9	9	Lt	Crescentic	110	68	7	8	10	4	3	4.8	38
10	10	Lt	Crescentic	106	62	4	5.6	12	3	4	6	35
11	11	Lt	Crescentic	92	64	6	7	10.2	4.4	3.9	4.2	28
12	12	Lt	Crescentic	106	64	6	6	16	4	4.6	4.4	36
13	13	Rt	Crescentic	100	68	6	5.6	12	4	3	5	34
14	14	Rt	Sickle	110	86	4	5	14	5	8	5	44
15	15	Rt	Crescentic	92	78	7	7.6	16	4	4.8	5	36
16	16	Rt	Crescentic	88	55	6	7	14	3	3	5	26
17	17	Rt	Crescentic	78	58	7	7.6	14	4	4.6	5	36
18	18	Lt	Crescentic	104	82	7	8	13	4	4.6	4.2	40
19	19	Rt	Crescentic	88	58	6	7.6	12	3.8	4	4.2	34
20	20	Lt	Crescentic	101	76	7	6	14	4	4.8	5	28
21	21	Lt	Crescentic	101	70	7	6	13	3	3	4	28
22	22	Lt	Crescentic	98	65	5	6	17	3	4	6	25
23	23	Lt	Crescentic	104	67	5	6	8	4	4	5	28
24	24	Rt	Crescentic	101	60	7	5	11	4	4	5	32
25	25	Lt	Crescentic	92	50	7	7	12	4	4	5	23
26	26	Lt	Crescentic	90	48	9	9	11	3	5	4	26
27	27	Rt	Crescentic	93	48	6	7	11	4	4	5	30
28	28	Rt	V shaped	97	57	8	8	13	3	3	6	28
29	29	Rt	Crescentic	102	55	7	9	11	4	5	5	24
30	30	Rt	Crescentic	93	58	5	6	10	3	4	4	23

MASTER CHART

ANNEXURE I

Adult Specimens		Side	Menisci Shape	length (mm)		Width (mm) at			Thickness (mm) at			Dist. b/w AH & PH(mm)
Sl.No	Specimen No		MM Shape	PL	IBL	Ant 1/3	Mid 1/3	Post 1/3	Ant 1/3	Mid 1/3	Post 1/3	
31	31	Rt	Crescentic	98	58	8.5	7.6	14.1	4	3.7	4.6	26
32	32	Lt	Crescentic	101	57	8	7.5	12	4	4.2	4.6	22
33	33	Rt	Crescentic	97	53	7	6.5	13	4	4	3.8	22
34	34	Lt	Crescentic	98	53	8	8	12	4	4	5	27
35	35	Rt	Crescentic	101	61	9	8.8	14	4	4	5	27
36	36	Rt	Crescentic	94	52	7	6.8	13	4.8	4.3	4	21
37	37	Lt	Crescentic	101	55	8	7.3	12	4	3	4.2	19
38	38	Rt	Crescentic	95	52	7	6.5	13	4	3	4.4	24
39	39	Lt	Crescentic	104	58	8	7.7	12	5	4	4	21
40	40	Rt	Crescentic	99	53.5	7	7	9	4	3.8	4	21
41	41	Rt	Crescentic	92	47	8.5	8	11.5	3	5.5	4	27
42	42	Lt	Crescentic	97	59	6	6	9	4	4	5	24
43	43	Lt	Crescentic	98	57	9	8	11	4	3	4	23
44	44	Lt	Crescentic	91	76	7	6	14	4	5	5.6	32
45	45	Lt	Crescentic	120	56	9	10	10	5	4	5	24
46	46	Lt	Crescentic	102	58	7	6.8	8.5	4	3	4	28
47	47	Rt	Crescentic	102	68	8	9	15	5	4	5.2	29
48	48	Rt	Crescentic	97	59	9	8.3	15	5	6.5	4	32
49	49	Lt	Crescentic	101	59	7	6.8	10	4	4	3	29
50	50	Lt	Crescentic	98	64	6	5	12	4	4	5	28
51	51	Rt	Crescentic	97	54	8	8.5	10	4	3	4	24
52	52	Rt	Crescentic	93	57	6	6.2	15	4	4.5	4	24
53	53	Rt	Crescentic	98	65	6	5	7	4	4	3.6	26
54	54	Rt	Crescentic	90	48	5	6	11	4	5	4	21
55	55	Rt	Crescentic	97	53	7	8	11	3	4	4.2	20
56	56	Rt	Crescentic	95	49	7	7.4	11	3.8	4	4.5	25
57	57	Lt	Crescentic	103	63	10	9	15	4	3	4	28
58	58	Lt	Crescentic	106	69	9	8.5	14	5.5	4	5	30
59	59	Lt	Crescentic	99	62	10	9	16	5	6	4	34
60	60	Lt	Crescentic	95	49	9	8	11.8	4	4.2	4	29

MASTER CHART

ANNEXURE I

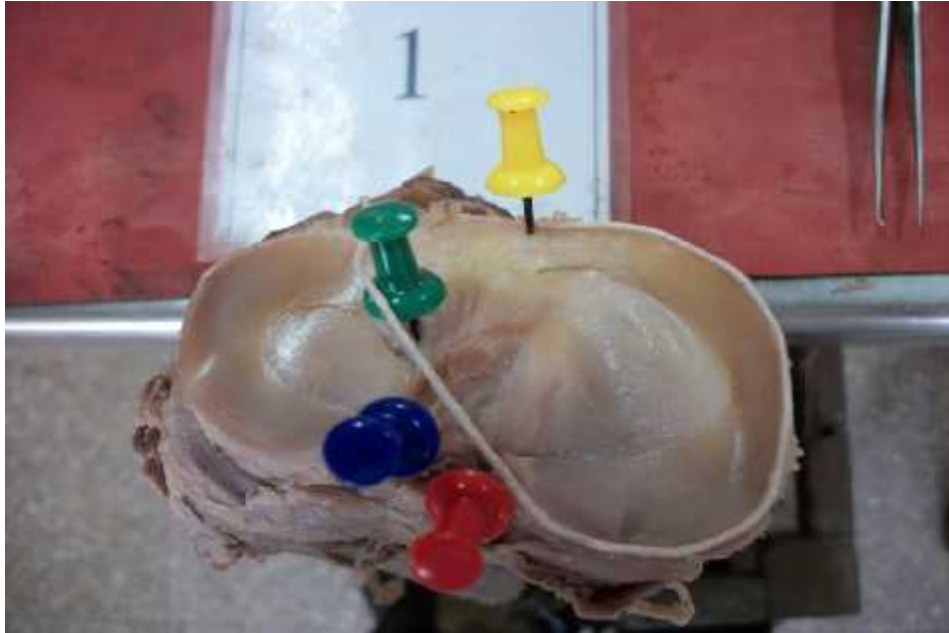
Adult Specimens		Side	Menisci Shape	length (mm)		Width (mm) at			Thickness (mm) at			Dist. b/w AH & PH(mm)
Sl.No	Specimen No			LM Shape	PL	IBL	Ant 1/3	Mid 1/3	Post 1/3	Ant 1/3	Mid 1/3	
1	1	Lt	C shaped	97	48	9	18	14	3	5	5	10
2	2	Lt	C shaped	96	52	12	14	13	4	7	7	13
3	3	Rt	C shaped	97	58	10	11	12	4	5	7	18
4	4	Lt	C shaped	86	46	9	10	10	1	3	4	12
5	5	Rt	U shaped	89	46	9	11	10	1	3	2	14
6	6	Rt	U shaped	91	58	8	12	10	5	6	7	16
7	7	Lt	C shaped	82	56	6	7	7	4	3	4	18
8	8	Lt	C shaped	86	58	5	6	5	4	6	5	18
9	9	Lt	Incomplete Discoid	88	56	9	8	9	4	3.9	4	7
10	10	Lt	C shaped	70	52	7	6	7	4	3	4	7
11	11	Lt	C shaped	74	50	9.2	8.4	10.3	4	4.3	4.8	14
12	12	Lt	C shaped	88	54	8	7	8.6	4	3.8	4	10
13	13	Rt	C shaped	92	50	4	6	5	4	4.8	4	10
14	14	Rt	C shaped	98	76	8	8.6	9	4	4.8	5	16
15	15	Rt	C shaped	88	68	8	8.2	8.6	5	5.2	4.8	16
16	16	Rt	C shaped	78	48	6	7	7	3	4	4	10
17	17	Rt	C shaped	60	32	5	5.8	5	3.8	4.2	4	5
18	18	Lt	C shaped	72	56	8	8.6	8.4	5	4.8	5.2	12
19	19	Rt	Incomplete Discoid	64	38	10	15	14	4	4.8	4.2	4
20	20	Lt	C shaped	90	46	8	13	8	6	5.8	16	12
21	21	Lt	C shaped	90	40	8	13	7	4	5	4	14
22	22	Lt	C shaped	97	60	8	10	11	6	5	6	13
23	23	Lt	U shaped	92	44	6	10	9	3	6	6	12
24	24	Rt	U shaped	95	50	8	13	10	4	7	6	10
25	25	Lt	Incomplete Discoid	88	46	9	10	11	4	5	6	13
26	26	Lt	C shaped	79	43	8	9	8	4	5	4	10
27	27	Rt	C shaped	90	40	9	13	11	3	4	4	10
28	28	Rt	C shaped	88	45	9	9	10	4	3	5	9
29	29	Rt	C shaped	90	40	5	6	6.8	9	11	10	11
30	30	RT	C shaped	82	41	16	8	9	3	4	5	10

MASTER CHART

ANNEXURE I

Adult Specimens		Side	Menisci Shape	length (mm)		Width (mm) at			Thickness (mm) at			Dist. b/w AH & PH(mm)
Sl.No	Specimen No		LM Shape	PL	IBL	Ant 1/3	Mid 1/3	Post 1/3	Ant 1/3	Mid 1/3	Post 1/3	
31	31	Rt	C shaped	89	50	9.6	8.4	10.4	4	4.5	4	12
32	32	Lt	C shaped	93	56	10	9	9.5	4	3.8	4	13
33	33	Rt	C shaped	91	51	9	8	11	4.5	3	4	10
34	34	Lt	C shaped	93	51	10	8.5	9	4	3	4	13
35	35	Rt	C shaped	92	58	9.8	9	9.5	4	3.9	4	12
36	36	Rt	C shaped	90	48	8.5	8	9.8	3	4	4	13
37	37	Lt	C shaped	89	56	9	8.8	9.7	4	3.8	4	12.5
38	38	Rt	C shaped	87	47	7.6	7	9	3	4	4	11
39	39	Lt	C shaped	92	51	7	6	9	4	3	4	12
40	40	Rt	C shaped	91	56	8	7.8	10	3	3.6	4	12
41	41	Rt	C shaped	81	47	8	9	10	4	4.5	4	11
42	42	Lt	C shaped	83	44	14	9	10.5	3	4	4	11.5
43	43	Lt	C shaped	91	55	9.8	9	8.5	3	4	3	12
44	44	Lt	C shaped	86	66	8	7	8.8	4	3.9	4	14
45	45	Lt	C shaped	87	48	11	9	10	3	3	4	13
46	46	Lt	C shaped	96	54	9	8	12	4	5	5.8	14
47	47	Rt	C shaped	94	50	11	10	11	4	3	4.4	12
48	48	Rt	C shaped	95	44	8	13	12	3	4	4	11
49	49	Lt	C shaped	98	59	11	9	13	4	5	6	19
50	50	Lt	C shaped	90	52	5	6	5	4	4	4.8	11
51	51	Rt	C shaped	91	52	11	8.6	9	3	4.2	4	12
52	52	Rt	C shaped	90	56	9.2	10.5	11	4	3	6	12
53	53	Rt	C shaped	91	43	6.8	10	9.5	3	5	4.5	11
54	54	Rt	C shaped	84	44	7	8	11	4	4.8	5	12
55	55	Rt	C shaped	89	52	9	8	8	4	3	4	10
56	56	Rt	C shaped	89	48	8	7.5	9	4	3	4	11
57	57	Lt	C shaped	95	59	9	9	10	4	3.5	3	11
58	58	Lt	C shaped	96	54	12	11	11	4	3	4	13
59	59	Lt	C shaped	97	47	9	12	13	4	4	5	13
60	60	Lt	C shaped	84	48	9	8	10	4	4	5	10

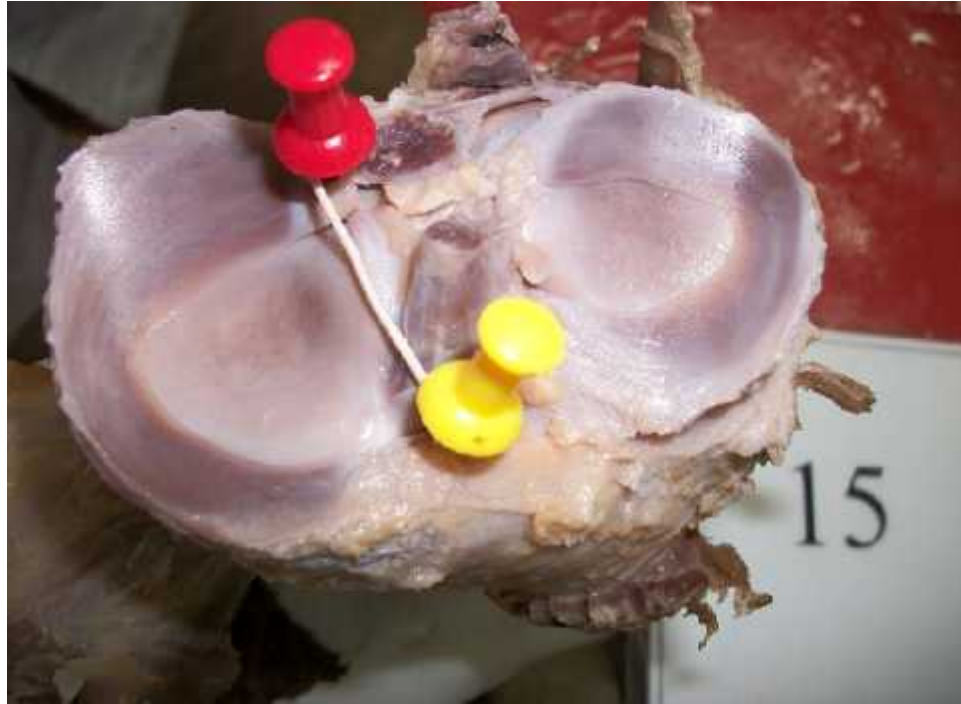
PHOTOGRAPHS



Photograph 1. Measurement the length of peripheral border of meniscus



Photograph 2. Measurement of the length of inner border of meniscus



Photograph 3. Measurement of the distance between anterior & posterior horns of meniscus



Photograph 4. Showing the division of meniscus into ant1/3, mid1/3 & post 1/3



Photograph 5. Measurement of the width at mid 1/3 of meniscus



Photograph 6. C shaped lateral meniscus



Photograph 7. Incomplete discoid lateral meniscus



Photograph 8. U shaped lateral meniscus



Photograph 9. V shaped medial meniscus



Photograph 10. Sickle shaped medial meniscus



Photograph 11. Crescentic shaped medial menisci