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Research Article

Comparative Anatomy of Knee Joint: Class Amphibian (Frog) versus Class Mamalia (Human Being)

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Abstract: The knee joint is the largest synovial joint in the body and most vulnerable to osteoarthritis, ligament & menisci damage. The joint was constructed by nature for the four, footed position (for tetrapod) and not for one in which end of femur bears directly in a vertical manner upon the end of tibia due to the assumption of the upright erect posture of man during evolution. Though not a very will fitting joint and in spite of being under load during locomotion still it functions perfectly. Understanding a bio-mechanical system as complex as the human knee may be made easier by studying the analogues structure in the limbs of other animals. In the present study an attempt has been made to study in detail the structural similarity and variations and correlate the possible functional significance of this morphological variation of knee joint in the animal from main line of ascend of phylogenetics development class amphibian, order anura (frog) to class mamalia,order primates (human being).
Keywords: Knee joint, Bony articular part, Intracapsular structure, Extracapsular structure, Frog,Human being.

INTRODUCTION

The manner in which the main articulations of the vertebrate have become variously modified in relation to diverse function has been investigated by many workers, notably, Parsons [1], Herzmark [2] and Haines [3]. The morphology of the knee joint of human has been studied in great detail[4,5,6], but the morphology of other animals is not completely studied and comparison of structural variation with functions is not attempted is any great detail.

The knowledge gained by comparative transaction of the knees in various species could lead to the discovery of more adequate animal model for studies of the knee and its functional mechanisms. The study of comparative anatomy [7,8,9] and evolution of the complex structure of the knee [2,10] may have a practical clinical application in the improvement of the ligamentous reconstructions and designs for total knee replacement [11].

The purpose of this article is to study and compare the morpholgy of knee joint of Tetrapod (Frog) - class-amphibia, order anura to Human beings class-mamalia order – primates. When the frog's leg is stretched back parallel to the longitudinal axis of the body, as in the act of swimming, it presents the ventral and dorsal surfaces, an outer border along which is the projection of the knee, and an inner border along the bend of the knee. The outer border, which corresponds to the front of the leg in man, is called the extensor surface, in as much as the muscles which extend or straighten the leg lie along this edge. The inner border is the flexor surface. The "Ventral"and "dorsal" surfaces only appear to be such in consequence of the extreme obliquity of the pelvic girdle. They are really anterior and posterior, and are better called preaxial and postaxial: they correspond respectively to the inner and outer surfaces of the human leg [12].

The posterior limb of frog is extended at right angle with the truck and is usually of the typical tetrapod type with a single bone, the femur, in the first segments; two rather similar bones, the tibia and fibula in the second segment; and, the tarsals and foot bones in the third segment. The long bones of the first and second segments do not show much specialization as in the higher vertebrates [13]. The distal end of femur is expanded laterally to form the trochlea. The shank (knee) consists of tibio-fibula which is longer than the femur. It is formed as a result of fusion of two bone, the tibia and Fibula in anura [14].

An attempt has been made to relate the structure and properties of the principal extensor muscles and bones of the frog leg, to their performance in jumping and swimming by various workers [15, 16].

In the knee joint of the anura Rana anteriorly three muscles arises from the femur-extensor cruris brevis, tibialis anticus longus and peroneus, corresponding to the crural extensor and peroneal musculature of other tetrapods. The true cavity of the knee joint lies posterior to these structures. The collateral ligaments are strong bands. In the knee joint cavity, the two menisci are firmly united both anteriorly and posteriorly to each other. The Medical meniscus is attached to the tibio-fibula by an anterior menisco-tibial ligament, while posteriorly both are attached to the inter condylar region of the tibia. Laterally, a small menisco – femoral ligament connects the lateral meniscus with the femur. The expanded tendon of origin of the m.peroneus is attached near its lateral margin to the lateral meniscus. Posteriorly the m. semimembranosus entirely, and the m.plantaris longus in part, are attached to the menisci. There is only one cruciate ligament. It is a large wide mass of fibrous tissue surrounded by the joint cavity on all sides [17].

The knee of a frog exhibit many similarities to the human knee except absence of patella and popliteus muscle. The femoro tibial articulation has both internal and external ligamentous connection and menisci. There is a single broad intra articular Ligaments that may represent the initial form of the cruciate ligament of extinct amphibians (Proto-Cruciate ligament). The medical collateral ligament is relatively broad and is inserted distally on the proximal part of the tibia. The lateral collateral ligament is more rounded in cross section and is inserted on the lateral aspect of the proximal part of the tibia the fibula having merged with the tibia [10].

MATERIALS AND METHODS

The study material consist of ten knee joints of frog collected from the animal house department of pharmacology and ten knee joint of human being from dissection hall department of Anatomy, TMU, Moradabad, India. All the animals were sacrificed,with prior clearance from ethical committee, *Teerthanker Mahaveer University* after giving Euthanasia dose of phenobarbitone and preserved in 10% buffer formalin. After stepwise disection the morphological study of knee joint was carried out under the following headings.

- Articular surface
- Muscle
- Collateral ligaments
- Fibrous capsule
- Cruciate ligament
- Menisci

OBSERVATION

Articular surfaces (figure 1a, 1b)

Distal end of femur: In frog the lower end of femur on its inferior aspects show poorly developed condyles separated by ill defined groove. The medial condyle is less prominent and flat while the lateral condyle is more prominent and expanded laterally to form the trochlea [13]. In human the distal end of femur on anterior aspect has a smooth articular surface over which the patella glides. Posterior to this are smooth, lateral and medial condyles for the articulation with the tibia, the rough elevation above each condyles are the epicondyles. The rough inter condylar fossa lies between the two condyles [4].

Upper end of tibia: The tibio-fibula in frog is a single bone, longer then the femur, slightly curved expanded and flattened at it either ends. It presents along the greater part of its length a groove indicating its formation by two bones, the tibia and the fibula [13, 14]. The upper end of tibia in human being is approxiamately triangular in shape. It has a pair of condyles for articulation with the femur and the anterior tuberosity for the attachment of patellar ligament. In between two condyles the inter condylar eminence is present. Its shaft has a prominent tibial crest which is continous from the tuberosity. A circular facet, the fibular facet is present on the inferior aspect of its overhanging posterolateral part and articulates with the head of the fibula [15]. In human being the fibula is separate and slender bone. It is outside the knee joint, the head of the fibula is slightly expanded and is attached to the lateral condyle of tibia [4].

Patella: Osseous patella is absent in frog. A large thick and well developed patella is observed in human being [4, 6].

Fig. 1A &1B: Bony characteristics photography showing distal end of femur, upper end of tibia, upper end of fibula of frog and man

Muscles

Quadriceps femoris: Is the main extensor of the knee joint. The origin of the muscle seems to vary from one species to another. As the name suggest the muscle take origin by four heads in human beings[4] while only three heads of origin was observed in frog in the present study similar finding was noted by Holmes S.J.[15] who named the muscle as triceps femoris and Venden Berge[18] who named it as femorotibialis.

Sartorius: is a superficial muscle situated in front of thigh in both frog and human being, running from the superiolateral angle to the inferomedial angle of thigh and acts as a flexor of hip and knee joint

The semimembranosus and semitendinosus: These muscles are the members of the hamstrings group. They are the muscle of the flexer compartment of the thigh. In the present study in both frog and human beings the muscle arises from the lower medial part of ischial tuberosity. The tendon of muscle is cord like and lies on the semimembranosus and gets inserted into upper part of the medial surface of tibia.

The semimembranosus muscle arises from the upper and lateral part of the ischial tuberosity and gets inserted into back of the medial condyle of tibia. The muscles are flexer and medial rotator of leg and extensor of hip joint [4, 15].

The biceps femoris muscle in human beings has two heads of origin while in frog has only one head of origin. In frog the muscle arises from the posterior surface of iliac crest and inserted on the back of the lateral condyles of the tibia [4, 15].

Popliteus: In the present study, the popliteus muscle is not seen in Frog, similar finding were observed by Dye scoti [10]. In human being the muscle takes origin within the capsule of joint from the caudal surface of lateral condyle of femur and get inserted into the upper part of the back of the tibia above the soleal line and acts as a a flexor of knee joint and tend to rotate the limb medially [19].

Gastrocnemius: In human being the tendo calcaneous get inserted on the posterior surface of calcaneous but in the frog it was observed that the tendo calcaneous wind around the ankle joint and is inserted in the planter apneurosis, which inturn makes connection with the planter aspect of toes [4, 15].

Extensor Digitorum Longus: In frog the muscle takes origin from the small fosse on the lateral femoral condyle and get inserted into the middle and distal phalanges of the outer four toes. In amphibian protraction of the hind foot in motion with simultaneous of knee and tarsus is apparently due to the contraction of the extensor digitorum longus.

In man the origin of the muscle slips down the femur and originates from the lateral condyle of tibia, upper three-forth part of the anterior surface of the shaft of the fibula and also from the interroseus membrane and get inserted into the medial and distal phalanges of the outer four toes.[1,20,21].

Table 1: Showing origin and insertion of various muscles acting of knee joint of species (frog) and human being

	Quadriceps femoris		**Sartorius**		**Semitendinosus**		**Semimembranosus**	
Animal	**Origin**	**Insertion**	**Origin**	**insertion**	**Origin**	**insertion**	**origin**	**insertion**
Frog	3 Head from ileum	Tibio fibula upper end	Ant. Superior iliac spine	Post medial surface of tibia	Ischial tuberosity	medial surface of tibia	Ischial tuberosity	Back of medial condyle of tibia
Human	4 head, 3 vasti-femur, R. femories –ileum	Patella	Ant. Superior iliac spine	Post medial surface of tibia	Ischial tuberosity	Post medial surface of tibia	Ischial tuberosity	1. Back of medial epicondyle of femur. 2. medial condyle of tibia
	Biceps femoris		**Popliteus**		**Gastrocnemius**		**Ext. digilongus**	
Animal	**Origin**	**Insertion**	**Origin**	**insertion**	**Origin**	**insertion**	**origin**	**Insertion**
Frog	Post. Aspect of iliac crest	Back of lateral tibial condyle	Absent	absent	2 heads back of medial, lateral femoral condyle	Planter aponeurosis of foot	Ant. Surfaces of lateral femoral condyle	Dorsal aspects of bases of distal phalanges of digits 2-5 metatarsus

Human	1.ischial tuberosity and sacro tuberous ligament 2.upper part of lat. Supra condylar line and lateral inter muscular septum	Upper and lateral part of head of fibula	Lat. Aspect of lat. Femoral condyle	Back of tibia above the soleal line	2 heads medial and lateral femoral condyle	Calcaneal tuberosity	Med. Surfaces of fibula	Dorsal aspects of prox, mid and distal phalanges of digits 2-5

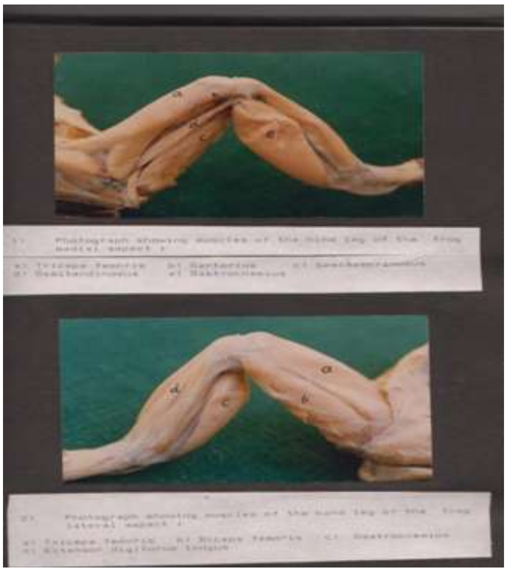

Fig. 2A & 2B: Photograph showing muscles of hind limb of the frog

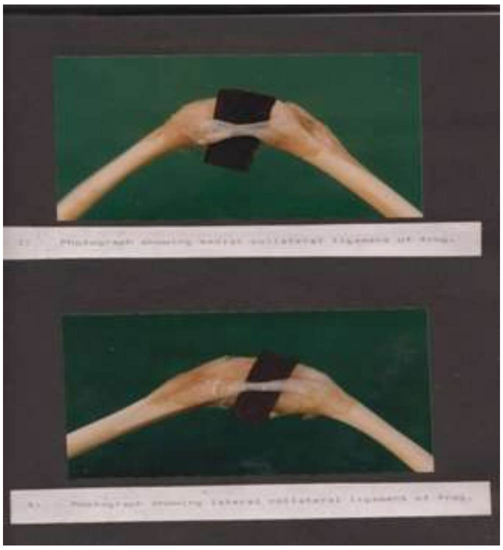

Fig 3A & 3B: Photograph showing medial and lateral collateral ligament of frog

Collateral Ligament (Table 2 & Figure 3A, 3B)

Asymmetrical i.e. longer medial and shorter lateral collateral ligaments were observed in both frog and man. In frog the proximal attachment of medial and lateral collateral ligament is to the medial and lateral condyle of femur while the distal attachment of medial and lateral collateral ligament is to medial and lateral aspect of the proximal part of tibia. In human being the two ligaments are superiorly attached to the medial and lateral epicondyle of the femur and inferiorly the medial ligament is attached to the medial condyle of tibia, the proximal part of medial surface and medial border of tibia. The distal attachment of lateral collateral ligament is to the styloid process and adjoining part of fibula .The anterior margin of medial collateral ligament is free whereas the posterior margin is attached to the medial meniscus. Due to this, the rupture of the medial meniscus is more common with the injury of medial collateral ligament [22].

Fibrous capsule: In the knee joint, the fibrous capsule is deficient in front in human being as its place is taken by the quadriceps tendon, the patella, the medical & lateral patellar retinaculi and the patellar ligament. As the patella is absent in frog, fibrous capsule surrounds the whole knee joint and is attached all along the periphery beyond articular area of lower end of femur and upper end of tibia [23, 24].

Table 2: Showing attachment of collateral and cruciate ligament

	Medial collateral ligament		**Lateral collateral ligament**		**Anterior cruciate ligament**		**Posterior cruciate ligament**	
Animal	**Proximal attachment**	**Distal attachment**	**Proximal attachment**	**Distal attachment**	**Distal attachment**	**Proximal attachment**	**Distal attachment**	**Proximal attachment**
Frog	Medial condyle of femur	Medial aspect of proximal part of tibia	Lateral condyle of femur	Lateral aspect of proximal part of tibia	Anterior intercondylar area of tibia	Post part of lateral wall of inter condylar fosse of femur	Absent	Absent
Human	Medial epicondyle of femur	Medial condyle Proximal part of medial surface and medial border of tibia	Lateral epicondyle of femur	Styloid process and adjoining part of head of fibula	Intermediate rough area on the proximal surface of tibia	Post part of lateral wall of inter condylar fosse of femur	Post part of post intercondylar area of the tibia	Anterior part of medial wall of intercondylar notch of femur

Cruciate ligament (Table 2 & Figure 4A & 4B)

In the frog knee joint a single intra articular ligament is observed[10].Distally it is attached to the anterior tibial intercondlyler area and partly attached to the anterior horn of lateral meniscus and promimally attached to the posterior medial aspect of the lateral femoral condyle. In human being two cruciate ligaments are observed inside the joint . The anterior cruciate ligament is attached below to the intermediate rough area of the proximal surface of the tibia just in front of the anterior attachment of lateral menisci. Above it is attached to the posterior part of medial surface of the lateral condyle of femur. The posterior cruciate ligament is attached below to the posterior part of the posterior intercondylar area of the upper end of the tibia. Above it is attached to the anterior part of the lateral surface of medial condyle of femur. It crosses the anterior cruciate ligament from the medial side [25].

Fig. 4A & 4B: Photograph showing (4A) mensci and (4B) cruciate ligament of frog

Menisci (Table 3, Figure 4A & 4B)

In frog to 'c' shape menisci firmly united both anteriorly and posteriorly are observed. Anteriorly the medial meniscus is attached to the tibia by An anterior menisco tibial ligament. Posteriorly both are attached to the intercondyler region of the tibia. Laterally the lateral menicus is connected with the femur by the small menisco femoral ligament [2].

In human being, the medial semilunar cartilage is somewhat oval in shape while the lateral semilunar cartilage is circular in shape. The anterior and posterior ends of the lateral menisci come much more nearer to each other. They lie in between anterior and posterior end of medial meniscus. Both the menisci are attached to the anterior and posterior intercondylar area of the tibia by means of their anterior and posterior horn respectively. The anterior fasiculus (Hamphry's ligament) exists only in man [23-28].

Table 3: Showing attachment of menisci

	Medial meniscus		**Lateral meniscus**	
Animal	Attachment of anterior horn	Attachment of posterior horn	Attachment of anterior horn	Attachment of posterior horn
Frog	Anterior intercondylar area of tibia	Posterior intercondylar area of tibia	Free connection with medial meniscus by transverse ligament	Posterior inter condylar area of tibia
Human	Anterior intercondylar area of tibia	Posterior intercondylar area of tibia	Anterior inter condylar area of tibia	Posterior inter condylar area of tibia

DISCUSSION

The structure of the feet & legs varies greatly among frog species depening in part on whether they live primarily on the ground, in water, in trees or in burrows. Frogs must be able to move quickly through their environment to catch pry & escape predators and numerous adaptation help them to do so. The frog's powerful hind legs are adapted for both swimming & leaping. Most frogs are proficient at jumping. The tibia, fibula and tarsal have been fused into a single, strong bone for absorbing the impact on landing. The metatarsals have become elongated to add to the leg length & allow the frog to push against the ground for a longer period on take-off. The illium has elongated & formed a mobile joint with the sacrum which in specialist jumpers such as ranids & hylids functions as an additional limb joints to further power the leaps. The tail vertebrae have fused into a uro-style which is retracted inside the pelvis. This enables the force to be transferred from the legs to the body during a leap.

The muscular system has been similarly modified. The hind limbs of ancestral frogs presumably contained pairs of muscles which would act in opposition one muscle to flex the knee, a different muscle to extend it, as is seen in most other limbed animals. However, in modern frogs, almost all muscles have been modified to contribute to the action of jumping with only a few small muscles remaining to bring the limb back to the starting position & maintain posture [16]. The muscles have also been greatly enlarges, with the main leg muscles accounting for over 17 % of the total mass of the frog. The strong extensor muscles of the thigh contract, extending the limb & thrusting the foot against the ground or against the water. The thrust is transmitted through the body of the frog by the pelvic girdle and the spine so that the whole animal is pushed forward in the water. The webbed hind feet provide a greater surface area for pushing backwards on the water. The smaller fore - limbs help to steer when the frog is swimming and absorb the shock of landing after a jump on land. On moving from water to land or over rough ground the frog will crawl rather than leap.

During early stages of development, the lower limb buds in human beings rotate medially through 90o,so that their preaxial or tibial border faces medially and the extensor surface forward. The antigravity muscles in the lower limb of human being are much better developed than in frog because they have to lift the whole body up during attaining the erect posture and also in walking up the staircase. These muscles are the gluteus maximus – extensor of hip, the quadriceps femoris-extensor of knee and the gastrocnemius and soleus – plantar flexors of ankle. They have an extensive origin and a large, bulky fleshy belly [29]. The largest muscles in the hind limb of quadrupeds are those which acts on two or more joint, while the one joint muscles predominate in lower limb of man [8].

Human is the only mammal to assume completely erect posture, and the knee joint is completely extended while bearing the weight of the body. The condyles of both the femur and the tibia are largest and affords extra surface of weight bearing and adds to stability. The fibula or the postaxial bone of the leg does not take part in the formation of knee joint. The patella or the knee cap, a large sesamoid bone developed in the tendon of quadriceps of femoris moves into a position directly above the joint line when the knee is fully extended. The collateral and the cruciate ligaments provides stability to the knee joint. The menisci in human being are proportionately much larger and suppose to be very important structure for weight bearing joint[2]. Thus the integrity of the knee joint depends upon the muscles and the tendons about the knee, the articular capsule, the intrinsic ligaments of the joint and the bony architecture of the tibia and the fibula [22].

Though there are lot many similarity in origin, insertion and action of various muscle acting on the knee joint some of the differences observed in frog are like the quadriceps femoris muscle in frog has three heads of origin instead of four heads of origin as in man similarly the bicep femoris muscle takes origin by only one head in frog whereas in human being it has two heads of origin. In frog it gets inserted on the back of the lateral condyle of the tibia as frog leg has only one bone tibio fibular. In human being the muscle get inserted on the lateral part of the head of fibula. The popliteus muscle is absent in frog as probably this animal do not require medical rotation in their normal locomotion. The gastrocnemus muscle in human being gets inserted into middle of the posterior surface of calcaneous and causes flexion of the knee and planter flexion of the foot, the muscle raises the heel during walking in man but in frog due to the shifting of the insertion to the planter aponeurosis and its further connection with the planter aspect of toes the same muscle act as the flexor of knee and strong extensor of ankle, inter tarsal joint and also influences planter flexion of digits. This probably helps in propelling movement. An ancient characteristic that is retained in the knees of most living tetrapods including mammals except man is origin of extensor digitorum longus located on the lateral femoral condyle. In man it slips below the femur and takes origin from the medial surface of the fibula and gets inserted on toes. Hence it does not have any action on the knee joint and the toes are free to exert flexion and extension in stance and other activities independent of the knee joint [10, 20, 21]. In both frog and human being the muscle get inserted into phalanges of outer four toes. The contraction of muscle in the frog produces extension in the knee joint and also extension of the foot and toes. The protraction of hind limb in motion with simultaneous extension of the knee and tarsus in frog is apparently due to the contraction of the extensor digitorum longus muscle. This creates advantage of distinct functional value.

Asymmetrical medical & lateral collateral ligament is observed in both frog & human being. But in human being the injury of medical collateral ligament is usually associated with rupture of medical meniscus as the posterior margin of medical collateral ligament is attached to the medical meniscus. The single intra-articular ligament in frog and bat correspond to double structure found in other tetrapods. Possibly the splitting of the single ligament into two ligaments is related to rotator moments of the knee in which the ligaments are twisted on to one another.

Primitively both the menisci medial and lateral were attached anteriorly to the tibia and posteriorly to the intercondylar area of the femur. This type of attachment is retained in garden lizard. In most mammals, the medial menisci have lost its posterior femoral attachment and are attached to the tibia. In the human knee, the lateral menisci, like the medial has gained a tibial attachment posteriorly. The posterior tibial attachment of the lateral menisci appear to be unique to man [1]. It seems to be progressive characteristic related to human bipedal locomotion. This specialization may be adoption to the erect posture. As during continued extension of the knee, as attained during human erect posture, the posterior part of the meniscus is greatly strained creating a need to fix both the horns to the tibia. Adoptation of the erect posture and biped gait required stability and relative freedom of action of the knee joint and liberation of the toes for independent activity for which several factors, not found in other species, are added in human being.

CONCLUSION

With the evolution of erect or plantigrade posture in man, the lower limb of human being despite its basic similarities to frog hind limb become speciallized for support and different mode of locomotion to meet the new functional need.

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