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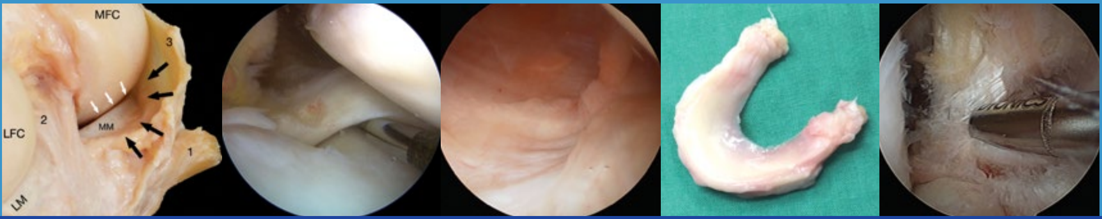
*Editors*



# Surgery of the Meniscus

European Society of Sports Traumatology, Knee Surgery & Arthroscopy
ESSKA

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Springer

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# Foreword

"Take it out, take it all out. Even if it is not torn, take it out"

Those were the slogan words by Smillie referring to meniscal injuries – and this is not even 100 years ago.

We have come a long way in trying to restore the anatomy and function of this weight-bearing cartilage body in the knee joint. Of course in Smillie's time, there was a clinical need to unlock the locked knee joint in order to restore limb function and allow for normal gait. In the young knee with good vital tissues and good and stable alignment, the remnant meniscus had a good chance to round off and function appropriately for years to come.

However, confronted even with minor additional injuries on ligaments or cartilage, the "organ", that is, the knee joint, was noted to start to fail rapidly leading to functional impairment and pain. Indeed, isolated ligament injuries having been addressed over the years with obvious success seem to behave less successfully when injury is associated with meniscal impairment or absence.

The biology and the mechanical integrity of this "organ" have to be preserved as best we can.

It is remarkable that this concept of meniscal preservation progresses over the years in our daily clinical practice.

However, the meniscectomy rate remains too high, even though robust scientific publications allow us to promote meniscal repair or abstention in traumatic meniscal injuries and abstention rather than meniscectomy in degenerative meniscal lesions.

There remains a major gap between "expert scientific publications" and daily clinical practice. Reasons enough: the myth of efficiency (I've always done that and it works!), the learning curve (but the suture is not more difficult than meniscectomy and has no higher morbidity), the societal push ("I have a meniscal injury" or "rehabilitation after repair takes too long") and finally the medical economics in practice (in many countries, return on meniscal repair is poor)

ESSKA has rightfully initiated sound efforts to further support this meniscal preservation.

Some years ago Philippe Beaufils and Rene Verdonk et al. published the first book ever on the meniscus covering it from its inception and foetal development through its close relationship with other anatomical bodies in the knee towards trauma and degeneration and describing the state of the art in repair and replacement.

Today ESSKA has taken over this setup with the best experts on the matter. Christophe Hulet has done a special job as editor in bringing together the scientific forces on all aspects that are important in saving the meniscus thus avoiding early biologic degeneration.

Taking the risk of failure in repairing the torn meniscus whenever possible (and well indicated) has become a state of mind of the prepared orthopaedic knee surgeon. Techniques are now available to make this job successful in many cases.

Taking the risk of failure in replacing the removed meniscus both partially as in its entirety may become the course of the future as new techniques and implants, improving on existing devices that may come up and support the protective effect on the weight-bearing cartilage as biology and mechanics may return to normal.

All individual authors are to be congratulated on a job extremely well done.

The drive to finalize this is to be found in the ESSKA Board and its scientific committees (Arthroscopy, Basic Science and Cartilage) creating the stamina needed to investigate again the subject of the meniscus and allowing common efforts to publish this piece of work. Let us hope that this book, carried by experts and a trusted scientific society, will contribute to pass the message along.

Pr. René Verdonk

Pr. Philippe Beaufils

# Foreword Surgery Meniscus Book

We are very proud to introduce this new book on the meniscus, this anatomic structure which was too often insufficiently considered by past generations of surgeons. Rapid advances in arthroscopy and surgical technology have provided orthopaedic surgeons with the necessary tools allowing us to preserve the meniscus in many circumstances in our current daily practice. In that sense, the pioneering work of our predecessors has paved the way to a better patient care and hopefully prevention of later osteoarthritis in those patients where the meniscus has been repaired.

Bertrand Russell once said that in science the successors stand upon the shoulders of their predecessors. In that sense, we want to acknowledge 2 of these pioneers, e.g. Prof. René Verdonk from Ghent, Belgium, and Prof. Philippe Beaufils from Versailles, France, who initiated the work with their book *The meniscus*, edited back in 2010. Half a decade later, the ESSKA arthroscopy committee – under the vigorous leadership of Prof. Christophe Hulet from Caen, France – has provided an update of the knowledge gathered in the pioneering book.

When approving this project after the Amsterdam congress during the summer of 2014, the ESSKA Board recognized that sufficient new knowledge had been generated in the field of meniscus surgery to dare initiating yet another book on the meniscus. The careful reader will find an interesting European perspective on meniscus surgery with many new perspectives testifying the scientific dynamism in this field. In some fields, the European view was completed with additional international expertise.

In that sense we are proud to include this new book *Surgerey of the Meniscus* into the ESSKA book programme portfolio and would like to thank all the authors for their excellent contribution. We hope that the book will further help to improve the treatment of meniscus pathologies in Europe and beyond and that it may stimulate surgeons, other healthcare professionals and researchers to keep the field of meniscus medicine and research as vivid as it was over the last years.

Milano and Luxembourg, January 2016

Matteo Denti
ESSKA President

Romain Seil
ESSKA 1st Vice President

Matteo Denti
ESSKA President

Romain Seil
ESSKA 1st Vice President

# Preface

Meniscus injuries are still one of the most frequent causes for orthopaedic surgery worldwide. Moreover, as Prof. René Verdonk from Ghent, Belgium, and Prof. Philippe Beaufils have stated, "nothing has changed so much in recent years in orthopaedics like the algorithm for treatment of meniscal injuries". We have moved from the promotion of removal of the tissue (meniscectomy) to preservation (repair or even replacement).

The book from these two forerunners launched in 2010 has constituted an important landmark in defining new concepts and bringing attention to the fact that "preserving the meniscus is also preserving the future" of the joint.

This new book was born within the spirit of ESSKA in contributing to continuous progress and update in topics with high impact to clinicians, patients and society.

It was born from an initiative of the current Arthroscopy Committee with immediate support from Basic Science and Cartilage Committees.

It intends to provide a comprehensive and multidisciplinary approach on meniscus structure, pathology and treatment. In this we are proud and happy for having gathered so many top experts in different related topics.

This is a book dedicated to those interested in "surgery of the meniscus". Despite the previous, it also includes the most recent hot topics on meniscus research as well as ongoing and future perspectives from uprising technologies.

We hope you can enjoy it and find it useful on your daily practice and as a support and guide for continuous research dedicated to meniscus injuries and their treatment.

**The Chairmen of Arthroscopy, Basic Science and Cartilage Committees**

Christophe Hulet
Hélder Pereira
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Hulet

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# Part I

# Meniscus Basic Science

# 1

# Knee Meniscal Phylogeny and Ontogeny

Christophe Hulet, Goulven Rochcongar,
Christine Tardieu, Julien Dunet,
Etienne Salle de Chou, Valentin Chapus,
and Andrei Korolev

## Contents

## 1.1 Introduction

Knee anatomy can be traced back more than 300 million years, to the pelvic appendages of the sarcopterygian lobe-finned fish [7]. Thorough knowledge of the gross anatomy and histology of the meniscus is a prerequisite to understanding its function. Furthermore, knowledge of meniscus-meniscal ligament complex phylogeny and ontogeny is necessary to correlate meniscal gross anatomy to meniscal function [4, 12, 14, 20]. The menisci are important primary stabilizers and weight transmitters in the knee. They primarily act to redistribute contact forces across the tibia femoral articulation. This is achieved through a

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combination of the material, geometry, and attachments of the menisci. Kinematic studies of intact knees have revealed a combined rolling and gliding motion, with posterior displacement of the femorotibial contact point with increasing flexion. Both the medial and lateral menisci translate posteriorly on the tibial plateau during deep knee flexion. The posterior translation of the lateral meniscus (8.2 ± 3.2 mm) is greater than that of the medial one (3.3 ± 1.5 mm) [37]. This asymmetry of kinematics between the medial and lateral compartment, an established characteristic of human and many other extant mammalian knees [12, 14], results in an internal rotation of the tibia, relative to the femur with increasing flexion. Four bony characters are relevant to understanding the functional anatomy of the knee related to bipedalism: femoral shaft obliquity relative to the infra condylaire plane, architecture of the lateral femoral trochlea with lateral lip elevation, profile of lateral condyle of the knee, and form and shape of the epiphysis in the horizontal plane [12, 14, 21]. As described by Tardieu [31], three different human femorotibial characters are selected as derived hominid features and are relevant to modern bipedal striding gait. One of these characters for the soft tissues concerns the lateral meniscus and its double insertion on the tibial plateau. This chapter will explore and successively describe knee and meniscal phylogeny, meniscal ontogeny, and the particular case of discoid meniscus.

## 1.2 Knee and Meniscal Phylogeny

Most of the complex functional morphologic characteristics of the human knee are not unique to humans. Hominids share a common evolutionary history with all living tetrapods relative to the development of the complex morphologic asymmetries of the knee [9]. Tetrapods include all amphibians, reptiles, birds, and mammals. Indeed, bird knees share similar morphologic characteristics with human knees, including the presence of cruciate ligaments, asymmetric collateral ligaments, menisci, and a patella [11]. This commonality of design between human and avian knees reflects a shared genetic lineage of great antiquity, which implies the existence of a common ancestor that may have possessed many of these characteristics.

The tetrapod knee joint has been well investigated by Haines [10, 11], who in 1942 reported an impressive dissection study of numerous living tetrapods. Mossman and Sargeant [20] described the phylogenetic relationships of the major classes of tetrapods. They showed *Eryops* (from the Paleozoic period) to be a common ancestor to living reptiles, birds, and mammals. An *Eryops* knee is not so different from a *Crocodilus* knee. *Crocodile* menisci are both massive structures fitted between the surfaces of the femur and the tibia and are connected anteriorly by an intermeniscal ligament. They are attached to the inner capsular surface by their peripheral margins and by meniscofemoral and meniscotibial ligaments. *Varanus varius* (lizard) menisci are quite different. The lateral meniscus is a continuous mass, completely separating the femur from the tibia, while the medial meniscus is circular shaped and perforated in its center, through which the cruciate ligaments pass. The lateral meniscus is also attached to the fibula by a posterior meniscofemoral ligament. Anatomic features and knee movements are different in these two specimens, illustrating a correspondence between shape and function during evolution. In *Eryops*, the common ancestor of reptiles, birds, and mammals, over 320 million years, the knee joint has no patella. It is only in the last 70million years that the patella has grown in birds, reptiles, and some mammals. It is a late development compared to the development of the femoral condyles' cruciate ligaments [12, 38].

Starting with *Eryops*, the lineage that leads to mammals includes pelycosaurs such as *Dimetrodon* (sail-backed animal) [18]. During the Mesozoic era, 215 to 70 million years ago, the femurs of protomammals and dinosaurs rotated internally, causing the knee to become apex anterior, as in modern humans. It corresponds to a decisive change in the position of the limbs, relative to the vertebral column: the transition from transversal limbs to parasagittal limbs. By the beginning of the Cenozoic era, an osseous patella had developed independently in fossil lizards, birds, and mammals [25]. An inspection of the knee of the black bear reveals a classic mammalian knee very similar in morphologic features to a human knee [29].

In the primate lineage leading to humans (Fig. 1.1), the hominids evolved to bipedal stance approximately 3 to 4 million years ago (period of *Australopithecus afarensis*: Lucy), and by 1.3 million years ago, the modern patellofemoral joint was established with a longer lateral patellar facet and matching lateral femoral trochlea [33].

In mammals, the anatomy of the knee is fairly basic with two rigid balls, and they have very little contact with the tibial glenoid cavities. These are the ligaments and menisci that stabilize all with insert points together to avoid excessive movements. The shape of the patellofemoral joint is highly variable and depends on the mode of locomotion. Tardieu and Dupont [33] specify that these differences in anatomical shape depend on the type of movement among quadripedes.

In horses in the family of Onguligrades, the knee is placed in flexion and still never knows full extension. There is no continuity between the condyles and femoral trochlea. The horses sleep standing up, and shape of the lower limb is adapted to the race with guided and quick movements. In *Cercopithecus* a quadruped animal (horse) [12], there is no obliquity of the femoral diaphysis. The trochlea is symmetric with no depth; the lateral femoral condyle is circular. The distal epiphysis is not the same; the medial condyle is larger than the lateral condyle and different in length.

In apes and bears (Fig.1.2), Plantigrade family, there is no obliquity of the femoral diaphysis, and the knees are adducted. The trochlea is flat and there is only one facet for the patella. The lateral femoral condyle is circular, but the shape of the distal epiphysis is more rectangular (medial condyle larger than lateral condyle). The cruciate ligaments are very similar [29].

Three different human femorotibial characters were selected as derived hominid features rele-

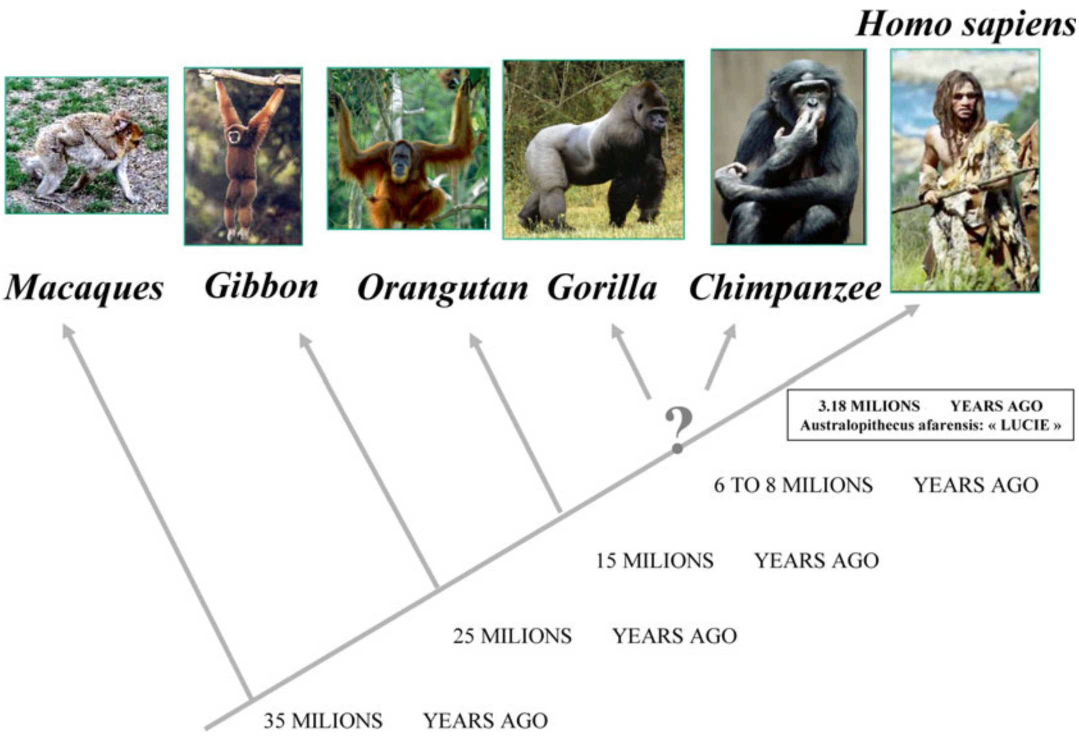

**Fig. 1.1** The primate lineage leading to *Homo sapiens*

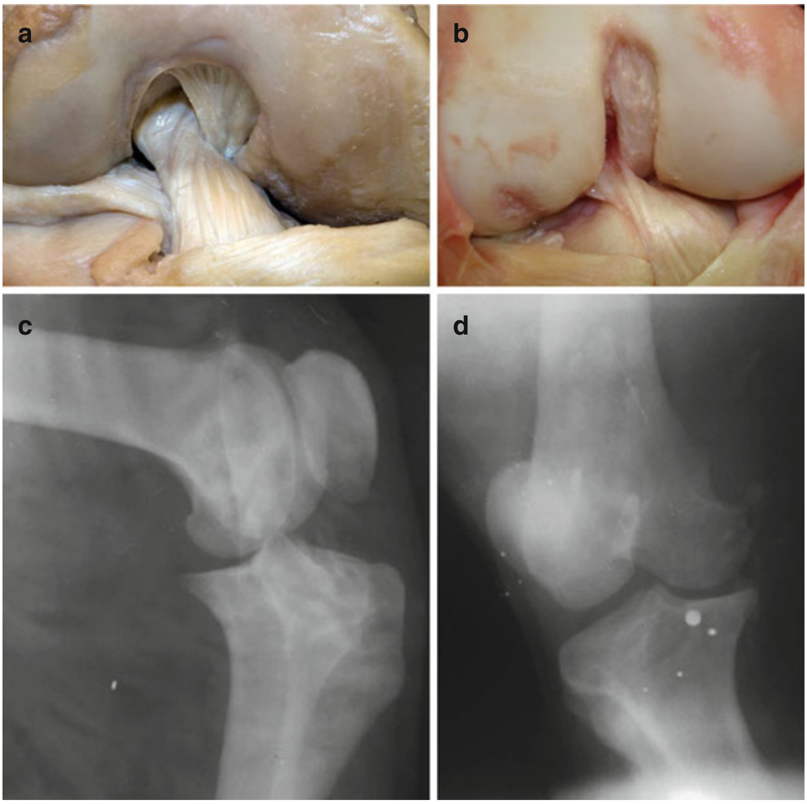

**Fig. 1.2** Macroscopic view of gorilla (**a**) and bear knees (**b**). X-ray evaluation of the bear's knee (**c, d**)

vant to modern bipedal striding gait. The first feature is the bicondylar angle of the femur, contrasting with a chimpanzee femur, which is straight. The second feature relates to the shape of the femoropatellar groove: flat for the chimpanzee (rectangular) and grooved in humans (square) [12, 14, 21] (Fig. 1.3).

Finally, the third feature concerns the lateral meniscus and its double insertion on the tibial plateau (Fig. 1.4). In humans, the presence of a posterior tibial insertion of the lateral meniscus limits its mobility on the tibial plateau compared to the single insertion in chimpanzee (Fig. 1.5). The second posterior insertion aids in preventing extreme anterior gliding of the lateral meniscus during frequent extension [30]. The lateral meniscus is also pulled strongly anteriorly during medial rotation of the femur on the tibia. As in extension, the posterior attachment of the lateral meniscus limits this anterior movement [31]. This insertion, posterior to the external tibial spine, is a derived feature, unique among living mammals.

Also, in the human knee, the development of the meniscofemoral ligament to the cruciate ligament is critical to reinforce the posterior fixation of the lateral meniscus. Laterally, the meniscofemoral attachment of the lateral meniscus to the tibia and to the posterolateral corner provides better stability and fixation compared to the chimpanzee anatomy. Indeed, other nonhuman primates are unable to fully extend the knee joint in bipedal walking, while they are able to do so during quadrupedal gait.

Since terrestrial bipedalism of *Australopithecus afarensis* was likely associated with abilities of arboreal climbing and suspension, and was different from that of modern humans [28], Tardieu [31–33] investigated the transition from occasional bipedalism to permanent bipedalism. She observed that primate and other mammal knees contain a medial and a lateral fibrocartilaginous meniscus.

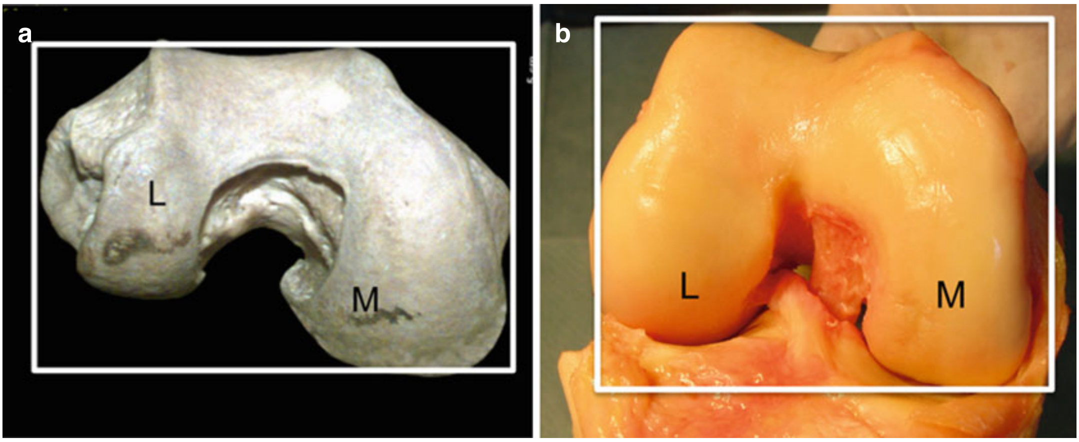

**Fig. 1.3** Femoropatellar groove of gorilla (**a**) and human (**b**) knees. The shape is more rectangular in the gorilla example, and there is asymmetry in femoral condyles

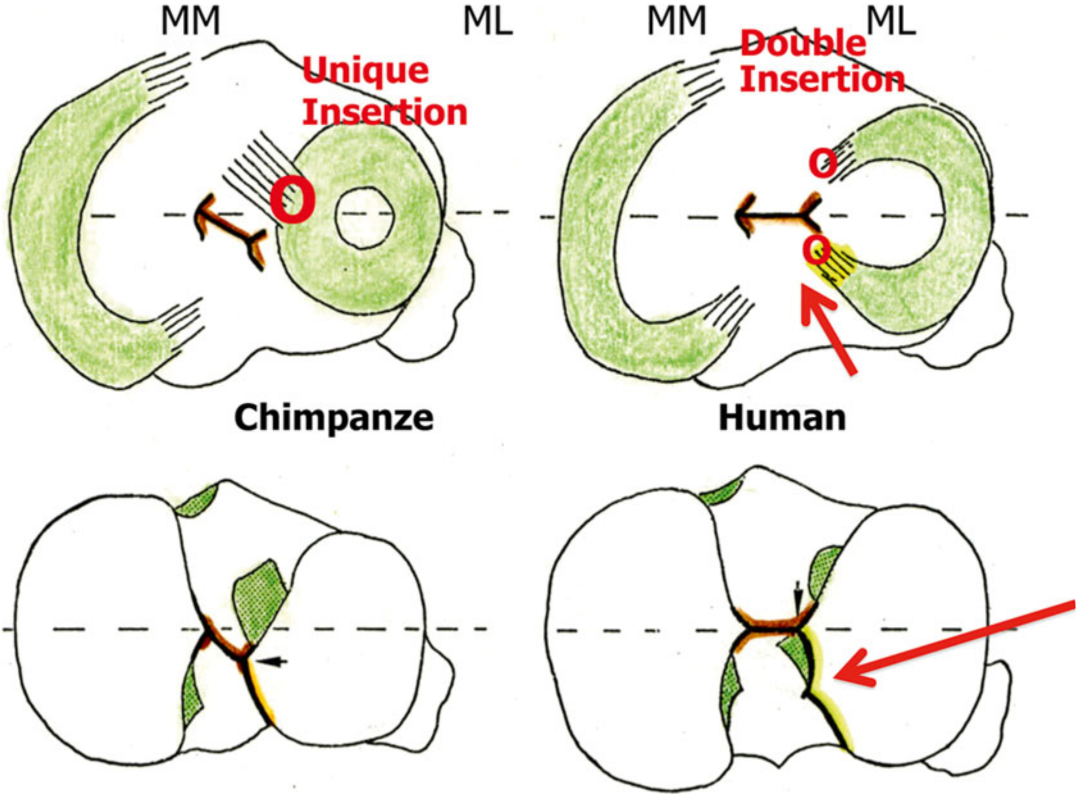

**Fig. 1.4** Comparison between human lateral meniscal morphology with double insertion (*red arrow*) compared to the unique lateral meniscal insertion with greater mobility

The medial meniscus is very similar in all primates. It is crescent shaped with two tibial insertions, not so different from the *Homo sapiens*' meniscus. By contrast, the lateral meniscus is more variable in shape and in the pattern of tibial insertions. Dissections of different primates showed that the lateral meniscus displays three distinct morphologies in extant primates [24, 32, 34]. A crescent-

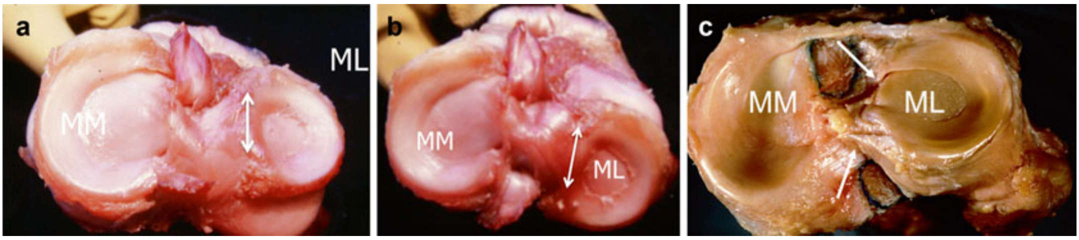

**Fig. 1.5** The unique insertion of the lateral meniscus in chimpanzee with the emphasis on the anterior and posterior meniscal displacement (**a, b**). On the contrary, the lateral meniscus in human with its double insertion is far more stable, and there is less displacement (**c**)

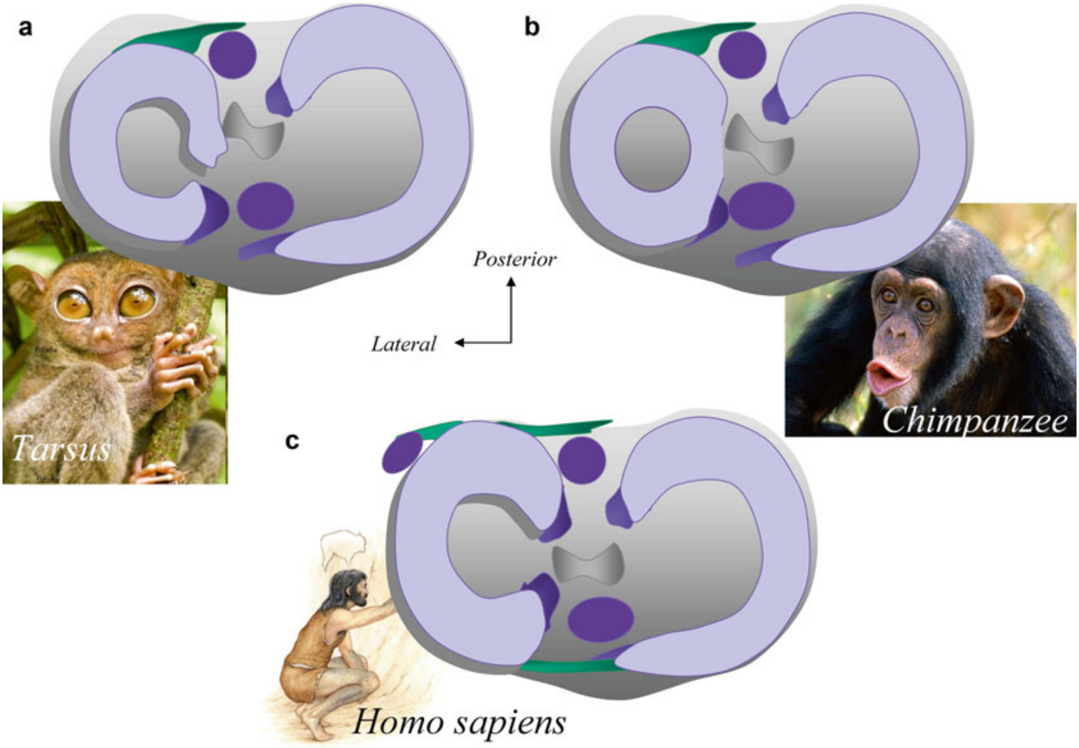

**Fig. 1.6** The three distinct morphologies of menisci in extant primates: (**a**) crescent shape of the lateral meniscus with one anterior insertion, (**b**) ring shape of the lateral meniscus with one anterior insertion, and (**c**) crescent shape of the lateral meniscus with two insertions

shaped lateral meniscus with one tibial insertion, anterior to the lateral tibial spine, is present in Lemuriformes, *Tarsius*, platyrrhines, and *Pongo*. A ring-shaped meniscus with one insertion anterior to the lateral spine is found in all catarrhines, except *Pongo* and *Homo.* A crescent-shaped lateral meniscus with two tibial insertions, one anterior and one posterior to the lateral spine, is only found in *Homo sapiens* (Fig. 1.6).

The fossil record also provides evidence of a transition from the fossil record of a single to double insertion of the lateral meniscus in hominid tibias. While *Australopithecus afarensis* exhibits a single insertion, early *Homo* clearly exhibits a double insertion of the lateral meniscus on the tibia. This feature indicates a habitual practice of full extension movements of the knee joint during the stance and swing phases of bipedal walking [23].

Other features are associated with striding bipedal gait. Many differences exist between the lower limbs of *Homo sapiens* and other primates. Contrary to humans, other primates walk with a flexed knee.

As a result, the shape of the femoral epiphysis is different (Fig. 1.7). During the primate lineage leading to *Homo sapiens*, lower limb evolution showed a transition from an abducted knee to an adducted knee, which means that the femoral anatomic angle evolved to 7° of valgus [33]. Nonhuman medial femoral condyles were more spherical with a shallow trochlear groove and a smaller bicondylar angle. On the other hand, human femoral trochlea had a higher lateral lip, and the patella is different (see Fig. 1.7).

In the human knee, the medial compartment is very similar in terms of medial meniscus insertions and bony shape with concavity in both human and chimpanzee (Fig. 1.8).

In the chimpanzee, the convexity of the lateral tibial plateau is more pronounced compared to the human tibial knee (Fig. 1.9). Therefore, there is augmentation of osseous femorotibial contact with greater stability. The lateral meniscus is more stable with two insertions. All these changes generate better extension of the knee compatibility with bipedal walk, giving greater stability and less mobility of the lateral compartment.

All these modifications coincide with pelvic modification, especially with a decreasing interacetabular distance. According to Tardieu, modification

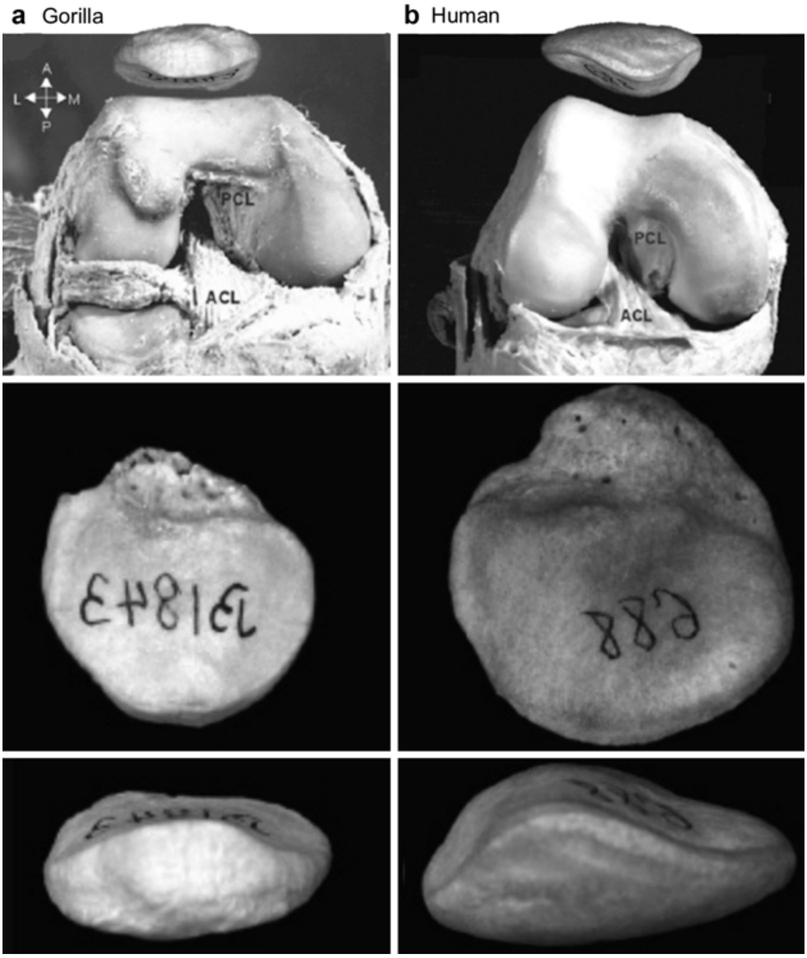

**Fig. 1.7** Comparison between a gorilla knee (column **a**) and human knee (column **b**) in terms of shape of the trochlea and the patella

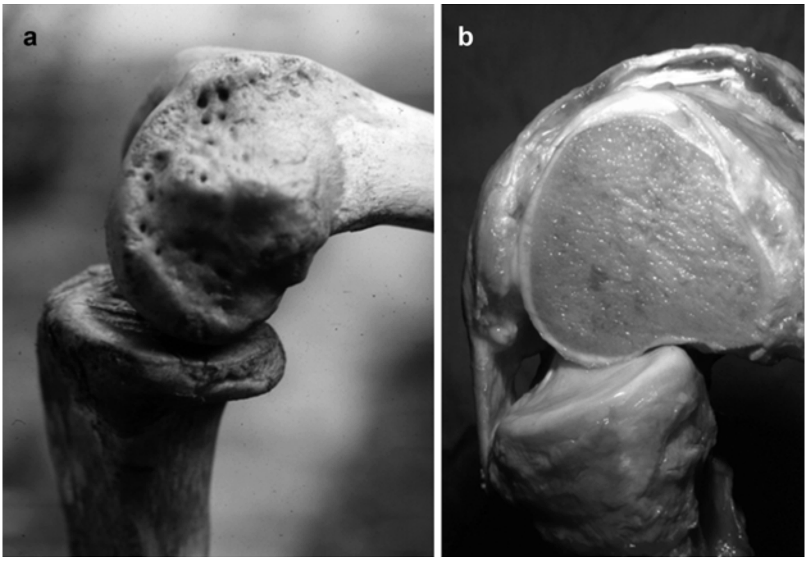

**Fig. 1.8** Similarity of the medial compartment between a chimpanzee knee (**a**) and human knee (**b**) in terms of shape of tibial plateau

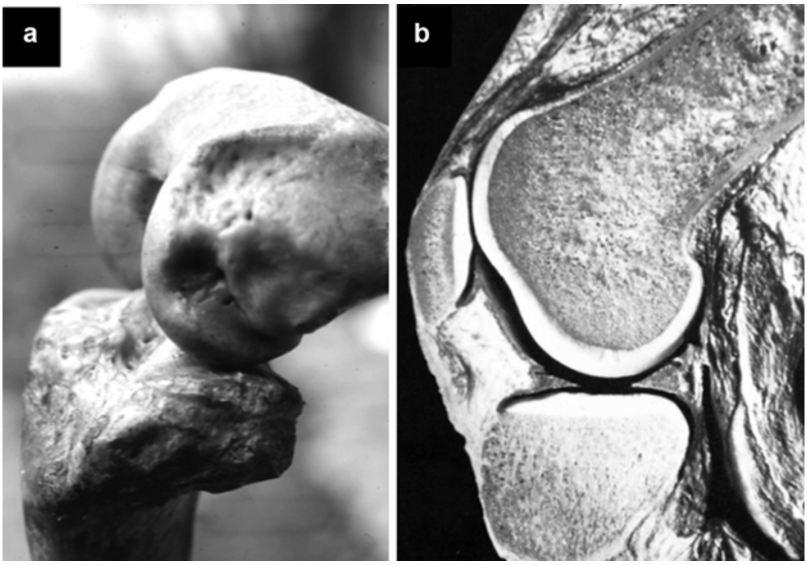

**Fig. 1.9** Differences of the lateral compartment between a chimpanzee knee (**a**) and human knee (**b**) in terms of shape of the lateral tibial plateau

of the bicondylar angle is an epigenetic functional feature and has never been included in the genome for 3 million years [31]. The higher lateral lip of the femoral trochlea already present in the fetus today is genetically determined. Nevertheless, it has probably been firstly acquired epigenetically and then "genetically assimilated" [33].

## 1.3 Meniscal Ontogeny

Even if several longitudinal developmental studies of nonhuman vertebrate knees exist, literature data on developing menisci are scarce [6]. Gardner and O'Rahilly [8], McDermott [17], and others provided detailed descriptions of the pre-