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Comparative Morphological Studies of the Stifle Menisci in Donkeys, Goats and Dogs

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Abstract

The present work aims to provide more anatomical information on the stifle joint of the investigated species using computed tomography with gross anatomical cross-sections. The current work analyzed the stifle joint of the pelvic limbs of 12 adult donkeys, goats and dogs of both genders. The medial condyle of the femur was larger than the lateral one in the donkey, while it was smaller and lower than the lateral one in the goat and in the dog. The unsuitable femoral and tibial condyles were adapted by the presence of menisci. In the donkey, the medial meniscus was crescentic in shape, but it was semicircular in the goat, while in the dog, the medial and lateral menisci were C-shaped. In the donkey, the medial meniscus was larger than the lateral one, but in the goat and in the dog, the lateral meniscus was the largest, and more concave and thicker. The lateral meniscus was semicircular in the donkey, but it was shaped like an elongated kidney in the goat. In the goat and in the dog, the central border of two menisci was thin, concave and notched centrally. The meniscal ligaments included cranial and caudal ligaments of the medial and lateral menisci, and meniscofemoral ligament of the lateral meniscus. In the dog, the cranial ligament of the medial meniscus was absent, and the medial meniscus had no bony attachment to the tibia but it attached to the transverse intermeniscal ligament, which connected the cranial horn of the medial meniscus with the cranial ligament of the lateral meniscus. The meniscofemoral ligament connected the caudal pole of the lateral meniscus with the intercondyloid fossa of the femur.

Keywords

- stifle joint
- meniscal ligaments
- computed tomography
- anatomical sections

Introduction

Anatomically, the stifle meniscus is described as a crescentic-shaped or semilunar fibrocartilaginous plate wedged between the femoral and tibial condyles. Its role is to provide structural integrity to the stifle joint during joint tension and torsion due to unsuitable articulation between the femoral and tibial condyles as well as to provide joint stabilization, shock absorption and protection of the articular surface.[1–6]

It is of vital importance to understand the morphological appearance of the stifle meniscus in animals because they are used as medical models to measure the degree of success of treatment options for meniscal injury [7] in humans and to know more about surgery of the stifle joint in animals.[8,9] A few examples of meniscal surgery models most frequently used are small animals (dog and pig), small ruminants (goat, sheep) and large ruminants (cow).[4,7,10–13]

The stifle joint is usually exposed to many problems that may require surgical treatment, such as patellar luxation, gonitis (stifle arthritis), synovitis, fracture, meniscal tearing and cruciate ligament sprain in the bovine.[14] Most commonly, sheep, goats, pigs, dogs, and rabbits are used as models of the human knee to test implants or to discover determinants of disease progression.[15–18]

Computed tomography (CT) is an efficient imaging modality that provides a cross-sectional image with superior soft

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tissue differentiation and no superimposition of the overlying structures, which can be used for better diagnosis of foot and foot pad abnormalities.[19,20] The CT is considered an important diagnostic tool in the human diagnosis, but due to its high cost, it is not used as often in veterinary diagnosis.[21] Moreover, the CT technique is useful for evaluation of the osseous structure, and it also gives three-dimensional CT images to provide a better view of the ligaments during surgery.[22]

The purpose of the present study was to provide a detailed anatomic reference of CT images interpreted with gross anatomical cross-sections of the normal stifle menisci of donkeys, goats and dogs for anatomists, surgeons and veterinary students.

Material and Methods

Samples

Six healthy adult animals of both genders, from each species, were used in the current study. The used animals were free of any anatomical abnormalities and any stifle joint affection. They were collected from the farms near the Kafr El-Sheik government. Joints from the right and left limbs were used. The current study was performed according to the guidelines for the care and use of laboratory animals and the Animal Welfare and Ethics Committee of the Faculty of Veterinary Medicine at Alexandria University, following the Egyptian's laws. The anatomical terms follow the Nomina Anatomica Veterinaria (NAV).[23]

Gross Morphology Examination

Four pelvic limbs from each animal species were used for studying the articular surfaces of the femorotibial joint. The animals were bled after being anesthetized; then, the three pelvic limbs were separated and buried in soil until complete decomposition of the tissues. After that, the bones of the two joints were collected, washed thoroughly using water and soap, and then bleached with hydrogen peroxide for 1 day and left to dry. The bones were then photographed after studying the characteristics of the articular surfaces of the stifle joint. Finally, the characteristic features of the bones were photographed with a Canon IXY 325 digital camera (Canon, Tokyo, Japan) after studying the characteristics of the articular surfaces of the stifle joint.

Four pelvic limbs from each species were used for studying the stifle meniscus ligaments. The animals were bled after being anesthetized, and, then, they underwent routine preservative technique (10% formalin mixed with 4% glycerin and 1% phenol) for 10 to 15 days until complete fixation. Finally, the two pelvic limbs were separated and the stifle meniscus ligaments were dissected.

Computed Tomography

Four pelvic limbs from each animal species were obtained, and the stifle joint was severed and used for studying it by means of a CT. The animas were anesthetized and then bled, and the joints were separated and transferred to the CT center within 24 hours, where they were analyzed using a Toshiba ASTEION SUPER-4 multi slice 4 CT scanner (Toshiba Corp., Minato, Tokyo, Japan) at 120 KV and 150 mAs. The distance between the slices taken was 0.5 cm. Three-dimensional images were also taken by the CT scanner for reconstruction of the stifle joint. Bone and soft tissue window images were taken.

Statistical Analysis

The IBM SPSS Statistics for Windows, Version 21.0 software (IBM Corp., Armonk, NY, USA)[24] was used for making a correlation between the articular surfaces of the femorotibial joint and the body weight of the donkey, the goat and the dog.

Results

Articular Surface

Anatomically, the stifle joint consists of two main joints: the femorotibial and femoropatellar joints. The femorotibial articulation (articulatio femorotibialis) is formed between the condyles of the femur, the condyles of the tibia and the medial and lateral menisci.

Medial and Lateral Condyles of the Femur (Condylus Medialis and Lateralis)

The head of the femur has two condyles: medial and lateral. The medial condyle was larger than the lateral one in the donkey (►**Fig. 1A/4**), while it was smaller and lower than the lateral one in the goat (►**Fig. 2A/4**) and in the dog (►**Fig. 3A/4**). Furthermore, the correlation between the length and weight of the medial and lateral condyles of the femur was demonstrated in ►**Fig. 4**.

In the three examined animals, the medial condyle of the femur was semispherical in shape and oblique in direction; on the other hand, the lateral condyle was sagittal in direction (►**Fig. 1A**; **2A** and **3A/5**). In the dog, the articular surfaces of the two condyles were continuous proximocaudally with small articular facet for sesamoid bones (►**Fig. 7C** and **12B/ms** and **Is**), which present in the tendons of the medial and lateral head of the gastrocnemius muscle.

In the three species, we observed a fossa located between the lateral ridge of the trochlea of the femur and the lateral condyle. This is called the extensor fossa (►**Fig. 1A**; **2A** and **3A/9**), which marks the origin of the long digital extensor muscle and peroneus tertius in the donkey and goat but the origin of the long digital extensor muscle only in the dog. The intercondyloid fossa (►**Fig. 1A**, **2A** and **3A/8**) was deep and sagittal in direction. In the dog, this fossa was deeper caudally than cranially. The length and width were calculated as means and recorded in ►**Table 1**.

Medial and Lateral Condyles of the Tibia (Condylus Medialis and Lateralis)

These condyles were not adapted with the condyles of the femur and there was only a small contact area with them. This adaptation was compensated by the presence of the menisci. In the donkey (►**Fig. 1A/10**) and in the goat (►**Fig. 2A/10**), the articular surface of the medial condyle of the tibia was triangular in outlines, while the lateral condyle was quadrilateral, but in the dog, the medial condyle (►**Fig. 3B/10**) was oval in shape, and the lateral condyle (►**Fig. 3B/11**) was nearly

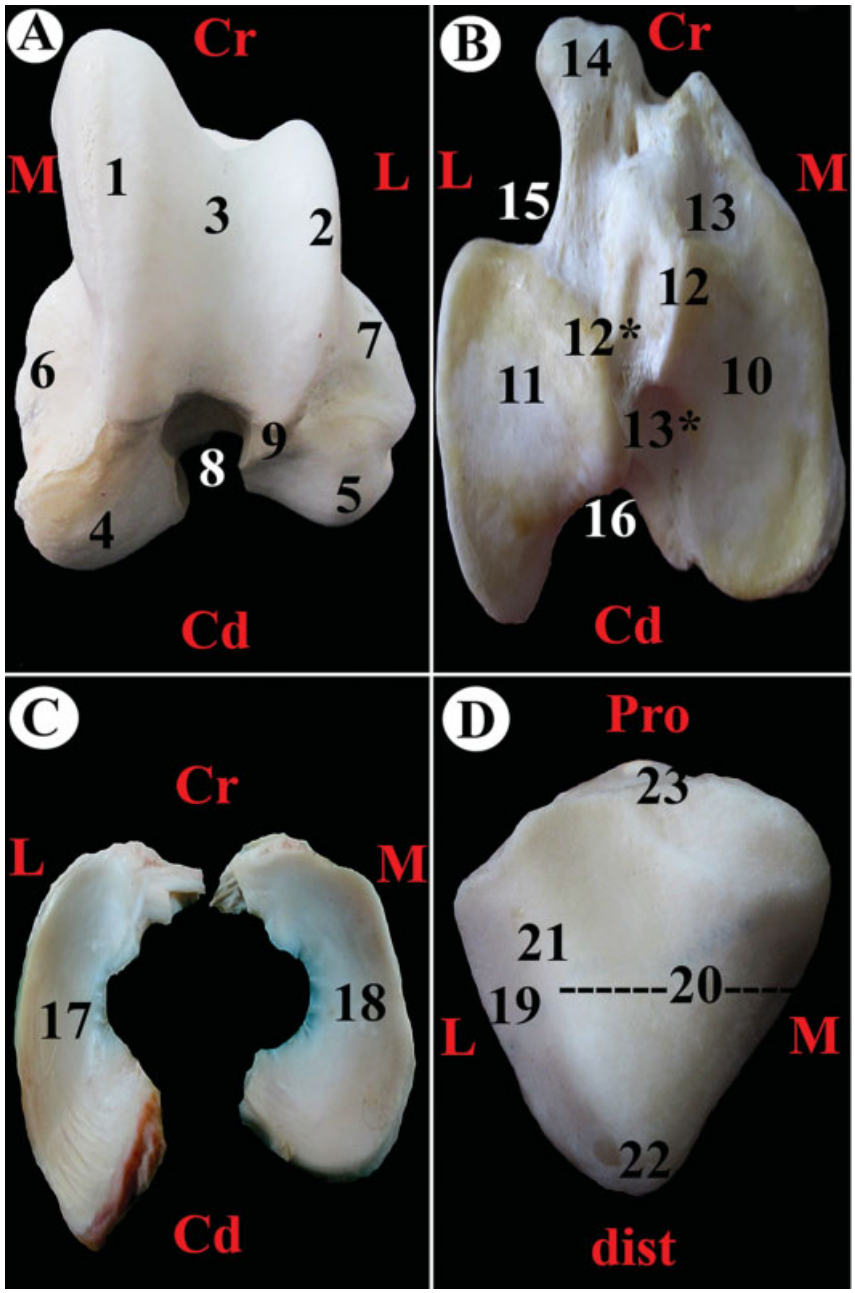

Fig. 1 Gross morphological views of the articular surfaces of the left stifle joint of the donkey: (View A) clarifies the distal extremity of the femur, (View B) clarifies the proximal extremity of the tibia, (View C) clarifies the menisci, (View D) clarifies the articular surface of the patella. 1- Medial ridge of the trochlea of the femur. 2- Lateral ridge of the trochlea of the femur. 3- Trochlear groove. 4- Medial condyle. 5- Lateral condyle. 6- Medial epicondyle. 7- Lateral epicondyle. 8- Intercondyloid fossa. 9- Extensor fossa. 10- Medial condyle. 11- Lateral condyle. 12- Medial part of the intercondyloid eminence. 12*- lateral part of the intercondyloid eminence. 13- Cranial part of intercondyloid fossa. 13*- Caudal part of intercondyloid fossa. 14- Tibial tuberosity. 15- Extensor groove. 16- Popliteal notch. 17- Lateral meniscus. 18- Medial meniscus.19- Medial articular surface. 20- Lateral articular surface. 21- Ridge. 22- Apex. 23- Base.

circular in shape. In the donkey, the medial condyle was larger than the lateral one, while in the goat (►**Fig. 2B/11**) and in the dog (►**Fig. 3B/11**), the lateral condyle was larger than the medial one. Furthermore, the correlation between the length and weight of the medial and lateral condyle of the tibia was demonstrated in ►**Fig. 5**.

The two condyles were separated by an intercondylar eminence that divided the intercondylar area into a medial and a lateral part. The medial intercondyloid eminence was more elevated than the lateral one in the donkey (►**Fig. 1B/12**) and in the goat (►**Fig. 2B/12**), while the lateral intercondyloid eminence (►**Fig. 3B/12***) was higher than the medial one in the dog (►**Fig. 3B/12**). In the three species, there was a fossa (►**Fig. 1B**, **2B** and **3B/13** and **13***) cranial and caudal to the intercondyloid eminence named the intercondyloid fossa. The lateral condyle separated from tibial tuberosity by the extensor groove that clear in (►**Fig. 1B**, **2B** and **3B/15**). The two condyles of the tibia separated caudally by the popliteal notch (►**Fig. 1**, **2** and **3**). The length and width were calculated as means and recorded in ►**Table 1**.

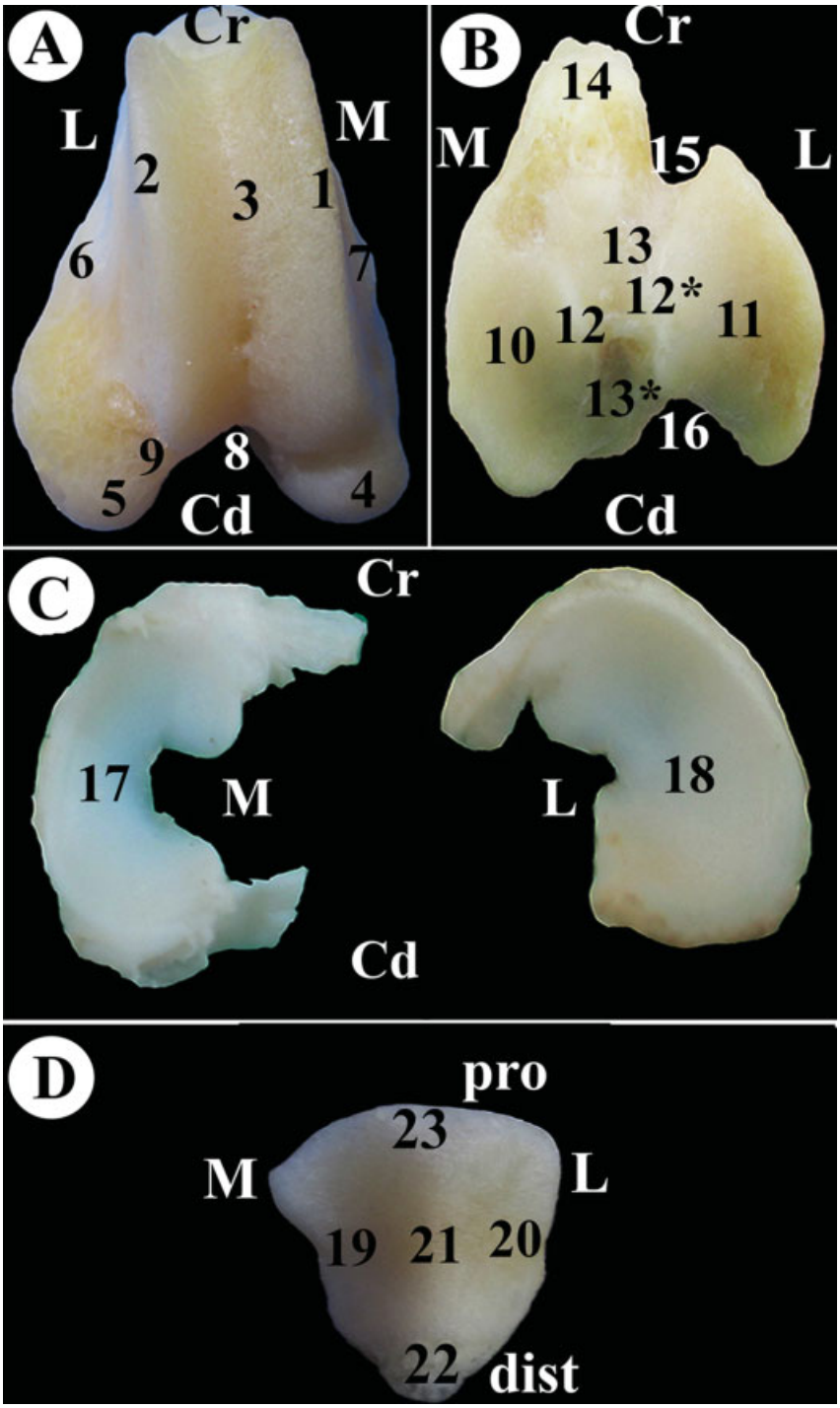

Fig. 2 Gross morphological views of the articular surfaces of the right stifle joint of the goat: (View A) clarifies the distal extremity of the femur, (View B) clarifies the proximal extremity of the tibia, (View C) clarifies the menisci, (View D) clarifies the articular surface of the patella. 1- Medial ridge of the trochlea. 2- Lateral ridge of the trochlea. 3- Groove. 4- Lateralcondyle.5- Medial condyle. 6- Lateral epicondyle. 7- Intercondyloid fossa. 8- Medial condyle. 9- Extensor fossa. 10- Medial condyle. 11- Lateral condyle. 12- Medial part of intercondyloid eminence. 12*- Lateral part of intercondyloid eminence. 13- Cranial intercondyloid fossa. 13*- Caudal intercondyloid fossa. 14- Tibial tuberosity. 15- Extensor groove. 16- Popliteal notch. 17- Medial meniscus. 18- Lateral meniscus. 19- Medial articular surface. 20- Lateral articular surface. 21- Ridge. 22- Apex. 23- Base.

Medial and Lateral Menisci (Meniscus Medialis and Lateralis)

Generally, the medial and lateral menisci were normal, smooth, white and glistening fibrocartilage that located between the two condyles of the femur and tibia. They presented cranial and caudal poles, axial and abaxial borders and proximal and distal articular surfaces. Their proximal surface was concave to adapt to the condyles of the femur, while the distal surface was convex to the condyles of the tibia. In the donkey, the medial meniscus (►**Fig. 1C/18**) was crescentic in shape, while in the goat (►**Fig. 2C/18**), it was semicircular, and in the dog, the medial (►**Fig. 3C/18**) and lateral menisci (►**Fig. 3C/19**) were C-shaped.

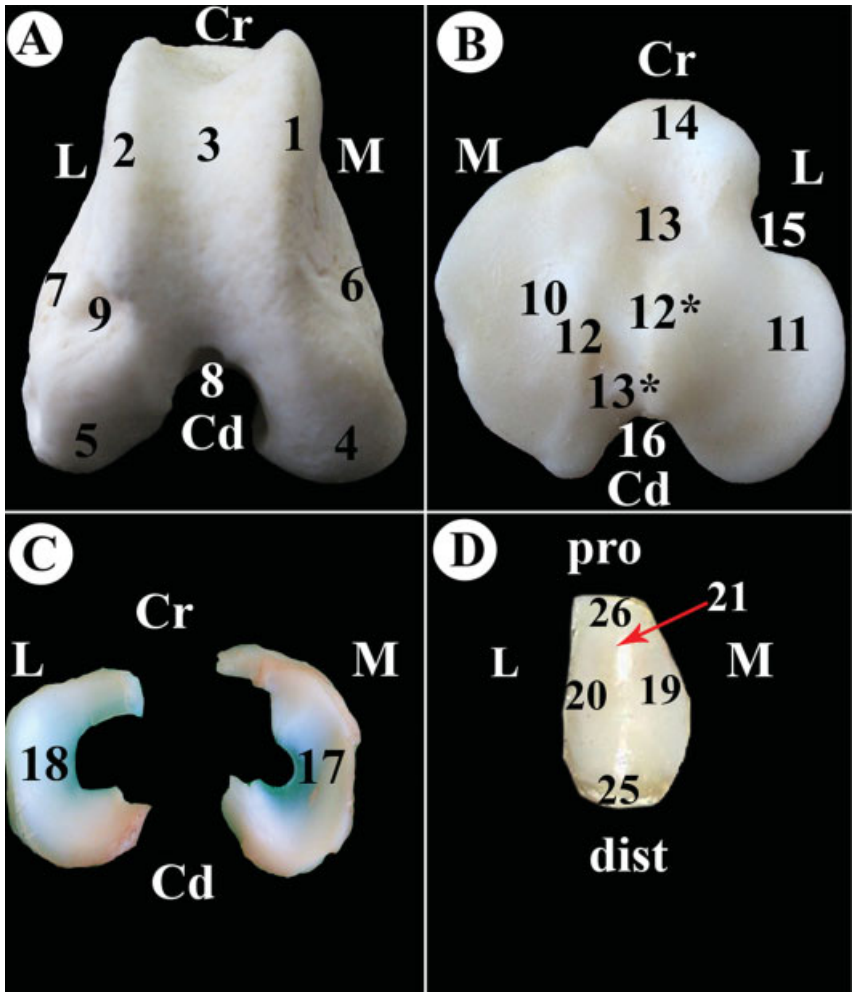

Fig. 3 Gross morphological views of the articular surfaces of the right stifle joint of the dog: (View A) clarifies the distal extremity of the right femur, (View B) clarifies the proximal extremity of the right tibia, (View C) clarifies the left menisci, (View D) clarifies the articular surface of the left patella. 1- medial ridge of the trochlea. 2- lateral ridge of the trochlea. 3- groove of the trochlea. 4- medial condyle. 5- lateral condyle. 7- popliteal fossa. 8- intercondyloid fossa. 9- extensor fossa. 10-Medial condyle. 11- lateral condyle. 12- medial part of the intercondyloid eminence. 12*- lateral part of the intercondyloid eminence. 13- cranial part of the intercondyloid fossa. 13*- caudal part of the intercondyloid fossa. 14- tibial tuberosity. 15- extensor groove. 16- popliteal notch.17-Medial meniscus. 18- lateral meniscus.19- medial articular surface. 20- lateral articular surface. 21- ridge. 22- Lateral sesamoid bone of the tendon of the gastrocnemius muscle. 23- Medial sesamoid bone of the tendon of the gastrocnemius muscle.24- sesamoid bone of the tendon of the popliteus muscle. 25- apex. 26- base.

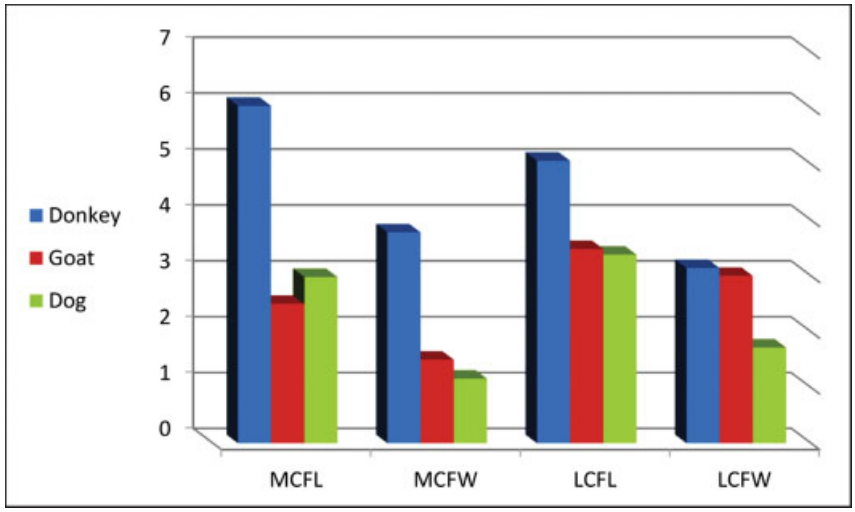

Fig. 4 Diagram to clarify the correlation between the length (MCFL) and weight (**MCFW**) of the medial condyle of the femur in addition to the correlation between the length (**LCFL**) and weight (**LCFW**) of the lateral condyle of the femur between the three examined animals: donkey (blue), goat (red) and dog (green).

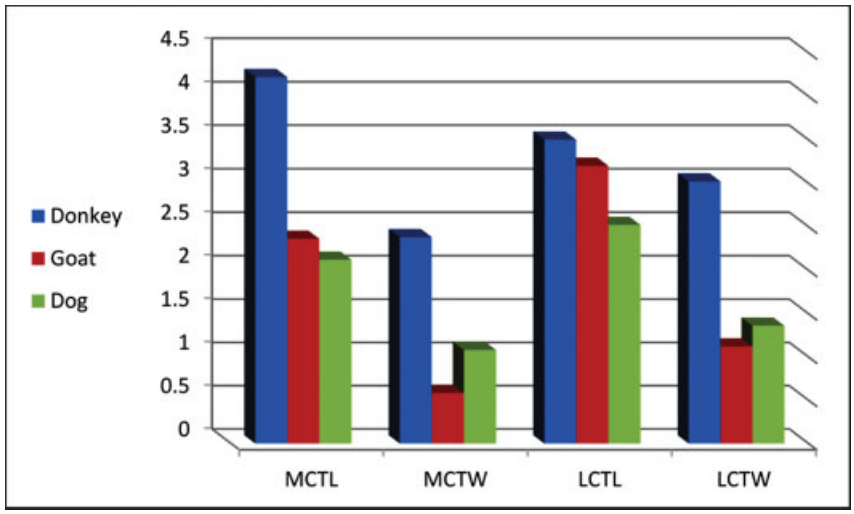

Fig. 5 Diagram to clarify the correlation between the length (**MCTL**) and weight (**MCTW**) of the medial condyle of the tibia in addition to, the correlation between the length (**LCTL**) and weight (**LCTW**) of the lateral condyle of the tibia between the three examined animals: donkey (blue), goat (red) and dog (green).

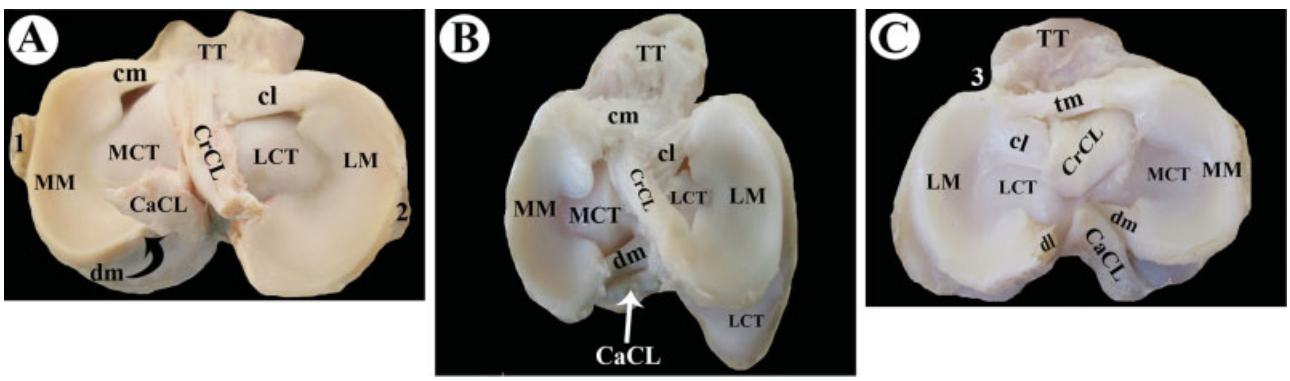

Fig. 6 Gross morphological views of the right stifle joint of the donkey (View A), right stifle joint of the goat (View B), and left stifle joint of the dog (View C) TT- tibial tuberosity. MM- medial meniscus. LM- lateral meniscus. MCT- medial condyle of the tibia. LCT- lateral condyle of the tibia. MFL- meniscofemoral ligament. CrCL- cranial cruciate ligament. CaCL- caudal cruciate ligament. cm- cranial ligament of the medial meniscus. cl- cranial ligament of the lateral meniscus. dm- caudal ligament of the medial meniscus. dl- caudal ligament of the lateral meniscus. tm- transverse meniscal ligament. 1- stump of the medial collateral ligament. 2. stump of the lateral collateral ligament. 3. Extensor groove.

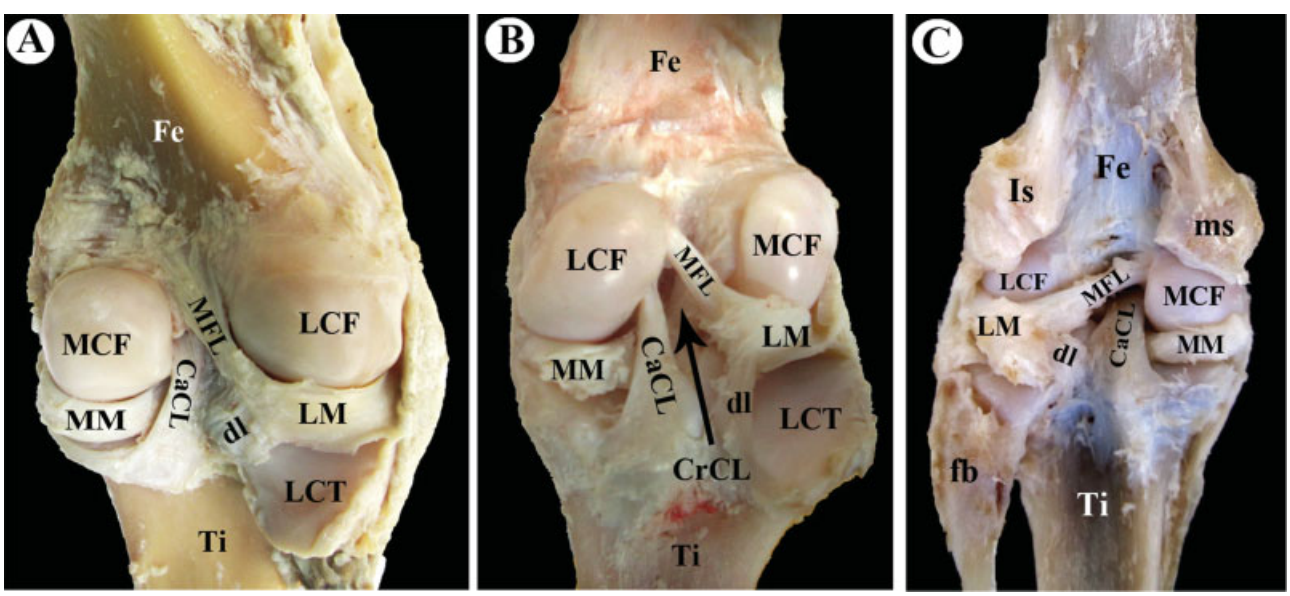

Fig. 7 Gross morphological views of the caudal view of the; right stifle joint of the donkey (View A), right stifle joint of the goat (View B), and left stifle joint of the dog (View C) Fe- femur. Ti- tibia. MM- medial meniscus. LM- lateral meniscus. MCF- medial condyle of the femur. LCF- lateral condyle of the femur. LCT- lateral condyle of the tibia. MFL- meniscofemoral ligament. CrCL- cranial cruciate ligament. CaCL- caudal cruciate ligament. dl- caudal ligament of the lateral meniscus.

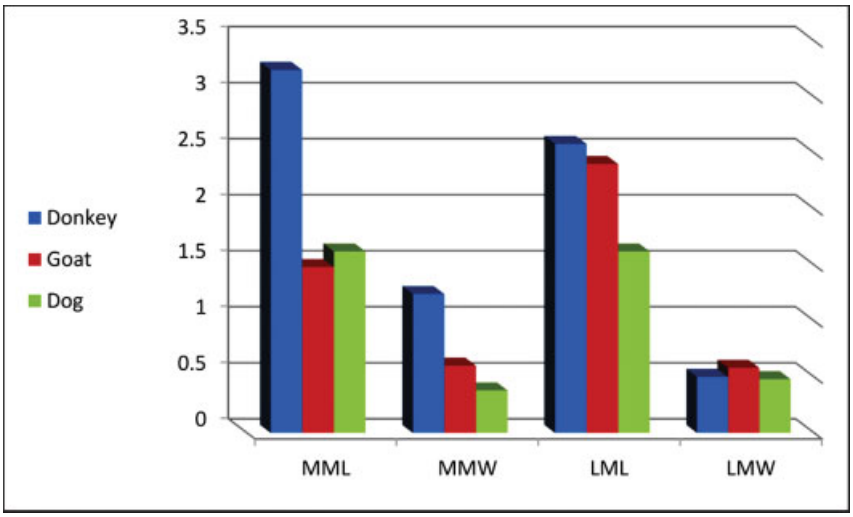

Fig. 8 Diagram to clarify the correlation between the length (MML) and weight (MMW) of the medial meniscus in addition to the correlation between the length (LML) and weight (LMW) of the lateral meniscus between the three examined animals: donkey (blue), goat (red) and dog (green).

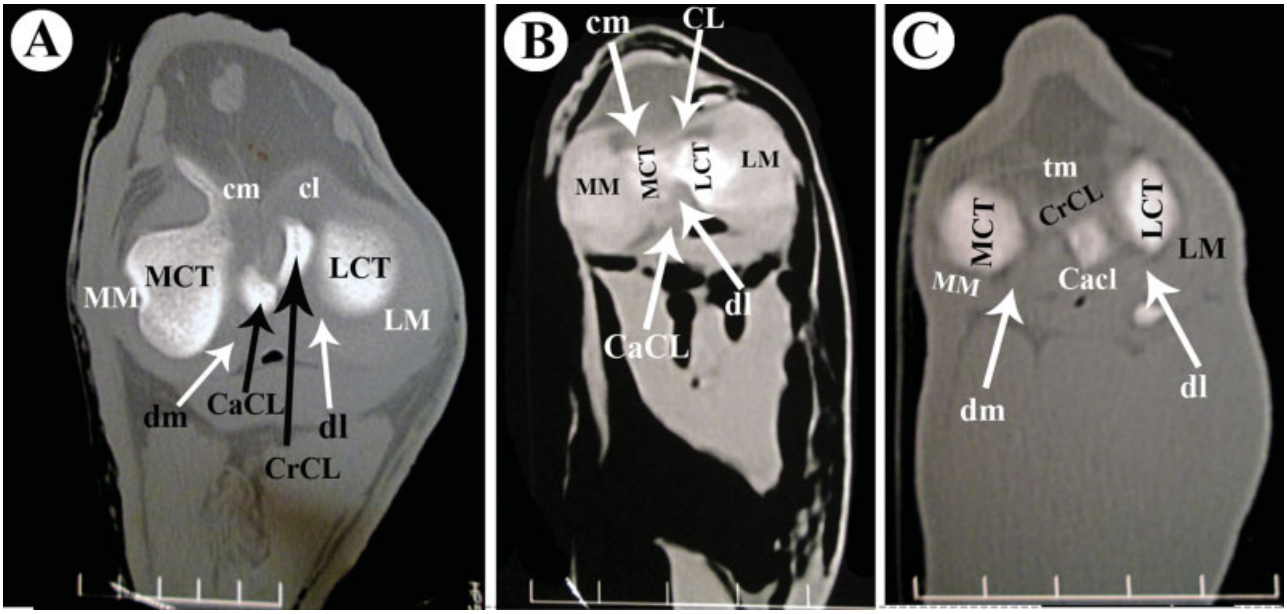

Fig. 9 Transverse computed tomography images of the right stifle joint of the donkey (view A), left stifle joint of the goat (View B), and left stifle joint of the dog (View C) TT- tibial tuberosity. MM- medial meniscus. LM- lateral meniscus. MCT- medial condyle of the tibia. LCT- lateral condyle of the tibia. MFL- meniscofemoral ligament. CrCL- cranial cruciate ligament. CaCL- caudal cruciate ligament. cm- cranial ligament of the medial meniscus. cl- cranial ligament of the lateral meniscus. dm- caudal ligament of the medial meniscus. dl- caudal ligament of the lateral meniscus. tm- transverse meniscal ligament. 1- stump of the medial collateral ligament. 2. stump of the lateral collateral ligament. 3. Extensor groove.

In the donkey, the medial meniscus was larger than the lateral one, but in the goat and in the dog, the lateral one was the largest, and more concave and thicker. In the three species, the central border of the medial meniscus was deeper than that of the lateral one, and the peripheral border was thicker and more convex than the lateral one.

The lateral meniscus was semicircular in shape in the donkey (►**Fig. 1C/19**), but it was shaped like and elongated kidney in the goat (►**Fig. 2C/19**). In the three examined species, the medial meniscus was firmly attached to the joint capsule while the lateral one was not. In the goat and in the dog, the central border of the two menisci was thin, concave and notched centrally. The length and width were calculated as means and recorded in ►**Table 1**. Furthermore, the correlation between the length and weight of the medial and lateral stifle menisci was demonstrated in ►**Fig. 8**.

The correlation between the body weight and dimensions of the articular surfaces of the stifle joint of the donkey, the goat and the dog are recorded in ►**Tables 2**, **3** and **4**.

Meniscal Ligaments

They included the cranial and caudal ligaments of the medial and lateral menisci, and the meniscofemoral ligament of the lateral meniscus. The cranial ligament of the medial meniscus connected the cranial pole of the medial meniscus with the cranial intercondyloid fossa of the tibia, and it measured

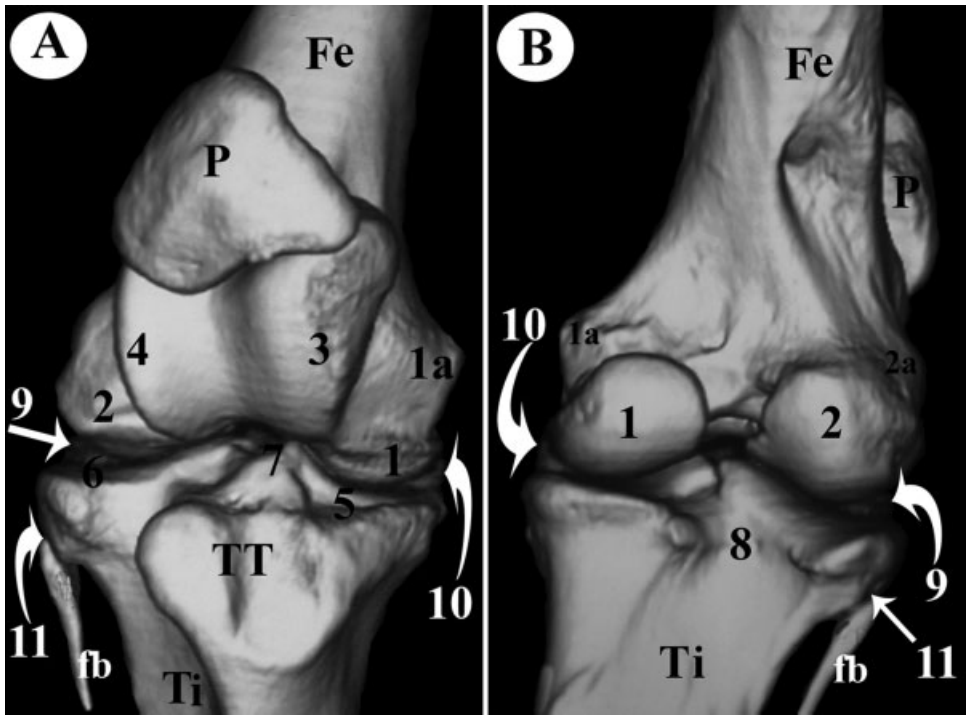

Fig. 10 Volume-rendered images (reconstruction) of the right stifle joint of the donkey: (View A) cranial and (View B) caudal views. F- femur. T- Tibia. P- patella. fb- fibula. TT- tibial tuberosity. EF- extensor fossa. 1- Medial condyle of the femur. 1a- Medial epicondyle. 2- Lateral condyle of the femur. 2a- lateral epicondyle. 3- Medial ridge of the trochlea of the femur. 4- Lateral ridge of the trochlea of the femur. 5- Medial condyle of the tibia. 6- Lateral condyle of the tibia. 7- Intercondyloid eminence. 8- Popliteal notch. 9- Extensor groove. 10- Proximal tibiofibular joint.

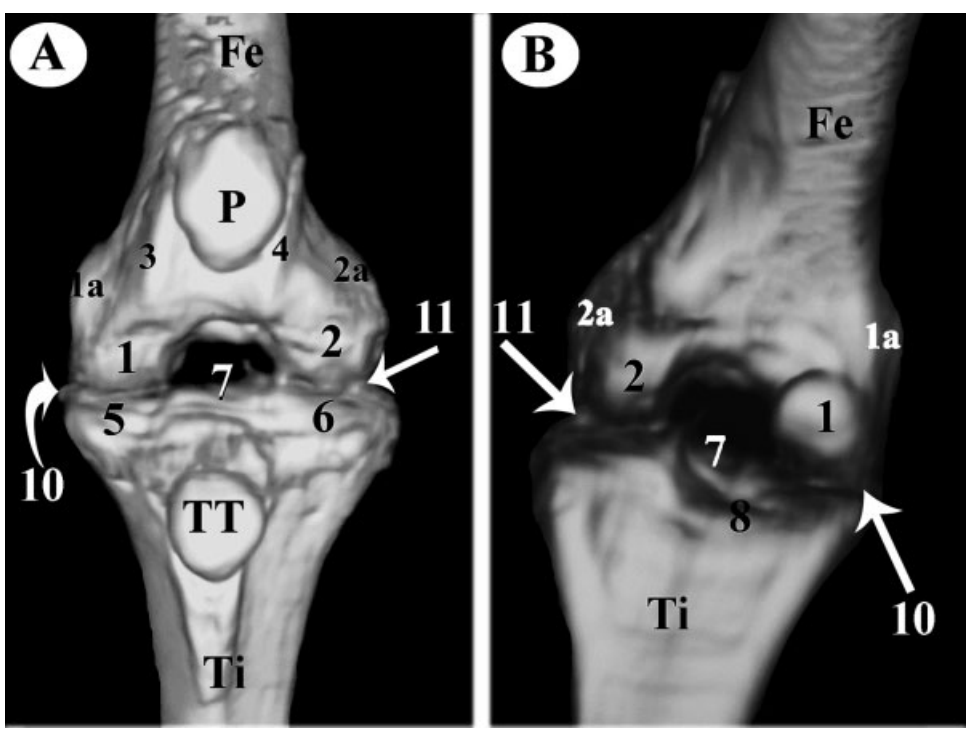

Fig. 11 Volume-rendered images (reconstruction) of the left stifle joint of the goat: (View A) cranial and (View B) caudal views. F- femur. T- tibia. P- patella. fb- fibula. TT- tibial tuberosity. 1- Medial condyle of the femur. 1a- Medial epicondyle. 2- Lateral condyle of the femur. 2a- Lateral epicondyle. 3- Medial ridge of the trochlea of the femur. 4- Lateral ridge of the trochlea of the femur. 5- Medial condyle of the tibia. 6- Lateral condyle of the tibia. 7- Intercondyloid eminence. 8- Popliteal notch. 9- Extensor groove. 10- Lateral meniscus.

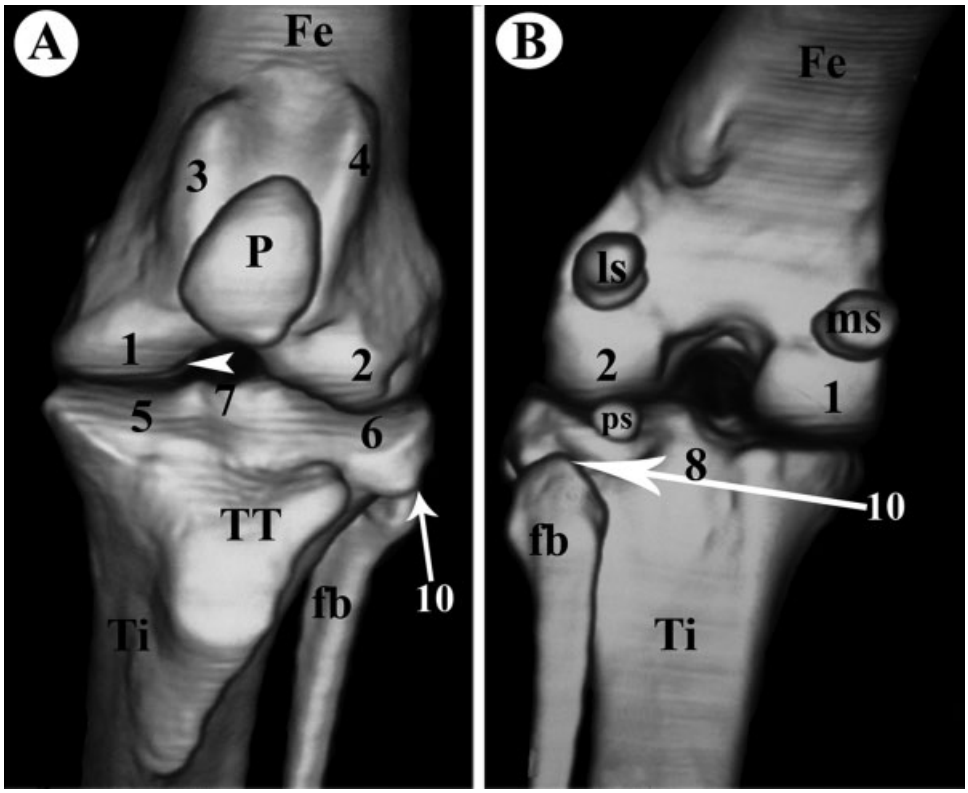

Fig. 12 Volume-rendered images (reconstruction) of the left stifle joint of the dog: (View A) cranial and (View B) caudal views. F- femur. T- tibia. P- patella. fb- fibula.TT- Tibial tuberosity. ms- medial sesamoid bone of the tendon of the gastrocnemius muscle. ls- Lateral sesamoid bone of the tendon of the gastrocnemius muscle. ps- Sesamoid bone of the tendon of the popliteus muscle. EF- extensor fossa. 1- Medial condyle of the femur. 2- Lateral condyle of the femur. 3- Medial ridge of the trochlea of the femur. 4- Lateral ridge of the trochlea of the femur. 5- Medial condyle of the tibia. 6- Lateral condyle of the tibia. 7- Intercondyloid eminence. 8- Popliteal notch. 9- Extensor groove. 10- Proximal tibiofibular joint.

Table 1 Average measurements of length (L) and weight (W) of the medial and lateral condyles of the femur and tibia in addition to the lateral and medial meniscus

Item	Donkey		Goat		Dog	
Medial femoral condyle	L	6 ± 0.3	L	2.5 ± 0.31	L	3 ± 0.29
	W	4 ± 0.5	W	1.5 ± 0.29	W	1.2 ± 0.2
Lateral femoral condyle	L	5 ± 0.35	L	3 ± 0.31	L	3.5 ± 0.21
	W	3 ± 0.48	W	3 ± 0.2	W	1.6 ± 0.21
Medial tibial condyle	L	4.5 ± 0.35	L	2.6 ± 0.22	L	2 ± 0.23
	W	2.6 ± 0.25	W	0.8 ± 0.25	W	1.2 ± 0.3
Lateral tibial condyle	L	3.5 ± 0.19	L	3.3 ± 0.21	L	2.9 ± 0.25
	W	3.2 ± 0.25	W	1 ± 0.3	W	1.3 ± 0.24
Medial meniscus	L	4 ± 0.5	L	1.4 ± 0.34	L	1.5 ± 0.4
	W	1.2 ± 0.2	W	0.8 ± 0.35	W	0.6 ± 0.34
Lateral meniscus	L	2.5 ± 0.21	L	2.4 ± 0.21	L	1.5 ± 0.2
	W	0.6 ± 0.19	W	0.5 ± 0.19	W	0.5 ± 0.24

∼ 1.3 cm long and 0.7 cm wide in the donkey (►**Fig. 6A** and **9A/cm**). In the goat, is measured ∼ 1.8 cm in length and 0.8 cm in width (►**Fig. 6B** and **9B/cm**). In the dog, the cranial ligament of the medial meniscus was absent, and the medial meniscus had no bony attachment to the tibia, but it was attached to the transverse or intermeniscal ligament that connected the cranial horn of the medial meniscus with the cranial ligament of the lateral meniscus, and it was located immediately cranial to the cranial ligament of the lateral meniscus, and the tibial attachment of the cranial cruciate ligament. It was ∼ 1.4 cm long and 0.2 cm wide (►**Fig. 6C** and **9C/tm**).

The caudal ligament of the medial meniscus attached the caudal pole of the medial meniscus with the caudal

Table 2 Correlation between the body weight and dimensions of the articular surfaces of the stifle joint of the donkey

	BW Vs MCFL	BW Vs MCFW	BW Vs LCFL	BW Vs LCFW	BW Vs MCTL	BW Vs MCTW	BW Vs LCTL	BW Vs LCTW
Correlation	0.535	0.076	.561	0.165	.425	.625	0.633	0.412
	BW Vs MML	BW Vs MMW	BW Vs LML	BW Vs LMW				
Correlation	0.798	-0.710	0.472	0.374				

There is positive correlation between body weight and MCFL, MCFW, LCFL, LCFW, MCTL, MCTW, LCTL, LCTW, MML, LML, LMW, and negative correlation with MMW.
Abbreviations: LCFL, length of the lateral femoral condyle; LCFW, Width of the lateral femoral condyle; LCTL, length of the lateral tibial condyle; LCTW, width of the lateral tibial condyle; LML, length of the lateral meniscus; LMW, width of the lateral meniscus; MCFL, length of the medial femoral condyle; MCFW, width of the medial femoral condyle; MCTL, length of the medial tibial condyle; MCTW, width of the medial tibial condyle; MML, length of the medial meniscus; MMW, width of the medial meniscus.

intercondyloid fossa of the tibia. In the donkey, it measured ~ 1 cm in length and width (►**Fig. 6A/dm**), while it was ~ 0.5 cm in length and 0.3 cm in width in the goat (►**Fig. 6B** and **9B/dm**). In the dog (►**Fig. 6C** and **9C/dm**), it attached cranial to the tibial attachment of the caudal cruciate ligament and it was ~ 0.2 cm in length and 0.1 cm in width.

The cranial ligament of the lateral meniscus connected the cranial pole of the lateral meniscus with the cranial intercondyloid fossa of the tibia. It was longer and thicker than that of the medial meniscus in the donkey (►**Fig. 6A** and **9A/cl**), it measured ~ 1.5 cm long and 1.3 cm wide. In the goat, it was ~ 0.7 cm in length and width (►**Fig. 6B** and **9B/cl**), while in the dog, it was ~ 0.3 cm in length and 0.1cm in width(►**Fig. 6C/cl**). In the dog, the cranial ligament of the lateral meniscus was located caudal to the transverse ligament, the caudal one was longer than the caudal ligament of the medial meniscus. The caudal ligament of the lateral meniscus connected the caudal pole of the lateral meniscus and divided into two parts, one attached to the medial part of the medial condyle of the tibia and the other to the popliteal notch. It measured ~ 1.5 cm long and 0.9 cm wide in the donkey (►**Fig. 5A** and **9A/dl**). In the goat, it measured 0.5 cm in length and 0.2 cm in width (►**Fig. 7B** and **9B/dl**), while in the dog, it was ~ 0.3 cm long and 0.2 cm wide (►**Fig. 7C** and **9C/dl**).

The meniscofemoral ligament connected the caudal pole of the lateral meniscus with the intercondyloid fossa of the femur. It measured ~ 2.7 cm in length and 0.8 cm in width in the donkey (►**Fig. 10A/MFL**); ~ 1.5 cm in length and 0.5 cm in width in the goat (►**Fig. 10B/MFL**), and ~ 1.3 cm long and 0.4 cm wide in the dog (►**Fig. 10C/MFL**). The length and width were calculated as means and recorded in ►**Table 5**.

The correlation between the body weight and dimensions of the articular surfaces of the stifle joint of the donkey, the goat and the dog are recorded in ►**Table 2**, **3** and **4**.

With volume-rendering reconstruction techniques, 3D-CT (►**Fig. 10**, **11** and **12**) images were produced, rotated and sectioned as desired. In 3D images (reconstruction), the characteristic features of the articular surfaces of the joint of each species evaluated (donkeys, goats and dogs), in which the lateral condyle of the femur appeared larger in the goat and in the dog.

Discussion

The present study was performed to describe the morphological features of the stifle menisci of donkeys, goats and dogs using gross anatomy, and CT, with special references to the articular surfaces. The animals have been chosen on the basis of the donkey being of the equine species, which is knows for carrying heavy loads for long distances; the goat being of the ruminant species, known for its limited mobility, and the dog of the carnivores that characterized by its fast-moving.

Table 3 Correlation between the body weight and dimensions of the articular surfaces of the stifle joint of the goat

	BW Vs MCFL	BW Vs MCFW	BW Vs LCFL	BW Vs LCFW	BW Vs MCTL	BW Vs MCTW	BW Vs LCTL	BW Vs LCTW
Correlation	0.226	0.042	.325	0.510	0.082	-0.075	0.246	0.0742
	BW Vs MML	BW Vs MMW	BW Vs LML	BW Vs LMW				
Correlation	0.344	0.283	0.356	0.439				

There is positive correlation between body weight and MCFL, MCFW, LCFL, LCFW, MCTL, LCTL, LCTW, MML, LML, LMW, and negative correlation with MCTW.
Abbreviations: LCFL, length of the lateral femoral condyle; LCFW, width of the lateral femoral condyle; LCTL, length of the lateral tibial condyle; LCTW, width of the lateral tibial condyle; LML, length of the lateral meniscus; LMW, width of the lateral meniscus; MCFL, length of the medial femoral condyle; MCFW, width of the medial femoral condyle; MCTL, length of the medial tibial condyle; MCTW, width of the medial tibial condyle; MML, length of the medial meniscus; MMW, width of the medial meniscus.

Table 4 Correlation between the body weight and dimensions of the articular surfaces of the stifle joint of the dog

	BW Vs MCFL	BW Vs MCFW	BW Vs LCFL	BW Vs LCFW	BW Vs MCTL	BW Vs MCTW	BW Vs LCTL	BW Vs LCTW
Correlation	0.247	0.403	0.449	0.054	0.037	0.165	0.322	0.453
	BW Vs MML	BW Vs MMW	BW Vs LMW	BW Vs LMW				
Correlation	0.559	0.505	0.559	0.291				

There is a positive correlation between body weight and MCFL, MCFW, LCFL, LCFW, MCTL, MCTW, LCTL, LCTW, MML, LML, LMW.
Abbreviations: LCFL, length of the lateral femoral condyle; LCFW, width of the lateral femoral condyle; LCTL, length of the lateral condyle of the tibia; LCTW, width of the lateral condyle of the tibia; LML, length of the lateral meniscus; LMW, width of the lateral meniscus; MCFL, length of the medial femoral condyle; MCFW, width of the medial femoral condyle; MCTL, length of the medial condyle of the tibia; MCTW, width of the medial condyle of the tibia; MML, length of the medial meniscus; MMW, width of the medial meniscus.

Table 5 Average measurements of length (L) and weight (W) of the meniscal ligament of the stifle joint

	Donkey		Goat		Dog	
Cranial ligament of the medial meniscus	L	1.3 cm	L	0.5 cm	Absent	
	W	0.7 cm	W	1.8 cm		
Transverse ligament	Absent		Absent		L	1.4 cm
					W	0.2 cm
Caudal ligament of medial meniscus	L	1 cm	L	0.5 cm	L	0.2 cm
	W	1 cm	W	0.3 cm	W	0.1 cm
Cranial ligament of lateral meniscus	L	1.5 cm	L	0.7 cm	L	0.3 cm
	W	1.3 cm	W	0.7 cm	W	0.1 cm
Caudal ligament of lateral meniscus	L	1.5 cm	L	0.5 cm	L	0.3 cm
	W	0.9 cm	W	0.2 cm	W	0.2 cm
Meniscofemoral ligament	L	2.7 cm	L	1.5 cm	L	1.3 cm
	W	0.8 cm	W	0.5 cm	W	0.4 cm

Concerning the articular surfaces of the femorotibial joint, they were the condyles of the femur and tibia and the menisci. The medial condyle of the femur of the donkey, goat and dog was oblique in direction and smaller than the lateral in the donkey and goat, this was observed by [25] in the donkey and mule and like that of the horse [26] and camel [27] while, the lateral condyle was sagittal in direction, this agreed with that observed by [25] in the donkey and mule,[26] in the horse and [28] in the dog.

The current investigation mentioned that the medial condyle of the femur was larger than the lateral one in the donkey, while it was smaller and lower than the lateral one in the goat and in the dog. The results in the dog and in the goat are similar to those obtained by[29] in the marsh deer and [9,30] in the ovine.

In the dog, the articular surfaces of the two condyles were continuous proximocaudally with small articular facet for sesamoid bones, which present in the tendons of the medial and lateral head of the gastrocnemius muscle; however, this is absent in the horse and in the goat. Similar results were noted by [9,29] in sheep and deer. In the dog, the femoral condyles were articulated with the sesamoid bones of the tendons of the gastrocnemius muscle, this agreed with that described by [28] in the dog.

The medial condyle of the tibia was triangular in shape in the donkey and goat likes that of the donkey and mule [25] and in the camel, [27] while that of the dog was oval in shape and the lateral condyle was circular as noted by.[28] The adaptation of the condyles of the femur and tibia was compensated by the presence of the menisci, which increase femorotibial joint stability and congruency and serve as the shock absorbers of the stifle.[31,32] The medial meniscus of the donkey was crescentic in shape, as mentioned by ,[25] while in the goat, it was semicircular, and in the dog, the medial and lateral menisci were C-shaped.

In general, the normal medial and lateral menisci were smooth, white and located between the two condyles of the femur and tibia to improve joint adaptation.[2,4,5,9,10,33] In the examined donkey and goat, the meniscal ligaments included the cranial and caudal ligaments of the medial and lateral menisci and the meniscofemoral ligament of the lateral meniscus, similar to that observed by[26,34,35] in horse,[36,37] in ovine, [27] in camel and [4] in humans, sheep and rabbits. In the dog, the cranial ligament of the medial meniscus was absent, and the medial meniscus had no bony attachment to the tibia, but it was attached to the transverse intermeniscal ligament, which connected the cranial horn of the medial

meniscus to the cranial ligament of the lateral meniscus. This did not agree with the findings of [28] in the dog. Moreover, the absence of the caudal ligament of the lateral menisci was recorded in rabbits by.[4,38]

In the current study, there is a transverse intermeniscal ligament that connects the cranial horn of the medial meniscus with the cranial ligament of the lateral meniscus in the dog, but the present study did not record this ligament in the donkey and the goat. The transverse intermeniscal ligament was also observed by[33] in tigers,[4,38] rabbits and [39–42] in dogs and cats. They also [43] described this ligament in the dog and pig, but reported that it was absent in sheep. The transverse intermeniscal ligament was also absent in donkey and goat, in the current study, and sheep [9] and deer.[29]

The meniscofemoral ligament connected the caudal pole of the lateral meniscus with the intercondyloid fossa of the femur. The similar observations were recorded in all animal species [25,29,33,39,42]

Conclusion

The medial condyle of the femur was larger than the lateral one in the donkey, while it was smaller and lower than the lateral one in the goat and in the dog. In the donkey, the medial meniscus was larger than the lateral one, but in the goat and in the dog, the lateral meniscus was the largest, more concave and thicker. The meniscus ligaments included cranial and caudal ligaments of the medial and lateral menisci, and the meniscofemoral ligament of the lateral meniscus. In the dog, the cranial ligament of medial meniscus was absent, and the medial meniscus had no bony attachment to tibia, but it attached to the transverse intermeniscal ligament, which connected the cranial horn of the medial meniscus with the cranial ligament of lateral meniscus. The meniscofemoral ligament connected the caudal pole of the lateral meniscus with the intercondyloid fossa of the femur.

Contribution of the Authors to the Manuscript

All authors confirm their contribution. Mohamed Abumandour was responsible for the data collection, data analysis, manuscript writing/editing, anatomical dissection and protocol/project development. Samir El-Gendy was responsible for the protocol/project development and the manuscript revision. Ashraf Karkoura was responsible for following up the protocol/project and for the manuscript revision. Raafat El-Bakary was responsible for following up the data analysis and the manuscript preparation. Naglaa Fathi was responsible for the manuscript writing/editing, protocol/project development, data collection, data analysis and anatomical dissection.

Ethics Approval and Consent to Participate

The present article was performed with the approval of the Bioethics Committee and in accordance with the guidelines for the care and use of laboratory animals and the Animal Welfare and Ethics Committee of the Faculty of Veterinary Medicine at Alexandria University, following the Egyptian laws.

Data and Material Availability

All data used in this study were included in this published article.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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