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A Detailed Anatomical Description of the Gastrocnemius Muscle—Is It Anatomically Positioned to Function as an Antagonist to the Anterior Cruciate Ligament?

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Abstract: Objective: The purpose of this cadaveric investigation was to provide a detailed morphologic description of the proximal gastrocnemius within the popliteal region of the knee and test the hypothesis that the gastrocnemius is anatomically positioned to function as an antagonist to the anterior cruciate ligament (ACL) of the knee. Methods: Twenty-two lower limbs from 11 embalmed cadavers underwent detailed dissection and anatomical analysis. Results: The results indicate that 63.3 ± 5.8% of the popliteal region is comprised of the hamstrings and the gastrocnemius, whereas 36.8 ± 5.7% is occupied by free space (fossa). Within the popliteal region, the gastrocnemius had a length crossing above the knee joint line of 5.4 ± 1.2 cm, which would likely result in a posterior pull on the femur during muscular contraction. Data provide an in-depth description of length and width morphology of the gastrocnemius and provide a detailed comparison between the medial and lateral heads of the muscle. Our results agree with earlier reports in the literature which suggest that the medial head is significantly longer and wider than the lateral head of the gastrocnemius. The medial head length was 23 ± 3.4 cm, compared to a lateral head length of 20.5 ± 2.9 cm. The medial head maximum width was 5.5 ± 1.6 cm, compared to a lateral head maximum width of 4.2 ± 1.1 cm. Conclusion: This research expands on past descriptions of the femoral origin of the gastrocnemius muscle's medial head and confirms past descriptions of the lateral head origin on the femur. Our data clearly illustrate that the femoral attachment of the medial head of the gastrocnemius was much different (or more complex) than previously described and that it wraps around the posterior side of the medial femoral condyle and attaches more anteriorly. Further research should be directed at exploring the functional significance (if any) of these differences and examining the effect they may have on ACL function and knee joint kinematics.

Keywords: cadaver; musculoskeletal; morphology

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1. Introduction and Background

The anterior cruciate ligament (ACL) is a critical stabilizing ligament within the human knee and functions to restrict excessive anterior tibial translation on the femur [1]. Research examining mechanisms of ACL injury indicate that the etiology is multifactorial and influenced by both extrinsic and intrinsic factors of the joint [2]. Anterior cruciate ligament injury has been described as the "beginning of the end of the knee", with retrospective research revealing that 50% of ACL-injured knees demonstrate severe degenerative changes (i.e., knee osteoarthritis) within 20 years of initial injury [3]. While ACL research has clearly established the important role that hamstring contraction plays in helping to resist anterior tibial translation during movement (i.e., serving as an agonist to ACL function) [4–9], several researchers have hypothesized that the gastrocnemius may also be anatomically positioned to influence knee joint kinematics [4–8]. Because both the hamstrings and the gastrocnemius are two-joint muscles that cross the knee and both function to reinforce and stabilize the posterior aspect of the joint and serve as key anatomical boundaries for the popliteal region of the knee, it is plausible that both muscles groups may influence knee joint kinematics.

Within the anatomical literature, the distal attachments of the three hamstring muscles (biceps femoris = head of fibula; semitendinosus = anteromedial aspect of proximal tibia (pes anserine region); semimembranosus = posterior aspect of medial tibial condyle) have been well documented [10] and a large body of research exists which describes how the hamstrings function to influence tibial–femoral motion at the knee. The hamstrings act as an ACL agonist, with contraction serving to limit the anterior translation of the tibia on the femur [4–9]. In contrast, the anatomy and function of the gastrocnemius about the knee joint are less well understood. In textbooks, the gastrocnemius is classically described as being comprised of two proximal sections—the lateral and the medial heads. The lateral head is described as originating from the lateral surface of the lateral femoral epicondyle, proximal to the popliteal tendon, while the medial head originates from the posterior surface of superior medial femoral condyle [11,12]. Anthropometric data from several detailed cadaveric investigations have served to confirm these classical descriptions but have also helped to extend our traditional understanding of gastrocnemius anatomy as it relates to the muscle's femoral footprint. These articles indicate that there are significant structural differences between the medial and lateral heads of the gastrocnemius [12–14], with the medial head being much larger than the lateral head when comparing the length, width, and depth of the respective muscle bellies [13,14]. Interestingly, this research has also demonstrated that the medial head arises from a much stronger and larger tendon, whose femoral attachment is very different as compared to that of the lateral head [12]. This enhanced anatomical knowledge has led to speculation that the gastrocnemius may be anatomically positioned to function as an ACL antagonist—with gastrocnemius contraction serving to increase posterior translation of the distal femur on the proximal tibia [4–8]. To date, functional investigations designed to examine the effect of gastrocnemius contraction on knee joint kinematics have suffered from a host of methodological inconsistencies and produced conflicting results [4–6,8,15–18].

The goal of this investigation was to conduct an in-depth anatomical inspection of the proximal aspect of the gastrocnemius within the popliteal region of the knee and test the hypothesis that the gastrocnemius is anatomically positioned to function as an antagonist to the anterior cruciate ligament (ACL) of the knee. The study had three specific aims: 1. quantify the diameter of the popliteal fossa; 2. provide a detailed anatomical description of the gastrocnemius (comparing the medial and lateral heads.); 3. determine whether the anatomical position of the gastrocnemius would support it functioning as an antagonist to the ACL.

2. Materials and Methods

Following institutional ethics approval, this observational-based investigation relied on blunt and sharp methods of dissection to perform a detailed anatomical examination of gastrocnemius and the popliteal region of the knee. Each of the cadaveric specimens were bequeathed to the medical program at the University of Manitoba under "The Human Tissue Gift Act" of the province of Manitoba. This government regulation ensures anonymity for donors and restricts access to all health records. The sample size chosen for this investigation was a "sample of convenience" and reflected the total number of intact (i.e., not previously dissected), embalmed cadaveric limbs available to our research group at the time of the study.

2.1. Popliteal Region

Measurements of the muscular boundaries of the popliteal region (i.e., biceps femoris, semimembranosus/semitendinosus, and medial and lateral heads of gastrocnemius), as well as the space between each muscle, where completed according to a standardized measurement rubric (Figure 1a–c), while each cadaveric specimen was positioned prone, knees fully extended, and held at zero degrees of rotation. More specifically, the superior and inferior boundaries of the hamstring (Figure 1b) and gastrocnemius (Figure 1c) muscles within the popliteal region were identified and marked, along with the point at which each muscle crossed the posterior joint line of the knee. The widths of each muscle were measured to the nearest cm at each of these points, helping to form a rectangular shape. The area of this rectangle was then used to calculate the total area of the posterior knee region. The knee joint line was defined as the space between the tibia and the femur.

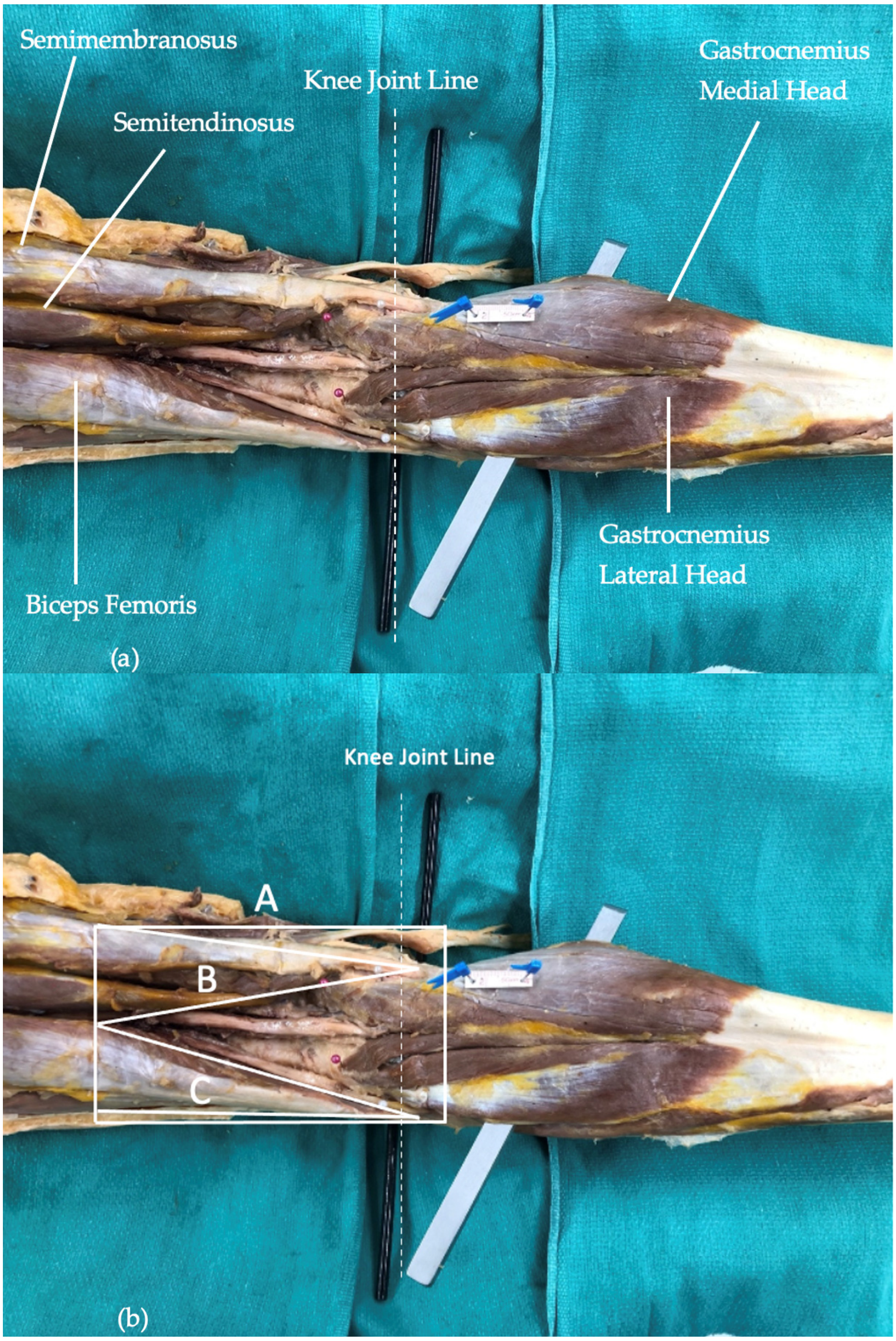

Figure 1. *Cont.*

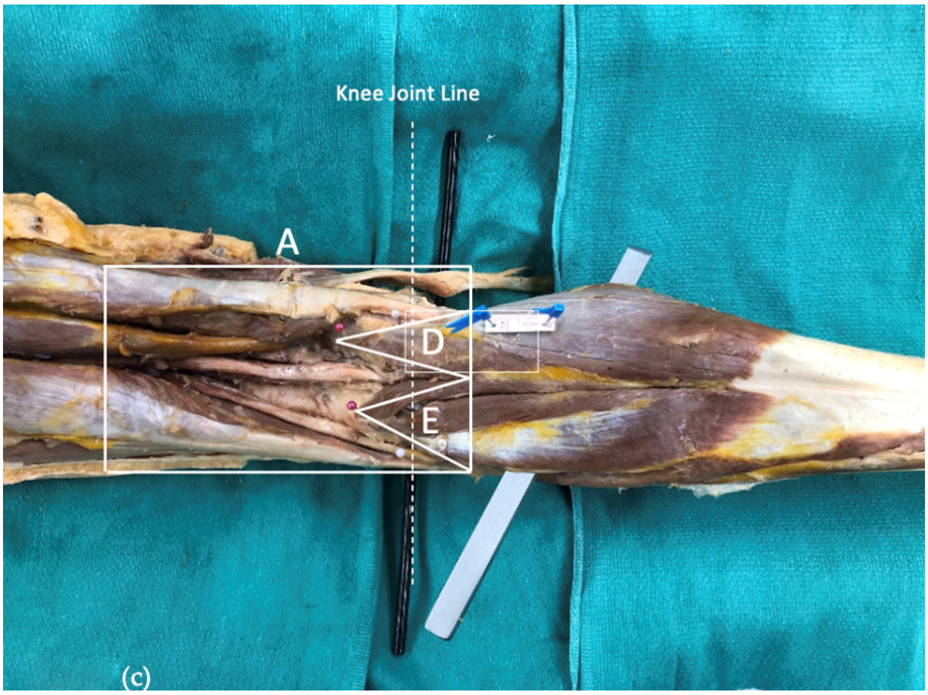

Figure 1. (**a**). Image of a fully dissected posterior knee. This figure illustrates the popliteal region of the posterior knee. The anatomical position of the hamstrings and gastrocnemius can be seen with respect to the knee joint line. (**b**). Hamstring muscle contribution to popliteal fossa. A: area of posterior knee region (rectangle). B: area of semimembranosus/semimembranosus within the posterior knee region. C: area of biceps femoris within the posterior knee region. (**a**,**b**) legend: The area of each of the muscles was calculated using Heron's formula. The total area of muscle within the posterior knee region = B + C + D + E. The total area of space (fossa) within the posterior knee region = A − (B + C + D + E). (**c**). Gastrocnemius contribution to popliteal fossa. A: area of posterior knee region (rectangle). D: area of medial gastrocnemius head within the posterior knee region (blue triangle). E: area of lateral gastrocnemius head within the posterior knee region (blue triangle). (**c**) legend: The area of each of the muscles was calculated using Heron's formula. The total area of muscle within the posterior knee region = B + C + D + E. The total area of space (fossa) within the posterior knee region = A − (B + C + D + E).

Beyond this, the distance from which the hamstrings intersect above the knee joint line to the point at which they insert distally below the knee joint line was also measured. These 2 distances, along with the width of each hamstring, were used to create a triangle superior to the knee joint line Figure 1b). Heron's formula (Appendix A) was then used to calculate the 'total area" of the superior triangle created by the hamstrings within the posterior knee region. (See "B" and "C" in Figure 1b). Similar calculations were made for gastrocnemius to calculate the area of the inferior triangle below the knee joint line that was created by gastrocnemius within the posterior knee region (See "D" and "E" in Figure 1c).

2.2. Gastrocnemius Morphology

A detailed examination of the morphological features of gastrocnemius was then completed. This included measurement of (1) total muscle belly length of the medial and lateral heads; (2) maximum width of each muscle belly; (3) length of each head's musculotendinous junction; (4) size and location of each head's femoral attachments; and (5) positioning of gastrocnemius relative to knee joint line. Measurements were taken of muscle length above knee joint line, total muscle belly length, and total muscle length including the Achilles tendon. Additionally, the width of each head of gastrocnemius was measured to the nearest cm at four points: (1) knee joint line; (2) 25% muscle head length below the knee joint line;

(3) 50% muscle head length below the knee joint line; and (4) 75% muscle head length below the knee joint line.

The Achilles tendon of each muscle was then transected, and the muscle was reflected superiorly to allow a full 360-degree view of both the anterior and posterior surfaces of each head of the muscle (Figure 2). This facilitated a detailed inspection of the femoral attachments of both heads of the muscle. The origin of the medial head of gastrocnemius had been previously described as including a thick tendinous region on the anterior (bony) side of the attachment that is only apparent once the muscle is reflected superiorly, whereas the lateral head of gastrocnemius does not have this thick tendinous region at its origin [10]. The size of the tendinous region at the origin of the medial head of the gastrocnemius was calculated by measuring the width of the tendinous attachment on the femoral condyle, the vertical height of the tendinous region, and the diagonal distance between the most distal part of the tendinous region and the lateral end of the attachment at the origin of the medial head origin from the femoral condyle. Using Heron's formula (Appendix A), these three distances were used to create a triangle that represented the total area of the proximal tendon of the medial head (See "A" in Figure 2). The same procedures were used to calculate the size of the lateral head's tendinous attachment to the femur.

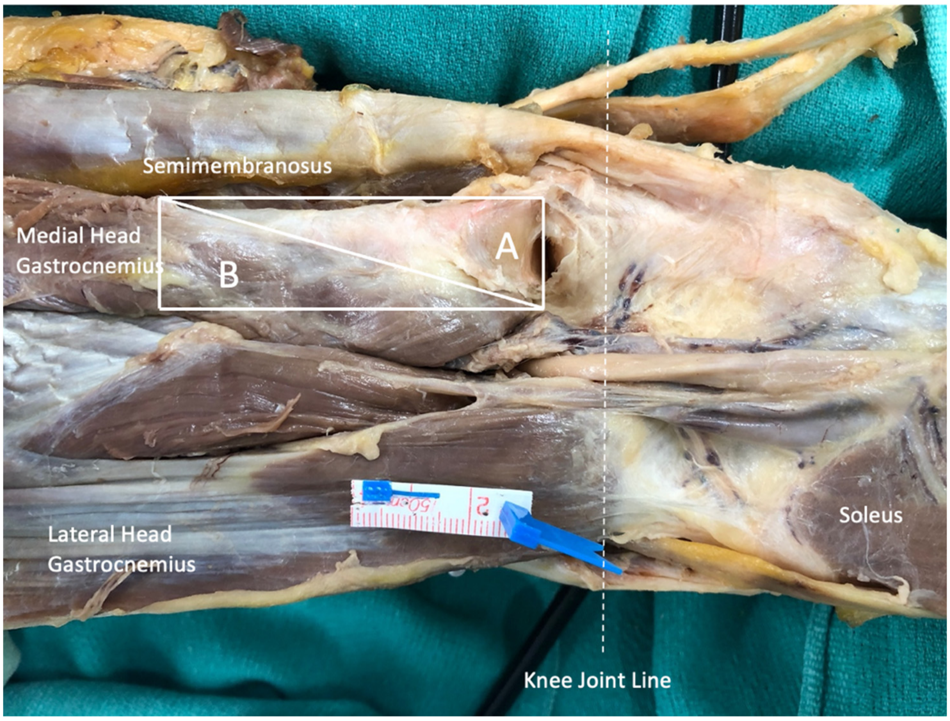

Figure 2. Origin of medial gastrocnemius (reflected superiorly) at medial femoral condyle. Medial gastrocnemius head reflected superiorly. Lateral gastrocnemius head reflected superiorly. A: area of tendon at the origin of the medial gastrocnemius head. B: area of muscle at the origin of the medial gastrocnemius head. Legend: The origin of the medial gastrocnemius head at the medial femoral condyle at the posterior knee is presented. The gastrocnemius is cut at the Achilles tendon and superiorly reflected over the hamstrings to provide a better view of the proximal attachment of the medial gastrocnemius head on the femoral condyle. The area of muscle only included the triangular area "B" from the proximal attachment to the femur until the most distal point of the musculotendinous junction. The area of the tendon "A" and area of the muscle "B" in the proximal region of the medial gastrocnemius head were calculated using Heron's formula (See Appendix A).

2.3. Statistical Analyses

Paired T-testing was used to analyze left and right limb data for each specimen, as well as to compare morphological data from the medical and lateral heads of gastrocnemius from the same limb. One-way ANOVA testing was used to compare measurements across all cadaveric specimens. A result was considered significant if it was $p \leq 0.05$.

3. Results

A total of 22 limbs (left leg = 11/right leg = 11) from 11 embalmed Caucasian cadavers were dissected for this investigation over a 14-month period.

Descriptive data for key measurements of the posterior knee region (as illustrated in Figure 1) are reported in Table 1. The total mean area of the posterior knee region for the 22 cadaveric limbs was 157.3 ± 5.6 cm^2. The total area of muscle within the posterior knee region averaged 97.1 ± 15.9 cm^2. While the hamstrings comprised a majority of the muscular area of the posterior knee region, their length below the knee joint line was calculated to be less than the length of the gastrocnemius located above the knee joint line. Globally, there were no significant differences between the left or right limbs for any of the posterior knee measurements.

Table 1. Posterior knee region measurements—mean ± SD (range).

Parameter	Left (n = 11)	Right (n = 11)	Total (n = 22)
Area of posterior knee region (cm^2)	153.1 ± 23.7 (116.0–177.6)	161.4 ± 29.5 (106.0–209.8)	157.3 ± 5.6 (106.0–209.8)
Area of semimembranosus/semitendinosus (cm^2)	* 30.6 ± 6.0 (24.7–46.1)	33.4 ± 8.0 (26.6–54.8)	32.0 ± 7.0 (24.7–54.8)
Area of biceps femoris (cm^2)	30.6 ± 5.2 (21.4–38.3)	31.7 ± 5.6 (22.4–40.2)	31.1 ± 5.3 (21.4–40.2)
Area of medial gastrocnemius (cm^2)	20.5 ± 5.4 (13.6–33.5)	20.0 ± 5.9 (11.4–29.6)	20.3 ± 5.5 (11.4–33.5
Area of lateral gastrocnemius (cm^2)	15.4 ± 4.9 (9.6–25.5)	15.8 ± 4.3 (9.0–23.9)	15.6 ± 4.5 (9.0–25.5)
Total % of region that is muscle	63.6 ± 5.2 (57.8–72.4)	62.9 ± 6.5 (56.0–78.0)	63.3 ± 5.8 (56.0–78.0)
Total % of region that is space (fossa)	36.4 ± 5.2 (27.6–42.2)	37.1 ± 6.5 (22.0–44.0)	36.8 ± 5.7 (22.0–44.0)

* $p \leq 0.05$.

Morphological data for the hamstrings and gastrocnemius are presented in Table 2. There were no significant differences between the left and right limbs for any of these measurements. However, the data did illustrate that the length of the gastrocnemius above the knee joint line (5.4 ± 1.2 cm) was consistently longer than the length of the semimembranosus (2.0 ± 0.5 cm) and biceps femoris (2.5 ± 0.5 cm) tendons below the knee joint line.

Table 2. Length measurements about the posterior lower extremity—mean ± SD (range).

Muscle	Muscle Lengths (cm)	Left (n = 11)	Right (n = 11)	Total (n = 22)
Gastrocnemius	Total gastrocnemius muscle belly	23.6 ± 3.5 (17.9–28.4)	23.4 ± 3.4 (17.7–29.1)	23.5 ± 3.4 (17.7–29.1)
	Gastrocnemius muscle including Achilles tendon	42.3 ± 3.9 (35.9–49.3)	42.6 ± 4.0 (37.0–50.2)	42.5 ± 3.9 (35.9–50.2)
	Gastrocnemius above knee joint line	5.2 ± 1.0 (4.4–7.1)	5.6 ± 1.4 (4.3–8.3)	5.4 ± 1.2 (4.3–8.3)
Hamstrings	Semitendinosus tendon below knee joint line	2.0 ± 0.6 (1.0–2.8)	1.9 ± 0.5 (1.4–2.8)	2.0 ± 0.5 (1.0–2.8)
	Biceps femoris below knee joint line	2.5 ± 0.6 (1.6–3.2)	2.5 ± 0.5 (1.8–3.2)	2.5 ± 0.5 (1.6–3.2)

An in-depth anatomical description of the width of the gastrocnemius at standardized points (25%, 50%, and 75%) within the posterior region of the knee are provided in Table 3. There were no significant differences between the left or right limbs. The maximum width of the muscle belly was at approximately 50% of the muscle head length below the knee joint line. The total width of the gastrocnemius at the knee joint line was 5.0 ± 1.6 cm.

Table 3. Gastrocnemius width measurements—mean ± SD (range).

Muscle Widths (cm)	Left (n = 11)	Right (n = 11)	Total (n = 22)
Maximum width	9.7 ± 2.5 (6.1–15.5)	9.6 ± 2.7 (6.2–15.7)	9.7 ± 2.5 (6.1–15.7)
At knee joint line	5.0 ± 1.6 (2.8–7.3)	5.0 ± 1.8 (2.5–7.8)	5.0 ± 1.6 (2.5–7.8)
At 25% muscle head length below the knee joint line	7.6 ± 1.9 (5.1–11)	7.2 ± 2.1 (4.2–11.6)	7.4 ± 2.0 (4.2–11.6)
At 50% muscle head length below the knee joint line	9.4 ± 2.5 (5.6–15.1)	9.4 ± 2.7 (5.9–15.6)	9.4 ± 2.5 (5.6–15.6)
At 75% muscle head length below the knee joint line	8.0 ± 2.3 (4.5–12.8)	7.7 ± 2.3 (4.7–12.8)	7.9 ± 2.2 (4.5–12.8)
At musculotendinous junction	6.9 ± 1.4 (5.1–9.2)	6.5 ± 1.7 (4.1–9.2)	6.7 ± 1.6 (4.1–9.2)

Table 4 compares the morphology of the medial and lateral heads of the gastrocnemius. All measurements indicate that the medial head was significantly different than the lateral head of the gastrocnemius. The mean muscle belly length of the medial head was 23.5 ± 3.4 cm, compared to a total muscle belly length of the lateral head measuring 20.5 ± 2.9 cm. The length of the medial head above the knee joint line measured 5.4 ± 1.2 cm, compared to 3.5 ± 1.0 cm measured for the lateral head.

Table 4. Medial vs. lateral head of gastrocnemius length measurements—mean ± SD (range).

Lengths (cm)	Medial Head (n = 22)	Lateral Head (n = 22)
Total muscle belly	** 23.5 ± 3.4 (17.7–29.1)	20.5 ± 2.9 (15.0–26.1)
Muscle belly above knee joint line	** 5.4 ± 1.2 (4.3–8.3)	3.5 ± 1.0 (1.4–5.9)
From the knee joint line to the point of muscle belly maximum width	* 8.5 ± 1.6 (5.2–11.6)	7.3 ± 2.2 (0.6–9.9)
Achilles tendon	** 18.9 ± 1.4 (16.7–21.1)	20.4 ± 1.4 (18.4–22.6)
Gastrocnemius muscle head and Achilles tendon (cm)	* 42.5 ± 3.9 (35.9–50.2)	40.9 ± 3.6 (35.2–47.7)
% of gastrocnemius muscle belly compared to Achilles Tendon	** 55.2 ± 3.9 (47.7–61.1)	50.0 ± 3.6 (40.0–54.7)

* $p \leq 0.05$; ** $p \leq 0.01$.

Table 5 compares the widths of the medial and lateral heads of the gastrocnemius. All measurements indicate that the medial head was significantly wider than the lateral head.

The maximum width of the medial head was on average 5.5 ± 1.6 cm, with its mean width at the knee joint line being 2.6 ± 0.9 cm.

Table 6 provides an anatomical description of the proximal attachment of the medial head of the gastrocnemius into the medial femoral condyle (please see Figure 2 for a detailed image of the anatomy). The data indicate that there were no significant differences between the left or right limbs. The thick tendinous region at the origin of the medial head of the gastrocnemius was seen in all 22 specimens.

Table 5. Medial vs. lateral head of gastrocnemius width measurements—mean ± SD (range).

Widths (cm)	Medial Head (n = 22)	Lateral Head (n = 22)
Maximum width of muscle belly	** 5.5 ± 1.6 (3.1–8.5)	4.2 ± 1.1 (2.9–7.2)
At knee joint line	** 2.6 ± 0.9 (1.3–4)	2.4 ± 0.8 (1.2–3.8)
At 25% distal to knee joint line	** 4.0 ± 1.2 (2–6.7)	3.5 ± 1.0 (1.9–5.8)
At 50% distal to knee joint line	** 5.3 ± 1.5 (2.8–8.4)	4.1 ± 1.2 (2.7–7.2)
At 75% distal to knee joint line	** 4.6 ± 1.5 (2.2–7.4)	3.3 ± 0.9 (2.0–5.5)
Musculotendinous junction	** 4.1 ± 1.1 (2.3–6)	2.6 ± 0.7 (1.8–3.9)

** $p \leq 0.01$.

Table 6. Measurements of the origin of the medial head of the gastrocnemius about the medial femoral condyle—mean ± SD (range).

Parameter	Left (n = 11)	Right (n = 11)	Total (n = 22)
Area of tendon (cm^2)	7.7 ± 2.4 (5.5–12.7)	7.8 ± 2.7 (5.0–12.8)	7.8 ± 2.5 (5.0–12.8)
Area of muscle (cm^2)	12.4 ± 4.9 (5.1–22.1)	11.9 ± 3.7 (7.4–18.9)	12.1 ± 4.2 (5.1–22.1)
% Tendon	39.5 ± 6.2 (31.7–51.9)	39.8 ± 7.4 (32.0–57.7)	39.7 ± 6.6 (31.7–57.7)
% Muscle	60.5 ± 6.2 (48.1–68.3)	60.2 ± 7.4 (42.3–68.0)	60.3 ± 6.6 (42.3–68.3)

4. Discussion

This investigation provides a cadaveric-based anatomical description of the muscular anatomy of the posterior knee (popliteal) region and includes a morphological description of the medial and lateral heads of the gastrocnemius which details how the femoral attachments of the two heads are different. To our knowledge, this is the first investigation to compare the femoral footprint and tendinous attachments of the medial and lateral heads of the gastrocnemius. The results provide an anatomical explanation that supports the assertion by previous authors that the gastrocnemius is anatomically positioned to influence knee joint kinematics [4–8]. The data help to further our anatomical understanding of the posterior region of the knee and the superior aspect of the gastrocnemius and serve to clarify that the muscle is structurally positioned to potentially function as an antagonist to the ACL.

4.1. Limb Symmetry

In the current investigation, bilateral limb symmetry was observed for all major measurements involving the popliteal region, hamstring and gastrocnemius morphology, and muscle–bone/muscle–tendinous attachments. This result is not surprising because bipedal movements of the lower extremity help to promote limb symmetry. Beyond this, the confirmation of limb symmetry among the cadaveric specimens helps to rule out underlying pathologies as a factor that may confound an accurate interpretation of the study dataset.

4.2. Popliteal Region

This investigation is one of the first to clearly define and measure the surface area of muscles within the popliteal region of the knee. While the hamstrings and gastrocnemius both function as knee joint flexors, their morphology about the popliteal region would seem to indicate that they play opposing roles in maintaining knee joint stability [4–8]. Our data indicate that only a small portion of each of the hamstring muscles was located below the knee joint line. In contrast, the length of the gastrocnemius crossing the knee joint line was much larger than that of the hamstrings. Therefore, if the hamstrings are positioned to function as an ACL agonist by providing a posterior pull on the proximal tibia during muscular contraction [4–9], it seems likely that the gastrocnemius is also anatomically positioned to function as an ACL antagonist, providing a posterior pull to the distal femur during muscle contraction. Our morphological data are important clinically because they suggest that a muscle contraction (or even passive lengthening) of either the hamstrings or gastrocnemius may influence knee joint kinematics. As such, when performing orthopedic tests (i.e., Anterior Drawer test and Lachman's test) that are designed to evaluate the integrity of the ACL, it is possible that activation of either muscle group may unduly influence the diagnostic accuracy of these tests [19]. Further research is clearly needed to clarify the exact effect that these two muscle groups (hamstring vs. gastrocnemius) have on knee joint kinematics and whether they influence anterior/posterior knee joint kinematics differently depending on the degree of knee flexion.

4.3. Gastrocnemius Morphology

The results of this investigation serve to confirm and clarify previous data about the morphology of the gastrocnemius. Our results show that there were significant differences between the medial and lateral heads of the gastrocnemius in length, width, and location. The medial head was consistently wider than the lateral head, across all measurements, with the gastrocnemius–Achilles musculotendinous junction for the medial head also being wider. A key finding of this investigation was that the medial head of the gastrocnemius was significantly longer than the lateral head when measured from knee joint line. The data indicate that the medial head extended 5.4 ± 1.2 cm above the knee joint line, while the lateral head extended only 3.5 ± 1.0 cm above the knee joint line. The larger morphology of the medial head is consistent with the anatomical arrangement of the lower extremity. The medial femoral condyle of the femur is significantly larger than the lateral condyle [20]; the medial meniscus is the larger of the two menisci [21–24]; the tibia is significantly larger than the fibula [21], and the medial longitudinal arch is larger than the lateral [25]. Beyond this, valgus-directed forces to the lower extremities occur with greater frequency than varus loads. However, it is important to note that our morphological data for the gastrocnemius do contradict the findings from at least one previous cadaveric study involving the gastrocnemius which reported that the length and width measurements of the medial and lateral heads of the gastrocnemius were similar [14]. Methodological differences between studies may account for this variation.

4.4. Femoral Attachment of Medial Head of Gastrocnemius

The results of the current study clearly illustrate that there were also significant differences in the positioning and architecture of the medial and lateral heads of the gastrocnemius when examining their femoral attachments. The proximal portion of the medial head of the gastrocnemius included a thick tendinous region that wrapped around the posterior surface of the medial femoral condyle to gain attachment on its anterior–superior surface—the uniqueness of this femoral attachment was only visible once the muscle was transected at its musculotendinous junction and reflected superiorly, thereby providing a view of the femoral attachment from below/behind (Figure 2). It is important to note that this thick tendinous region of the gastrocnemius at its medial origin on the femoral condyle was observed in all 22 specimens included in this study. In contrast, the lateral head of the gastrocnemius did not have as thick of a proximal tendon and simply attached to the posterior–superior surface of the lateral femoral condyle, proximal to the popliteal muscle tendo—consistent with what is classically described in anatomy textbooks [11,12]. In the literature, the medial head of the gastrocnemius has been described as originating posteriorly from a strong tendon at the upper medial femoral condyle [11,12]. The results of our study serve to confirm this earlier description but also clearly demonstrate that the medial head of the gastrocnemius actually wraps around the posterior side of the medial femoral condyle and attaches more anteriorly than has been previously reported. To our knowledge, this is the first cadaveric-based report to provide a detailed account of the exact width and length measurements for the medial head as it arises from the medial femoral condyle. As such, the unique structural features of the medial head (as compared to the lateral head) may support the assertion by previous authors that the gastrocnemius is positioned to pull the distal femur posteriorly on the tibia—thus functioning as an antagonist to ACL restraint at the knee [4–8]. Interestingly, a significant difference in the orientation of muscle fibers was also observed between the medial and lateral heads near their femoral attachments. The fiber angles for the medial head were highly variable and lacked a consistent pattern of orientation. In contrast, fibers of the lateral head appeared in a homogeneous manner, positioned consistently parallel in a longitudinal manner as they ran down the length of the muscle to gain attachment to the musculotendinous junction. Further research is needed to determine whether there is a functional difference between the individual roles of the medial and lateral heads of the gastrocnemius in knee joint stability and their effects on ACL strain.

4.5. Limitations of the Study

This study is not without limitations. As part of the data collection process, we failed to document the number of male vs. female cadavers that were dissected. Sex differences have been observed in other anatomical investigations, and as such, it is possible that biological sex may have influenced our results. An additional oversight in our data collection was that we did not directly measure the length or width of each medial and lateral femoral condyle. This prevented us from being able to calculate the exact percentage of the medial and lateral femoral condyles that provide bony attachment for the medial and lateral heads of the gastrocnemius, respectively. Beyond this, facility and program limitations restricted the total number and age range of cadaveric specimens available for this investigation, as well as the method used to preserve human tissue. The generalizability of this dataset would have been enhanced by the inclusion of fresh-frozen cadaveric specimens from a broader range of ages.

5. Conclusions

The results of this cadaveric-based investigation provide a detailed morphologic description of the popliteal region and the proximal gastrocnemius. Data help to further clarify our understanding of the anatomy of the popliteal region by describing the percentage of area of the posterior knee that is the fossa (space occupying) compared with the percentage of area of the posterior knee that is comprised of the hamstrings and the medial and lateral heads of the gastrocnemius. Additionally, the results provide length measurements for the hamstrings below the knee joint line and the gastrocnemius above the knee joint. These measurements provide an anatomical explanation and confirmation of functional studies within the literature that have identified the hamstrings as an ACL agonist and the gastrocnemius as an ACL antagonist [4–9]. Most importantly, the results present an in-depth description of the morphology of the gastrocnemius and provide a detailed comparison between the medial and lateral heads. The data serve to confirm and clarify many of the morphological features of the gastrocnemius that have been previously described in the literature [13–15]. The data also clearly illustrate that the femoral attachment of the medial head of the gastrocnemius was significantly different than the lateral head and more complex than has been previously described within the literature. As such, further research should be directed at exploring the functional significance (if any) of these differences and examining the effect they may have on ACL function and knee joint kinematics.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (HREB ethics #H2020:190, HS23868) on 10 April 2020. All data was collected and stored as required by the Human Tissue Gift Act of the province of Manitoba.

Informed Consent Statement: As per the Human Tissue Gift Act of the province of Manitoba, consent of the body donner is implied.

Data Availability Statement: As per the Human Tissue Gift Act of the province of Manitoba, sharing of data specific to body donners is prohibited/restricted.

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Conflicts of Interest: The authors have nothing to disclose and have no conflicts of interest to declare.

Appendix A

Heron's Formula

$$\text{Area} = \sqrt{s(s-a)(s-b)(s-c)}$$
$$s = \frac{a+b+c}{2}$$

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