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석 사 학 위 논 문

Topography of the
gastrocnemius muscle
and its clinical significance

계 명 대 학 교 대 학 원
의 학 과

정 지 윤

지도교수 이 재 호

2 0 2 4 년 8 월

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이 논문을 석사학위 논문으로 제출함

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의 학 과

정 지 윤

정지윤의 석사학위 논문을 인준함

주 심 박 종 호

부 심 이 재 호

부 심 연 창 진

계 명 대 학 교 대 학 원

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1. Introduction

The leg region is a meticulously organized system of compartments, each serving a unique role in facilitating movement, stability, and protection. These anatomical compartments, delineated by tough fibrous septa and interconnected fascial layers, are major components of biomechanical engineering. There are four compartments in legs, such as anterior, lateral, superficial part of posterior, and deep part of posterior. The gastrocnemius muscle is located in the superficial layer and crosses the knee and ankle joint [1,2]. The gastrocnemius has medial and lateral heads which originates from the medial and lateral condyles of the femur, respectively. Along with the soleus, the gastrocnemius muscle forms the Achilles tendon, inserted to the calcaneus [3]. This muscle contains many muscle fibers, such as fast twitch type II that cause rapid movement and function to perform movements, such as running, walking, and jumping [4]. In contrast, the soleus muscle predominantly has slow-twitch type I muscle fibers for slow movements [5]. Both gastrocnemius and soleus muscles are innervated by the tibial nerve [6,7].

Tension on the medial head in the gastrocnemius muscle has higher priority than that on the lateral head [9]. It arises from the depressive area of the supero-posterior parts of the medial condyle behind the adductor tubercle. the slightly raised area on the femoral-popliteal surface proximal to the medial condyle, subjacent areas of the articular capsule, and the anterior surface of the aponeurosis covering the head. The lateral head arises from the impression of the upper and posterior parts of the lateral surface of the lateral condyle of the femur, the lower part of the lateral supracondylar line of the femur, and the anterior

surface of the aponeurosis covering the head. The larger the cross-sectional area of the muscle, the stronger the force it generates, and the cross-sectional area of the medial head is 2.5 times that of the lateral head. Conversely, the lateral head has priority over the medial head in terms of velocity [8]. As a result, the contraction of the lateral head takes precedence over the contraction of the medial head. In the gastrocnemius muscle, the medial and lateral heads have an anterior surface aponeurosis. The separated aponeurosis is connected to a continuous aponeurosis that is connected to the soleus muscle. Clinically, it targets the deep gastrocnemius aponeurosis and extends it during gastrocnemius intramuscular aponeurosis retraction. The area of the incision where there is little risk of full-thickness muscle rupture is called the “transection zone,” which is a portion of the muscle-bound gastrocnemius aponeurosis [10]. The muscle-tendon junction connects its distal part to the soleus aponeurosis and ultimately merges with the Achilles tendon.

Many studies have explored leg dimensions to better determine the shape and proportion of leg muscles for beauty. Esthetic and reconstructive surgery for the calf requires knowledge and understanding of its topography. The demand for superior esthetic outcomes is rising; however, detailed anatomical studies on the gastrocnemius are lacking. Moreover, its variations are common, and its origins include rare origins and accessory head at the knee joint level. Anatomical variants such as the additional musculature are more frequently found because of the increased use of ultrasound and MRI. Clinicians performing invasive procedure or surgical approach in the knee joint should be aware of variations in the proximal attachment of the gastrocnemius.

In this study, the overall length of the gastrocnemius muscle, the length of the medial and lateral heads, and the length of the

muscle-tendon junction were measured. Knowing the size and shape of the gastrocnemius muscle and the extent of anatomical changes may be clinically helpful for surgeons performing gastrocnemius recession. Understanding its precise anatomical details will allow clinicians and researchers to comprehend its role in gait mechanics, posture, and the prevention and treatment of musculoskeletal disorders.

2. Materials and Methods

2.1 The measurement of the gastrocnemius muscle:

Total 30 cadaveric legs (16 donated cadavers) were dissected in this study. Two legs were excluded due to unmeasurable variables. The average age at death was 81.74 years old, and each cadaver was placed in the prone position. All cadavers were fixed in formalin according to standard procedures, and those with pathologies or a history of surgical procedures in legs were excluded. The skin and subcutaneous tissue of the calf were excised and exposed from the head of the gastrocnemius muscle to the AT insertion site of the Achilles tendon. After incising the origin of the medial and lateral heads of the gastrocnemius muscle, an incision was made in the area where the gastrocnemius and soleus muscles merged forming the muscle-tendon junction. To carefully dissect the popliteal region, efforts were made to accurately locate the proximal attachment sites on the lateral and medial heads of each cadaver.

The reference line in my study was defined as the line from the fibular head to calcaneal tuberosity. The distance from the point where the two heads of the gastrocnemius merged to the medial head, lateral head, and calcaneal tubercle was measured. Additionally, the two heads, which are the origins of the gastrocnemius muscle, were incised and tilted the calcaneal tuberosity to expose the muscle-tendon junction with the soleus muscle. The lengths from the medial and lateral parts of the muscle-tendon junction to the calcaneal tuberosity were measured. The length of each variable was calculated and described as the

percentile result by using the reference line (Figure 1). Based on the measured results, the groups were compared and analyzed according to the learning direction of the tendon-muscle junction and the height of the lateral and medial heads.

2.2. Statistical analysis:

All statistical analyses were conducted using SPSS (version 22.0; IBM SPSS®; Chicago, IL, USA). The Mann - Whitney U was used to compare non-continuous variables. The Pearson correlation test was used to analyze the correlation between structures. All statistical significance was set at $P < 0.05$.

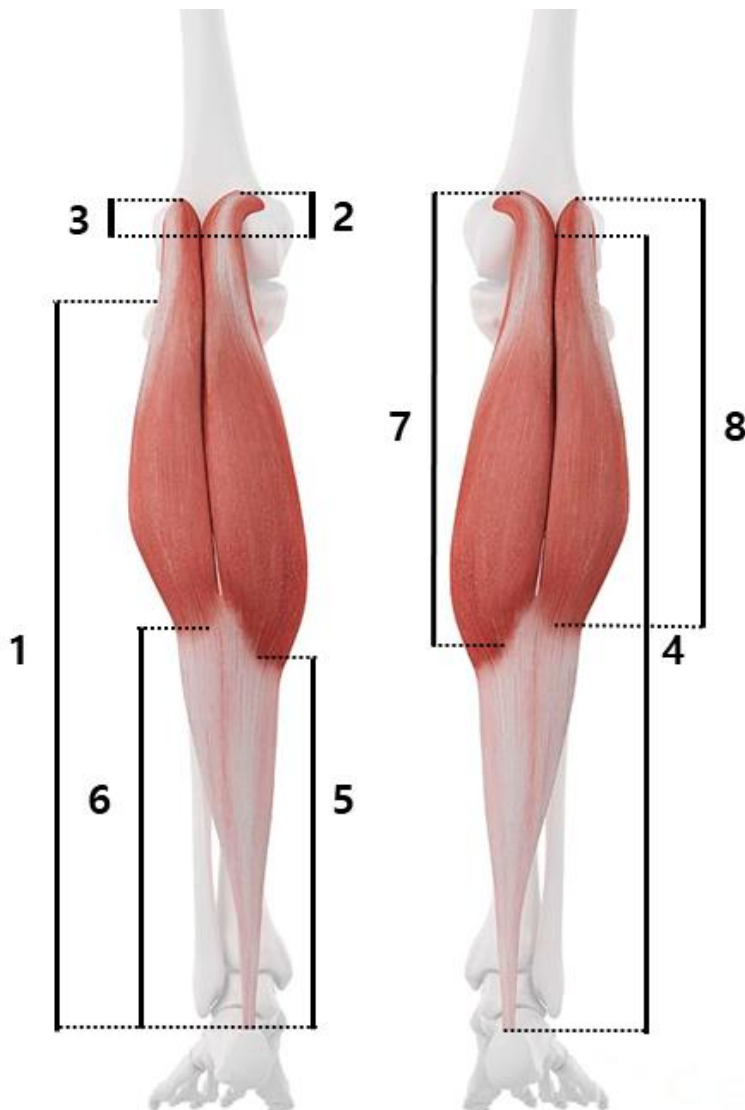


Figure 1. The measurement of the gastrocnemius muscle. 1: reference line, 2: merged point to medial head, 3: merged point to lateral head, 4: merged point to calcaneal tuberosity, 5: muscle-tendon junction (medial), 6: muscle-tendon junction (lateral), 7: medial muscle length, 8: lateral muscle length.

3. Results

3.1. The topography of the gastrocnemius muscle:

The topography of the gastrocnemius was successfully identified (Figure 2) and the variables are presented in Table 1. The average length of the reference line from the calcaneal tuberosity to the fibular head was 337.09 ± 27.89 mm. The distances of the origin of medial and lateral heads from the merged point were 124.79 ± 44.10 mm and 113.47 ± 44.21 mm, respectively. The mean distance from the merged point to the calcaneal tuberosity was 268.50 ± 33.53 mm. The tendinous part of the medial and lateral sides were 152.13 ± 26.15 mm and 174.80 ± 32.30 mm, respectively. The muscular parts of the medial and lateral sides were 222.78 ± 27.47 mm and 195.69 ± 29.11 mm, respectively. The relative values were obtained by using dividing the length of the reference line.

From the calcaneal tuberosity, the tendon continued upward to the 50th percentile and changed into a muscle; this region was named the muscle-tendon junction (MTJ). The medial and lateral MTJs were located at the $45.17^{\text{th}} \pm 7.42$ percentile and $51.97^{\text{th}} \pm 9.83$ percentile, respectively. The merged point was located at the $80.15^{\text{th}} \pm 11.29$ percentile. From this point, the medial and lateral heads were located at the $36.68^{\text{th}} \pm 10.36$ percentile and $33.15^{\text{th}} \pm 11.08$ percentile, respectively. The relative length of the medial and lateral muscles was 66.11 ± 6.35 percent and 58.01 ± 7.03 percent, respectively.

3.2. The pattern of the gastrocnemius muscle according to the variation:

In 27/32 (84.37%) cases, the MTJ was more proximal (higher) on the lateral side. Only five legs (MTJ) were horizontal or higher on the medial side. The topography of the gastrocnemius was analyzed according to the direction of the MTJ and is summarized in Table 2. The lateral MTJ was significantly different according to the direction of the MTJ (182.76 ± 28.45 mm vs. 135.00 ± 18.20 mm, $P < 0.001$). The length from the merged point to the lateral head (ML) was longer in legs with medial-dominant (121.80 ± 34.66 mm) than those with lateral-dominant (114.76 ± 46.79 mm), but the difference was not statistically significant. The medial and lateral muscle lengths also showed a noteworthy difference; however, this difference was not statistically significant. There were no statistical significances in the other variables.

In 28/32 (87.5%) legs, the medial head of the gastrocnemius was longer than the lateral head, and the distance from the merged point was longer on the medial side. The lengths of both heads were similar or the lateral head was located more proximal than the medial head in only four legs. The topography of the gastrocnemius was analyzed according to the length of the head and is summarized in Table 3. The merged point was higher in legs with longer lateral heads (300.25 ± 20.87 mm) than those with longer medial heads (263.96 ± 32.74 mm), and this difference had statistical significance ($P < 0.001$). The reference line and lateral and medial muscular lengths were longer in legs with longer lateral heads; however, the differences were not statistically

significant. There were no significant differences in the other variables. Except for the length from the merged point to the medial head (MM), all variables were longer in legs with longer lateral heads.

3.3. Anatomical correlation between the gastrocnemius muscle and its parts:

The results of the correlation analysis of variables in calf region are presented in Table 4. The reference line was positively correlated with both the medial and lateral head lengths from the merged point ($R = 0.627$, $P < 0.001$; $R = 0.686$, $P < 0.001$). It was also associated with the medial and lateral muscle parts ($R = 0.646$, $P < 0.001$ and $R = 0.619$, $P < 0.001$, respectively). The medial and lateral head lengths were positively correlated ($R = 0.971$, $P < 0.001$). The merged point was negatively correlated with the medial head length ($R = -0.619$, $P < 0.001$) and lateral head ($R = -0.524$, $P = 0.002$). The length of the medial MTJ was positively correlated with the distance from the merged point to the calcaneal tuberosity ($R = 0.379$, $P = 0.039$). The lengths of the medial and lateral MTJs were positively correlated ($R = 0.405$, $P = 0.026$). The lengths of the medial and lateral muscle parts were also significantly positively correlated ($R = 0.825$, $P < 0.001$). Other variables showed no associations.

Based on these results, the topography of the gastrocnemius muscle is shown in Fig. 3. From the calcaneal tuberosity, the MTJ was located at the 50th percentile, and the lateral MTJ was higher in most legs. At the 80th percentile, the two heads of the gastrocnemius muscle were merged. From this point, the lateral and medial heads continued to the 33rd and

37th percentile, respectively. The height of the head was more proximal (higher) on the medial side, and the height of the MTJ was more proximal (higher) on the lateral side. The total muscle area was greater on the medial side (66 percentile) than lateral side (58 percentile).

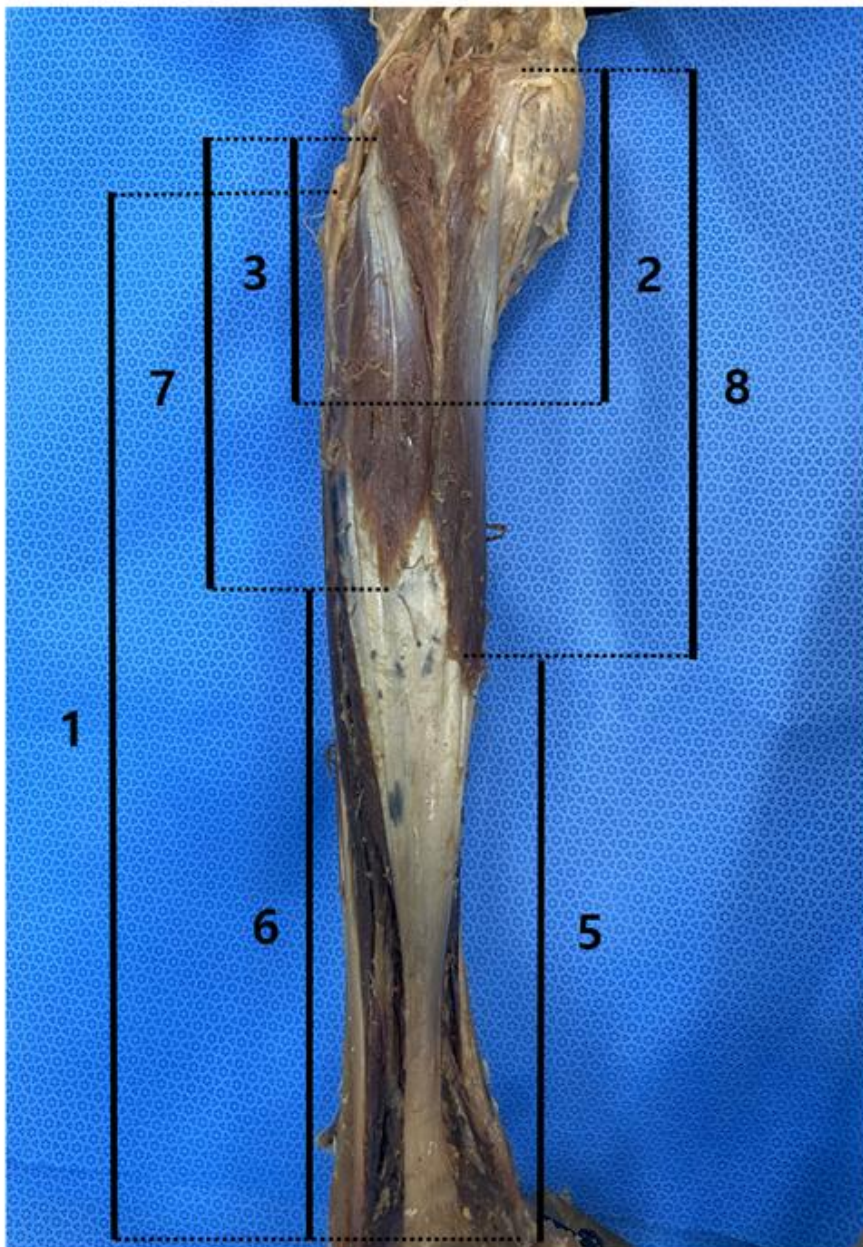


Figure 2. Identification of the gastrocnemius muscle and its muscular and tendinous parts.

Table 1. Topography of the gastrocnemius

	Distance (mm)	Percentile (%)
Reference line	337.09± 27.89	–
Merged point to medial head (MM)	124.79 ± 44.10	36.68 ± 10.36
Merged point to lateral head (ML)	113.47 ± 44.21	33.15 ± 11.08
Merged point to calcaneal tuberosity (MC)	268.50 ± 33.53	80.15 ± 11.29
Medial Muscle-tendon junction (mMTJ)	152.13 ± 26.15	45.17 ± 7.42
Lateral Muscle-tendon junction (lMTJ)	174.80 ± 32.30	51.97 ± 9.83
Medial muscle length (MML)	222.78 ± 27.47	66.11 ± 6.35
Lateral muscle length (LML)	195.69 ± 29.11	58.01 ± 7.03

Table 2. Topography of the gastrocnemius according to the direction of muscle-tendon junction

	Direction of muscle-tendon junction	
	Lateral (n = 27)	Medial (n = 5)
Reference line	337.88 ± 29.20	335.40 ± 25.21
Merged point to medial head (MM)	126.96 ± 44.31	127.60 ± 37.45
Merged point to lateral head (ML)	114.76 ± 46.79	121.80 ± 34.66
Merged point to calcaneal tuberosity (MC)	266.28 ± 33.30	267.60 ± 33.37
Medial Muscle-tendon junction (mMTJ)	150.96 ± 25.66	158.00 ± 30.91
Lateral Muscle-tendon junction (lMTJ) *	182.76 ± 28.45	135.00 ± 18.20
Medial muscle length (MML)	223.92 ± 29.15	215.40 ± 19.42
Lateral muscle length (LML)	194.72 ± 31.77	202.00 ± 17.01

* $P < 0.001$

Table 3. Topography of the gastrocnemius according to the height of lateral and medial heads

	Higher Head	
	Lateral (n = 4)	Medial (n = 28)
Reference line	362.00 ± 20.46	333.56 ± 27.23
Merged point to medial head (MM)	110.25 ± 18.19	127.07 ± 44.29
Merged point to lateral head (ML)	118.75 ± 21.87	112.71 ± 46.75
Merged point to calcaneal tuberosity (MC) *	300.25 ± 20.87	263.96 ± 32.74
Medial Muscle-tendon junction (mMTJ)	171.75 ± 12.20	149.12 ± 26.54
Lateral Muscle-tendon junction (lMTJ)	182.00 ± 16.49	173.69 ± 34.17
Medial muscle length (MML)	233.25 ± 6.99	221.29 ± 29.02
Lateral muscle length (LML)	212.25 ± 24.14	193.32 ± 29.36

* $P < 0.001$

Table 4. Anatomical correlation between the gastrocnemius muscle and its parts.

		MM	ML	MC	mMTJ	lMTJ	MML	LML
Ref.	R	.627**	.686**	.037	.333	0.240	.646**	.619**
	P	.000	.000	.842	.073	.202	.000	.000
MM	R	1	.971**	-.619**	.002	.195	.670**	.569**
	P		.000	.000	.991	.303	.000	.001
ML	R		1	-.524**	.107	.212	.680**	.634**
	P			.002	.573	.260	.000	.000
MC	R			1	.379*	-.061	-.117	.069
	P				.039	.748	.525	.707
mMTJ	R				1	.405*	-.187	.091
	P					.026	.323	.634
lMTJ	R					1	-.028	-.110
	P						.882	.564
MML	R						1	.825**
	P							.000

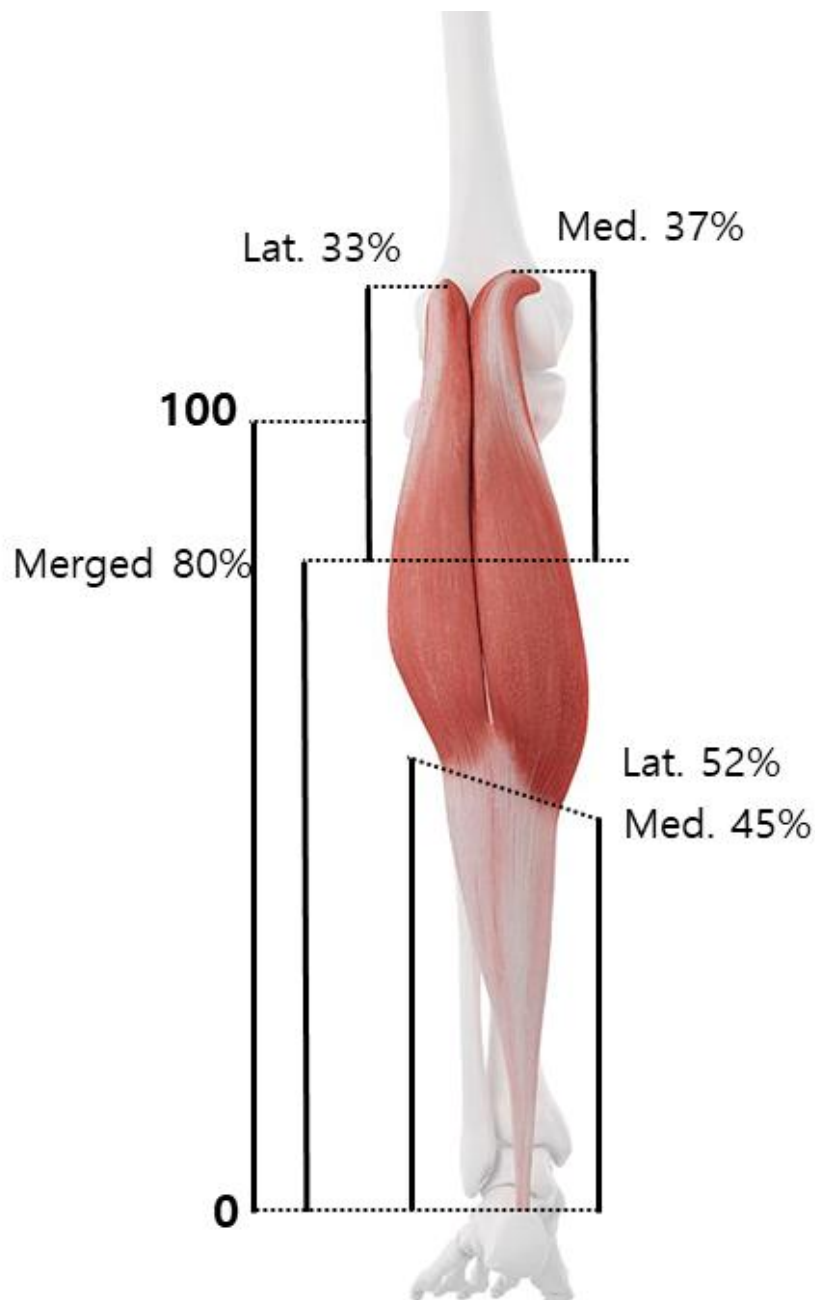


Figure 3. The topography of the gastrocnemius muscle by the length of the reference line as a percentile.

4. Discussion

The gastrocnemius, soleus, and plantaris muscles lie in the superficial part of the posterior compartment of the leg. These three muscles are known, as the triceps surae inserts into the middle third of the posterior surface of the calcaneus as the calcaneal or Achilles tendon. The plantaris is small and absent in approximately 10% of legs [8]. The gastrocnemius is a biarticular and bipennate muscle that acts on both the knee and ankle joints, whereas the soleus muscle is multipennate and monoarticular that acts only on the ankle joint [11]. The main function of the triceps surae is plantar-flexion of the foot at the ankle joint, but it is also active as an antigravity muscle in the upright stance position [12,13]. While walking, the quadriceps and gastrocnemius muscles are activated, particularly during the first phase of the foot support and swing phases. In these movements, there is a complete extension of the knee [14]. The gastrocnemius intervenes to stop the tibial translation forward, while the quadriceps extend the knee [15], and the medial head of the gastrocnemius muscle intervenes with greater power in plantar flexion than the lateral head [14,15]. In a walk without running, the soleus muscle intervenes the most in the plantar flexion of the foot.

The gastrocnemius is reported as a two-headed fusiform muscle. The lateral head originates from the lateral aspect of the femoral condyle. The medial head originates from the medial condyle and the popliteal surface of the femoral shaft. These two bellies continued in half of the calves and became aponeurotic. The main textbook and recent studies have demonstrated that the medial head of this muscle extends more proximally and is longer than the lateral head [16,17]. However, these

studies do not provide a clear explanation for this disparity. The musculotendinous junction (MTJ) of the gastrocnemius merges to the soleus tendon as the calcaneal tendon. The MTJ typically passes laterally upward. Moreover, the detailed morphology has not been clearly defined. Here, the topography of the gastrocnemius muscle was studied in 30 legs.

For standardization, the reference line in my study was defined as the distance between the calcaneal tuberosity and the fibular head. Two heads were merged at the 80.15th \pm 11.29 percentile (268.50 \pm 33.53 mm) from the calcaneal tuberosity. At this point, the medial and lateral head continued upward, to approximately the 36.68th (124.79 \pm 44.10 mm) and 33.15rd (113.47 \pm 44.21 mm) percentile. A previous study in an Indian population showed that the average lengths of the medial and lateral heads were 16.25 and 14cm, respectively [18]. These data are similar to my results, although our results for the Korean population are relatively short. The present study also showed that the medial head of the gastrocnemius muscle was longer than the lateral head in 48 limbs (80%). In my study, the medial head was longer than the lateral head in 28/32 (87.5%) legs. The lengths of both heads were similar and the lateral head was located more proximal than the medial head in the other 4 legs. Therefore, the topography of the gastrocnemius was compared according to head length. The merged point was higher in legs with a longer lateral head. Correlation analysis also showed that the lateral head length was negatively correlated with the merged point.

The muscle and tendon parts of the gastrocnemius muscle merged into the MTJ at the 50th percentile approximately. The lateral MTJ was more proximal (higher) than the medial MTJ in most legs. In five legs, this line was horizontal, or the medial MTJ was located more proximal than the lateral one. Interestingly, the head is located more proximally

on the medial side, whereas the MTJ is located more proximally on the lateral side. The misalignment of these points is balanced overall; therefore, it may contribute to the balanced strength of the gastrocnemius muscle.

Embryologically, most skeletal muscles are formed during the eighth week of gestation [19]. The muscle is derived from the paraxial mesoderm, which in turn is derived from the lips of the lateral dermatomyotome. The gastrocnemius muscle originates from the calcaneal blastomere and migrates upward towards the inferior epiphysis of the femur [20]. Before termination, the femur is divided into the medial and lateral bellies. The topography of the gastrocnemius is expected to vary based on the differences in the degree of development of the muscular and tendinous parts during this period. However, an embryological study is required to support this hypothesis.

The anatomy of this muscle is clinically important because Achilles tendon disorders are relatively common injuries [21]. The injury mainly occurs in basketball and soccer players and is a consequence of sharp muscle contraction. Achilles tendon repair surgery is one treatment option for this condition. Another common injury, known as 'Tennis Leg', is a tear in the gastrocnemius muscle. A previous study demonstrated that the medial head of the gastrocnemius muscle is more frequently involved [22]. This injury is caused by sudden muscle overstretching owing to ankle dorsiflexion or knee extension [23]. In these surgical approaches, the anatomical aspect of the gastrocnemius is extremely important to prevent unexpected injuries during surgery.

In the present study, the topography of the gastrocnemius muscle was demonstrated and it was associated with muscular and tendinous parts. One limitation of this study is that the neurovascular structures of the gastrocnemius muscles were not included. The tibial nerve and popliteal

artery are located superficially in the popliteal cavity and can be palpated [24]. Therefore, the topography of the neurovascular structures must be considered. For a better understanding, MRI or ultrasound studies with larger sample sizes should be performed to support our hypothesis. Clinicians should perform invasive procedures and surgical approaches based on the anatomical knowledge of this calf region.

5. Summary

The gastrocnemius muscle is located in the superficial layer of the calf region and is clinically very important. This muscle merged to the soleus muscle, creating a connection calcaneal tendon. The anatomy of the gastrocnemius muscle is very complex, and the pattern of muscle-tendon junction (MTJ) is also diverse. In this study, I examined the anatomical structure of the gastrocnemius muscle and presented its topography. This muscle maintains overall balance through the asymmetrical shape of the muscle head and MTJ. This allows powerful forces to work in a balanced manner, helping human stand or walk. More evolutionary research on this is needed, and research that can be used clinically should continue.

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Topography of the gastrocnemius muscle and its clinical significance

Jung, Ji Yoon

Department of Anatomy
Graduate School

Keimyung University

(Supervised by Professors Lee, Jae Ho)

(Abstract)

Gastrocnemius muscle forms by two heads and its morphology is extremely important for the shape of the calf. I studied topography of the gastrocnemius muscle with a view to providing anatomical and surgical implication. The 32 cadaveric legs were dissected to determine the topography of the gastrocnemius muscle. The length of medial and lateral heads were measured and its muscular and tendinous parts were divided. The reference line was the line between the fibular head and the calcaneal tuberosity. The distances from the calcaneal tuberosity to merged point of two heads was 268.50 ± 33.53 mm, and it located at 80.15 ± 11.29 percentiles from the calcaneal tuberosity. From merged point, medial and lateral heads continued superiorly 124.79 ± 44.10 mm and 113.47 ± 44.21 mm, respectively. Medial head was longer than

lateral head in 28 legs (87.5%) and it was associated with shorter merged point ($P = 0.041$). The medial and lateral point of muscle-tendon junction (MTJ) was 152.13 ± 26.15 mm, and 174.80 ± 32.30 mm from the calcaneal tuberosity, respectively. Lateral point of MTJ was higher than medial point in 25 legs (78.12%). Correlation analysis showed that these lengths was associated with each other. This study provides anatomical knowledge regarding the location of the gastrocnemius muscle that may be clinically relevant during surgical procedures.

장딴지근의 해부학적 지형과 임상적 의의

정 지 윤

계명대학교 대학원

의학과 해부학 전공

(지도교수 이 재 호)

(초록)

장딴지근은 두 개의 머리로 구성되며 그 형태는 종아리 모양에 매우 중요하다. 나는 해부학적, 수술적 의의를 밝히기 위해 장딴지근의 지형을 연구했다. 장딴지근의 지형을 결정하기 위해 32개의 사체의 다리를 해부했다. 안쪽머리와 가쪽머리의 길이를 측정하고 근육부분과 힘줄부분을 나누었다. 기준선은 종아리뼈의 머리와 발꿈치뼈융기 사이의 선이다. 발꿈치뼈융기에서 두 머리의 합류점까지의 거리는 268.50 ± 33.53 mm였으며, 발꿈치뼈융기로부터 80.15 ± 11.29 백분위수에 위치하였다. 합쳐진 지점에서 안쪽머리와 가쪽머리는 각각 124.79 ± 44.10 mm 및 113.47 ± 44.21 mm 위쪽으로 이어졌다. 28개 다리에서 안쪽머리가 가쪽머리보다 길었고 (87.5%), 합류점이 짧은 것과 관련이 있었다($P = 0.041$). 안쪽 및 가쪽 접합점(MTJ)은 발꿈치뼈융기에서부터 각각 152.13 ± 26.15 mm, 174.80 ± 32.30 mm였다. 25개 다리에서 MTJ의 가쪽점이 안쪽점보다 높았다 (78.12%). 상관분석에 따르면 이러한 길이는 서로 연관되어 있는 것으로

나타났다. 이 연구는 수술 과정에서 임상적으로 관련될 수 있는 장딴지근의 위치에 대한 해부학적 지식을 제공한다.