ONLINE FIRST

This is a provisional PDF only. Copyedited and fully formatted version will be made available soon.

ISSN: 0015-5659

e-ISSN: 1644-3284

Morphometric profile in fetuses and evolution of Achilles tendon

Authors: A. Waśniewska, Ł. Olewnik, M. Polguj

DOI: 10.5603/FM.a2021.0013

Article type: Original article

Submitted: 2020-11-10

Accepted: 2020-12-28

Published online: 2021-02-09

Morphometric profile in fetuses and evolution of Achilles tendon

A. Waśniewska[1], Ł. Olewnik[2], M. Polguj[1]

[1]Department of Normal and Clinical Anatomy, Chair of Anatomy and Histology, Medical University of Lodz, Poland

[2]Department of Anatomical Dissection and Donation, Chair of Anatomy and Histology, Medical University of Lodz, Poland

Address for correspondence: Anna Waśniewska, Department of Normal and Clinical Anatomy, Chair of Anatomy and Histology, Medical University of Lodz, ul. Żeligowskiego 7/9, 90-752 Łódź, Poland, email: ania.wasniewska@gmail.com

Abstract

Background: The Achilles tendon (AT) develops from the merge of the tendinous part of the gastrocnemius (GM) and soleus (SM) muscles. The AT is the structural base for the biomechanical work of the ankle joint. Understanding morphometry of the AT is crucial due to the tendon vulnerability to rupture and damage which requires further surgical repair and management. Despite its clinical significance, data concerns measurements of the AT in human fetuses are scare. The aim of our study was to assess the AT, GM and SM morphometry in human fetuses.

Materials and methods: Thirty-seven spontaneously-aborted human fetuses (17 male, 20 female) aged 18–38 weeks of gestation were examined. The morphometry of the GM, SM and AT were evaluated.

Results: No significant correlation between sex or side and size of the AT in human fetuses was observed. The only significant correlation was between sex and the length of the tendon of the SM, in 3rd trimester it was longer in male than in female. In 2nd trimester the SM muscle to tendon ratio was higher in female than in male.

Conclusions: There was no significant correlation between sex or side in size of the AT in human fetuses, probably due to scant muscle load during prenatal period.

Key words: Fetuses, Achilles tendon, calcaneal tendon, triceps suralis

Introduction

The Achilles tendon (AT), also known as calcaneal tendon, is the largest and the strongest tendon in human body [1–3]. The Achilles tendon develops from the merge of the tendinous part of the gastrocnemius and soleus muscles[1, 4, 5]. The gastrocnemius muscle (GM) and soleus muscle (SM), that is beneath the GM, componentize the triceps surae or “calf” muscle [4, 6]. The triceps surae and the Achilles tendon belong to superficial compartment of the calf [3]. The GM is composed of two heads, the medial and lateral. The medial head originates from the medial supracondylar line and adductor tubercle of the femur and the lateral head originates from the posterior part of the lateral femoral condyle, posterior and superior to the lateral epicondyle [4]. The lateral head is smaller, shorter and extends in lesser degree than the medial head [4, 7]. The soleus muscle originates from the soleal line and the middle part of the border of the tibia, from the posterior surface of the head and proximal part of the shaft of the fibula, and from a fibrous band between this two bones [7]. The AT is supplied by the posterior tibial artery, the peroneal arteries and the tibial nerve [3]. The AT inserts to the calcaneal tuberosity, to its posterior-superior aspect [8, 9].

The AT is the structural base for the biomechanical work of the ankle joint[10]. The GM with the SM, is the main plantar flexor of the ankle joint [3, 11]. The SM is also a powerful knee flexor [12]. It is not able to exert full power at both joints simultaneously, for example when the knee is flexed, GM is unable to generate as much force at the ankle [12]. The opposite is true when the ankle is flexed.

Multiple morphological variations were described in this area, whereas most of them concerns plantaris muscle, GM and SM, especially their attachments, number of heads or even presence [12–14].

Increasing interest in sport activity results in increasing number of tendon injuries [1]. Problems with tendons are dominated by the AT, among athletes as well as the general public [1, 8, 10]. Disorders of the AT might be traumatic and nontraumatic, e.g. tendinopathy, ruptures of the tendon and insertional tendinitis [15–17]. Congenital disorders of the AT may result in toe walking or equinus deformation in children [18]. Understanding morphometry of the AT is crucial due to the tendon vulnerability to rupture and damage which requires further surgical repair and management[8]. Previous studies compared the measurements of the AT i.a. between sexes or sides in adults and proposed that differences were more correlated with the muscle strength, rather than gender [19]. Despite its clinical significance, data concerns measurements of the AT in human fetuses are scare.

The aim of our study was to assess the AT, GM and SM morphometry in human fetuses. We hypothesize that there will not be significant correlation between sex or side in size of the AT in human fetuses because of scant muscle load during prenatal period.

Materials and methods

Thirty-seven spontaneously-aborted human fetuses (17 male, 20 female) aged 18–38 weeks of gestation were examined. The fetuses were obtained from spontaneous abortion after parental consent. Everything was in accordance with the legal procedures in force in Poland and in accordance with the program Donation Corpse both adults and fetuses. Their ages were determined on the basis of cranio-sacral and head measurements. Fetuses were divided into two groups according to trimester. Permission for the study was received from the Local Bioethic Commission (agreement no. RNN/218/20/KE).

A dissection of the leg and foot was performed by traditional techniques [17, 20–22]. Firstly GM was exposed by the subcutaneous tissue. Morphometric measurements of the lateral and medial head and the tendon of the GM were performed. Secondly GM was separated from the SM, then measurements of the muscle and tendon of the SM were performed. The thickness and width of the AT was measured at its insert to calcaneal tuberosity. Detailed measurements are characterized in Table I and Figure 1. Measurements were carried out with an electronic digital caliper (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). Each measurement was performed twice with an accuracy of up to 0.01 mm.

The collected measurements of muscles and tendon were compared using the Statistica 13.1 software package (StatSoft, Cracow, Poland). The Mann–Whitney U test and the chi2 test were used to compare nominal and contentious variables between two groups; the Shapiro–Wilk test was used to determine the normality of the distribution. The level of significance was 0.05.

Results

The mean length of medial head of GM was longer than lateral head in both second and third trimester (27.33±6.04 mm vs. 29.46±5.95 mm, p=0.049; 45.84±5.85 mm vs. 40.47±5.9 mm, p=0.036; respectively). The mean length of the tendon of the medial part of the GM was shorter than lateral part, however statistical difference was observed only in second trimester of the gestation (2nd trimester: 24.92±4.48 mm vs. 27.93±4.29 mm, p<0.001; 3rd trimester: 42.22±10.05 mm vs. 48.64±90.1 mm, p=0,113). In 3rd trimester the mean length of muscle part of soleus is longer in male than in female, 62.98±13.14 mm and 53.57±2.57mm, respectively. The mean length of tendon of SM in 3rd trimester is also longer in male (24.83±3.42mm) than in female (18.95±2.36 mm), what was significant, p= 0.045. The mean width and thickness of the AT is larger in male than in female in 3rd trimester. The mean width and thickness of the AT in male was 8.26±1.94 mm and 1.46±0.28 mm, in female 7.38±0.31 mm and 1.33±0.05 mm respectively. However in 2nd trimester the mean width of the AT was larger in female (5.01±1.5mm) than in male (4.81±1.12mm). The mean thickness of the AT in 2nd trimester was larger in male (1.07±0.46mm) than in female (1.01±0.43mm). In 2nd trimester, the muscle to tendon ratio of the SM was significantly higher in female (2.75±0.76 mm) than in male (2.29±0.77 mm), p= 0.029. The detailed analysis of the performed measurements are presented in Table II and III and Figure 2.

Discussion

To best of our knowledge our investigation is the first study to analyze morphometric measurements of the AT in such numerous group of human fetuses, what may be useful as a basic research for future studies concerning the AT. The key result of our study was that there is no significant correlation between sex or side and size of the AT in human fetuses. The only significant correlation was between sex and the length of the tendon of the SM, in 3rd trimester it was longer in male than in female, p=0.045. In 2nd trimester the SM muscle to tendon ratio was higher in female than in male, p=0.029.

In order to understand the differences in the structure of such a complex tendon, it is necessary to understand the basics of embryology. In an 11 mm embryo the common flexor mass begins to show signs of differentiation into the muscle rudiments [23, 24]. In a 14 mm embryo the two muscle groups are fairly distinct, a superficial, proximolateral group for the GM SM, and PM, and a deep, more medial group for the flexor hallucis longus, flexor digitorum longus and popliteus, and tibialis posterior [23, 24]. The gastrocnemius group is connected with the blastema of the calcaneus and the two long flexor muscles with the flat aponeurotic "foot-plate" from which tendons extend to the blastema of the digits [23, 24]. The gastrocnemius-soleus group gradually spreads from its original lateral position towards the medial side of the leg to attain the tibial attachment, and the two heads of the GM develop during the second half of the second month, the medial head attaining its attachment later than the lateral [23, 24]. The PM seems to split off at a comparatively late stage from the lateral head of the GM [23, 24].

From an evolutionary point of view, the difference between morphology of the triceps surae in human and the other species is apparent [25]. Humans' bellies of GM are short, their tendon fuse with SM tendon and develop massive AT [25]. In herbivorous apes, the AT is absent or very short, thus their muscles of posterior leg extended to their tarsal bones [26]. Changes in lifestyle, like food supply, forced apes to adapt to this situation and evolve their anatomy [26]. Differences in food intake, correlate with differences in locomotion [25]. Gorillas, orangutans, bonobos and chimpanzees share a wide range of locomotor behaviors such as clambering and orthograde suspension, quadrupedalism, whereas modern humans are primarily bipeds [6, 25]. The longer AT were observed in early hominis than in apes [26]. The key role in development of the AT was in fast locomotion, e.g. hunting, that is why the AT is more evolutionary advantage in athletes [26].

In Pang and Yings' sonographic study, the cross sectional area of the AT was significantly higher in 50 years old and older patients than in younger patients [27]. Furthermore, in that study, the cross-sectional area of the AT in the dominant leg was significantly higher than that in the nondominant leg [27]. Also Ying et al. noticed that the thickness of the AT for dominant leg in the both regularly exercise group and the irregularly exercise group, is significantly higher than in the nondominant leg [28]. Moreover, in their study, the mean thickness of the AT in the regularly exercise group was significantly higher in comparison with the irregularly exercise group [28]. Previous studies noted that differences in mechanical properties of the AT between male and female is more correlated with the differences in muscle strength, rather than sex [19]. Probably due to that in our research there was no significant differences in thickness or width of the AT between sexes or body side, the use of muscle in fetuses is minimal.

The medial head of the GM dominate in size and power over lateral head [4, 7]. This superiority of medial belly was also visible in our measurements. Kearns et al. examined soccer players and compared them with moderate active and untrained college students [29].

The thickness of the medial head of the GM of the dominant leg was significantly larger in the soccer players than in others [29]. However, in our study, there was no positive correlation between muscle size and body side or sex. It might be also the result of the low muscle load in human fetuses.

Although the AT is the most powerful tendon in human body [1–3], it is very vulnerable to injuries [10, 26]. The "Achilles tendinitis" has formerly been used for describing any pain in the posterior region, however, nowadays vocabulary of disorders in this region of leg is more miscellaneous and precise[9]. We can differentiate inflammation of the AT with its adjacent structures, such as: paratenonitis, tendonitis and bursitis [9, 15–17]. Tendinosis, that is another AT disorder, is a noninflammatory process caused by fatty or mucinoid degeneration with a disorganization in collagen structure [9, 30]. Ball or racquet sports or other athletic activity has been noted as a cause of the AT rupture up to 80% of cases [9, 31]. The high proneness of the AT, despite its enlargement, may raise us a question, what is the future of the AT? How thick, long and wide it will be in our descendants? Will it endure in its shape?

The present study does have some limitations. First of all, no sample size calculation was performed. Moreover, the abundance of group according to sex was not equal. However, the number of the human fetuses in our research was larger in comparison with previous studies.

Conclusions

There was no significant correlation between sex or side in size of the AT in human fetuses, probably due to scant muscle load during prenatal period. However, we still do not know how important is genetics and environment regarding the etiopathology of the disorders of the AT. The vulnerability of the AT to injuries should motivate our efforts in carrying out research to better understanding its complicated pathology and increase the effectiveness of its treatments.

Ethical approval and consent to participate

The cadavers belonged to the Department of Anatomical Dissection and Donation, Medical University of Lodz.

References

1. Järvinen TAH, Kannus P, Maffulli N, Khan KM (2005) Achilles tendon disorders: Etiology and epidemiology. Foot Ankle Clin. 10:255–266

2. Park SY, Khemani D, Nelson AD, et al (2017) Rectal Gas Volume Measured by Computerized Tomography Identifies Evacuation Disorders in Patients With Constipation. Clin Gastroenterol Hepatol 15:543-552.e4. https://doi.org/10.1016/j.cgh.2016.11.013

3. O'Brien M (2005) The anatomy of the achilles tendon. Foot Ankle Clin. 10:225–238

4. Dayton P (2017) Anatomic, Vascular, and Mechanical Overview of the Achilles Tendon. Clin. Podiatr. Med. Surg. 34:107–113

5. Ballal MS, Walker CR, Molloy AP (2014) The anatomical footprint of the Achilles Tendon. Bone Jt J 96B:1344–1348. https://doi.org/10.1302/0301-620X.96B10.33771

6. Ferrero EM, Pastor JF, De Paz FF, et al (2012) Primates: Classification, Evolution and Behavior. In: Hughes E, Hill M (eds). Nova Science Publishers, pp 1–70

7. Pichler W, Tesch NP, Grechenig W, et al (2007) Anatomic variations of the musculotendinous junction of the soleus muscle and its clinical implications. Clin Anat 20:444–447. https://doi.org/10.1002/ca.20421

8. Latiff S, Bidmos MA, Olateju OI (2020) Morphometric profile of tendocalcaneus of South Africans of European ancestry using a cadaveric approach. Folia Morphol (Warsz). https://doi.org/10.5603/fm.a2020.0026

9. Schepsis AA, Jones H, Haas AL (2002) Achilles tendon disorders in athletes. Am. J. Sports Med. 30:287–305

10. Szaro P, Witkowski G, Śmigielski R, et al (2009) Fascicles of the adult human Achilles tendon - An anatomical study. Ann Anat 191:586–593. https://doi.org/10.1016/j.aanat.2009.07.006

11. Patel NN, Labib SA (2018) The Achilles Tendon in Healthy Subjects: An Anthropometric and Ultrasound Mapping Study. J Foot Ankle Surg 57:285–288. https://doi.org/10.1053/j.jfas.2017.10.005

12. Olewnik Ł, Zielinska N, Paulsen F, et al (2020) A proposal for a new classification of soleus muscle morphology. Ann Anat 232:. https://doi.org/10.1016/j.aanat.2020.151584

13. Olewnik Ł, Zielinska N, Karauda P, et al (2020) A three-headed plantaris muscle: evidence that the plantaris is not a vestigial muscle? Surg Radiol Anat 42:1189–1193. https://doi.org/10.1007/s00276-020-02478-8

14. Olewnik, Kurtys K, Gonera B, et al (2020) Proposal for a new classification of plantaris muscle origin and its potential effect on the knee joint. Ann Anat 231:151506. https://doi.org/10.1016/j.aanat.2020.151506

15. Weinfeld SB (2014) Achilles tendon disorders. Med. Clin. North Am. 98:331–338

16. van Dijk CN, van Sterkenburg MN, Wiegerinck JI, et al (2011) Terminology for Achilles tendon related disorders. Knee Surgery, Sport Traumatol Arthrosc 19:835–841. https://doi.org/10.1007/s00167-010-1374-z

17. Olewnik L, Wysiadecki G, Podgórski M, et al (2018) The Plantaris Muscle Tendon and Its Relationship with the Achilles Tendinopathy. Biomed Res Int 2018:. https://doi.org/10.1155/2018/9623579

18. Gourdine-Shaw MC, Lamm BM, Herzenberg JE, Bhave A (2010) Equinus Deformity in the Pediatric Patient: Causes, Evaluation, and Management. Clin. Podiatr. Med. Surg. 27:25–42

19. Muraoka T, Muramatsu T, Fukunaga T, Kanehisa H (2005) Elastic properties of human Achilles tendon are correlated to muscle strength. J Appl Physiol 99:665–669. https://doi.org/10.1152/japplphysiol.00624.2004

20. Olewnik Ł, Wysiadecki G, Polguj M, Topol M (2017) Anatomic study suggests that the morphology of the plantaris tendon may be related to Achilles tendonitis. Surg Radiol Anat 39:69–75. https://doi.org/10.1007/s00276-016-1682-1

21. Olewnik, Karauda P, Gonera B, et al (2020) Intramuscular innervation of plantaris muscle evaluated using a modified Sihler's staining protocol — Proposal for a new classification. Ann Anat 230:151504. https://doi.org/10.1016/j.aanat.2020.151504

22. Olewnik Ł, Gonera B, Kurtys K, et al (2019) A proposal for a new classification of the fibular (lateral) collateral ligament based on morphological variations. Ann Anat

222:1–11. https://doi.org/10.1016/j.aanat.2018.10.009

23. Diogo R, Siomava N, Gitton Y (2019) Development of human limb muscles based on whole-mount immunostaining and the links between ontogeny and evolution. Development 146:dev180349. https://doi.org/10.1242/dev.180349

24. Boyle EK, Mahon V, Diogo R (2020) Muscles Lost in Our Adult Primate Ancestors Still Imprint in Us: on Muscle Evolution, Development, Variations, and Pathologies. Curr Mol Biol Reports 6:32–50. https://doi.org/10.1007/s40610-020-00128-x

25. Aerts P, D'Août K, Thorpe S, et al (2018) The gibbon's Achilles tendon revisited: Consequences for the evolution of the great apes? Proc R Soc B Biol Sci 285:. https://doi.org/10.1098/rspb.2018.0859

26. Malvankar S, Khan WS (2011) Evolution of the Achilles tendon: The athlete's Achilles heel? Foot 21:193–197

27. Pang BSF, Ying M (2006) Sonographic measurement of Achilles tendons in asymptomatic subjects: Variation with age, body height, and dominance of ankle. J Ultrasound Med 25:1291–1296. https://doi.org/10.7863/jum.2006.25.10.1291

28. Ying M, Yeung E, Li B, et al (2003) Sonographic evaluation of the size of Achilles tendon: The effect of exercise and dominance of the ankle. Ultrasound Med Biol 29:637–642. https://doi.org/10.1016/S0301-5629(03)00008-5

29. Kearns CF, Isokawa M, Abe T (2001) Architectural characteristics of dominant leg muscles in junior soccer players. Eur J Appl Physiol 85:240–243. https://doi.org/10.1007/s004210100468

30. Calleja M, Connell DA (2010) The achilles tendon. Semin Musculoskelet Radiol 14:307–322. https://doi.org/10.1055/s-0030-1254520

31. Soroceanu A, Glazebrook M, Sidhwa F, et al (2012) Surgical versus nonsurgical treatment of acute achilles tendon rupture: A meta-analysis of randomized trials. J Bone Jt Surg - Ser A 94:2136–2143. https://doi.org/10.2106/JBJS.K.00917

Table I. Detail measurements of muscles and tendon

Structure	Measurements
Gastrocnemius muscle	Length of the lateral head — distance from posterior part of the lateral femoral condyle to the end of its muscle part
	Length of the medial head — distance from posterior part of the medial femoral condyle to the end of its muscle part
	Length of the lateral tendon — distance from the end of its muscle part to the calcaneal tuberosity
	Length of the medial tendon — distance from the end of its muscle part to the calcaneal tuberosity
Soleus muscle	Length from its beginning at soleal line on tibia to the end of the muscle part
	Length of the tendon from the end of its muscle part to the calcaneal tuberosity
Achilles tendon	Width at the calcaneal tuberosity
	Thickness at the calcaneal tuberosity

Table II. Measurements of the Achilles tendon, Gastrocnemius muscle and Soleus muscle in 3rd trimester fetuses

GM — gastrocnemius muscle; LH — lateral head of gastrocnemius; MH — medial head of gastrocnemius; SM — soleus muscle

Features (3 trimester)		**Sex**			**Body side**		
		Male (n=10)	**Female (n=2)**	**p**	**Left (n=6)**	**Right (n=6)**	**p**
GM	LH muscle	41.61±5.77	34.81±2.54	0.144	39.57±3.59	41.38±7.85	0.619
	LH tendon	49.58±9.44	43.98±6.18	0.449	48±10.36	49.28±8.38	0.818
	MH muscle	46.38±6.3	43.12±1.12	0.498	44.12±4.72	47.56±6.78	0.331
	MH tendon	44.24±9.75	32.13±3.22	0.124	43.39±10.76	41.05±10.14	0.706
SM	muscle	62.98±13.14	53.57±2.57	0.354	59.68±12.54	63.14±13.31	0.652
	tendon	**24.83±3.42**	**18.95±2.36**	**0.045**	25.2±4.32	22.50±3.26	0.251
Achilles	Width	8.26±1.94	7.38±0.31	0.551	7.98±2.06	8.24±1.65	0.817
	Thickness	1.46±0.28	1.33±0.05	0.559	1.47±0.29	1.4±0.25	0.639
GM LH to MH muscle		0.9±0.07	0.81±0.08	0.141	0.89±0.04	0.87±0.11	0.559
GM LH muscle to tendon ratio		0.86±0.12	0.80±0.17	0.615	0.85±0.13	0.85±0.14	0.983
GM MH muscle to tendon ratio		1.08±0.18	1.35±0.17	0.075	1.05±0.18	1.19±0.20	0.231
SM muscle to tendon ratio		2.6±0.73	2.86±0.49	0.650	2.42±0.66	2.86±0.69	0.281

Table III. Measurements of the Achilles tendon, Gastrocnemius muscle and Soleus muscle in 2nd trimester fetuses

Features (2 trimester)		**Sex**			**Body side**		
		Male (n=24)	**Female (n=38)**	**p**	**Left (n=31)**	**Right (n=31)**	**p**
GM	LH muscle	26.12±4.97	28.07±6.55	0.225	27.04±5.31	27.61±6.75	0.718
	LH tendon	27.22±3.86	28.36±4.53	0.318	28.06±4.16	27.80±4.47	0.812
	MH muscle	28.35±5.42	30.13±6.22	0.26	29.84±5.37	29.09±6.53	0.625
	MH tendon	23.99±3.42	25.48±4.97	0.212	24.86±4.57	24.97±4.46	0.921
SM	muscle	34.77±5.44	37.24±6.61	0.137	36.31±6.30	36.31±6.33	0.999
	tendon	16.3±4.17	14.43±4.19	0.096	14.72±4.02	15.53±4.48	0.465
Achilles	Width	4.81±1.12	5.01±1.5	0.586	4.87±1.41	4.99±1.34	0.734
	Thickness	1.07±0.46	1.01±0.43	0.622	0.95±0.43	1.11±0.44	0.170
GM LH to MH muscle		0.93±0.15	0.94±0.15	0.891	0.91±0.08	0.96±0.19	0.150
GM LH muscle to tendon ratio		0.96±0.17	1.01±0.29	0.579	0.96±0.15	1.01±0.33	0.489
GM MH muscle to tendon ratio		1.19±0.26	1.21±0.27	0.889	1.22±0.23	1.18±0.29	0.587
SM muscle to tendon ratio		**2.29±0.77**	**2.75±0.76**	**0.029**	2.61±0.7	2.54±0.88	0.734

GM — gastrocnemius muscle; LH — lateral head of gastrocnemius; MH — medial head of gastrocnemius; SM — soleus muscle

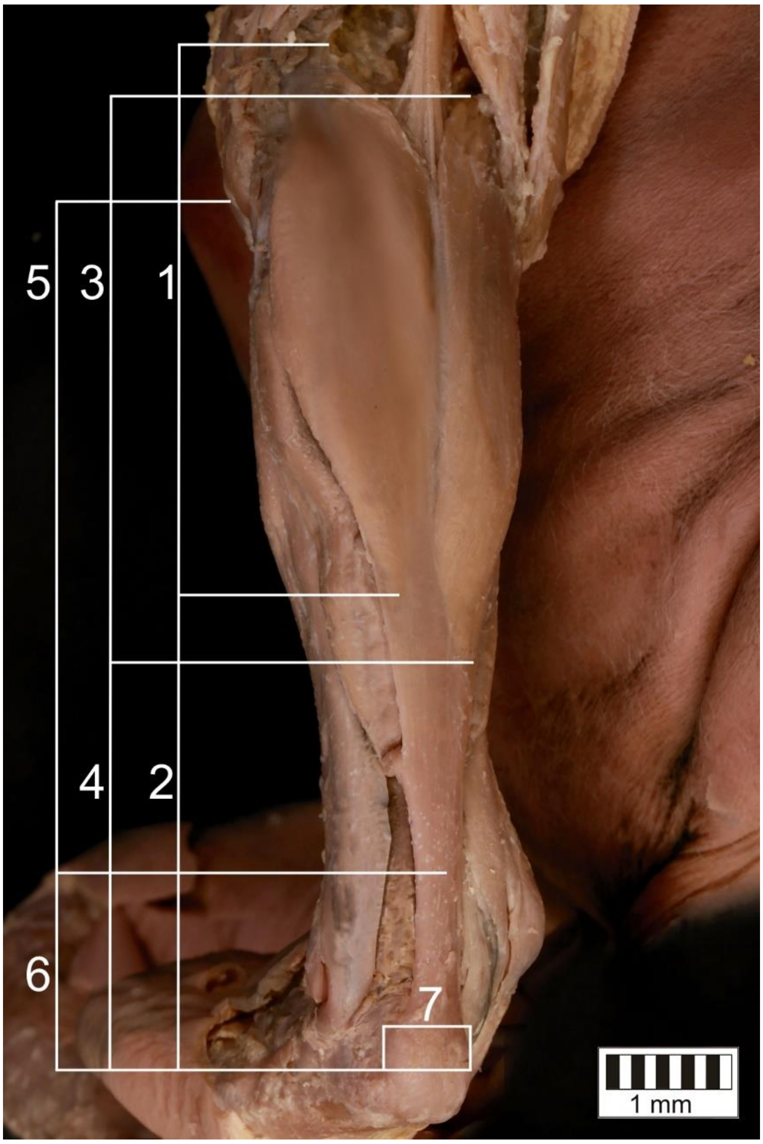

Figure 1. Detail measurements of muscles and tendon; 1 — length of the lateral head of the GM; 2 — length of the lateral tendon of the GM; 3 — length of the medial head of the GM; 4 — length of the medial tendon of the GM; 5 — length of the muscle of the SM; 6 — length of the tendon of the SM; 7 — thickness and width of the AT.

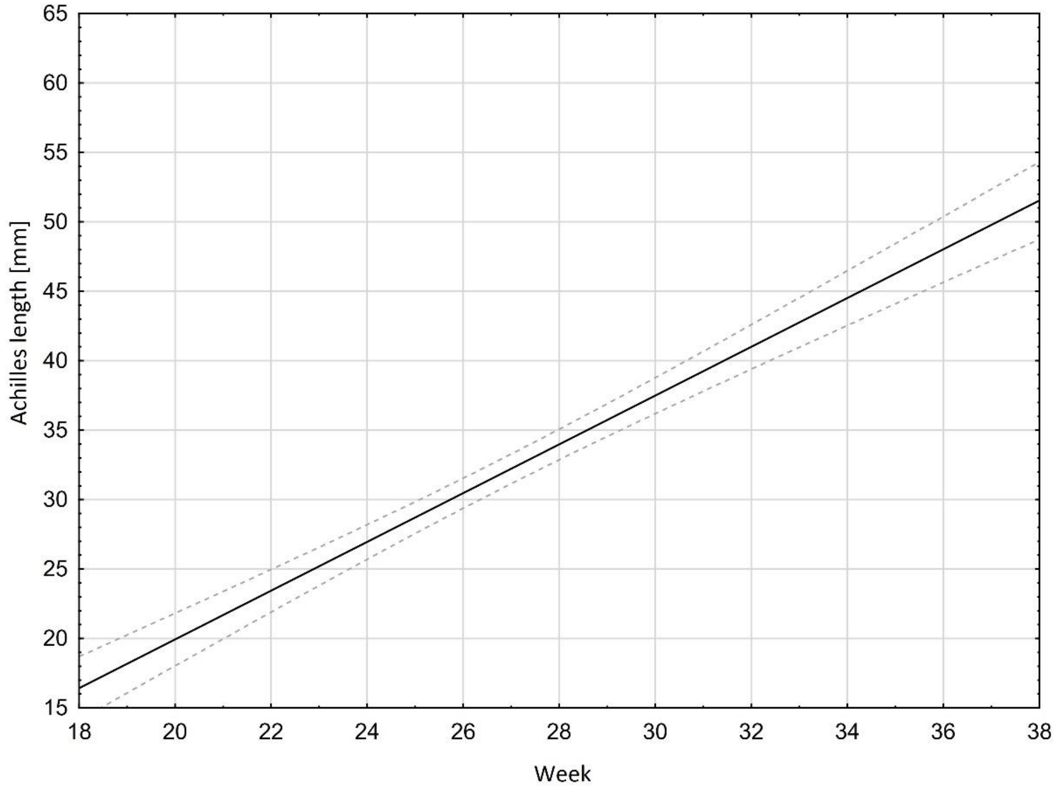

Figure 2. Linear correlation between length of the Achilles tendon and week of gestation with 95% confidence interval.