Anatomical Study Of Sites And Footprints Of Tibial Posterior Tendon Attachment

Inori Uchiyama

Niigata University of Health and Welfare

Mutsuaki Edama (✉ edama@nuhw.ac.jp)

Niigata University of Health and Welfare

Hirotake Yokota

Niigata University of Health and Welfare

Ryo Hirabayashi

Niigata University of Health and Welfare

Chie Sekine

Niigata University of Health and Welfare

Sae Maruyama

Niigata University of Health and Welfare

Mayuu Syagawa

Niigata University of Health and Welfare

Ryoya Togashi

Niigata University of Health and Welfare

Yuki Yamada

Niigata University of Health and Welfare

Ikuo Kageyama

Nippon Dental University

Research Article

Keywords: tibialis posterior tendon dysfunction, attachment site, footprint

Posted Date: February 11th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1325594/v1>

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Abstract

Background: The purpose of this study was to clarify variations in the tibialis posterior tendon (TPT) attachment site using a large sample and to quantify the contribution of each attachment site by examining the surface area of the attachment region.

Methods: We examined 100 feet from 50 Japanese cadavers. The TPT of attachment to the the navicular bone (NB), medial cuneiform bone [1], and lateral cuneiform bone (LCB) was set as the main attachment site (Type I). Type II was defined as one extra attachment site in addition to those of Type I, meaning attachment to a total of four sites. Classification up to Type VII was seen according to the number of additional attachment sites. Furthermore, surface area was measured using a 3-dimensional scanner to make the foot sample three-dimensional. Surface area was then calculated using 3-dimensional software.

Results: Attachment to the NB, MCB, and LCB was present in all specimens. Attachment to the intermediate cuneiform bone was seen in 25 feet (25%), and to the cuboid bone in 66%. Among 1st–5th metatarsal bones, 4th metatarsal bone was the most attached, at 95%. The TPT attachment to the NB, MCB, and LCB were comprising 75.1% of total attachment surface area. The ratio of the NB, MCB and LCB in each type was about 90% in Types II and III, and 70–80% in Types IV–VII.

Conclusion: Attachment of the TPT to the NB, MCB, and LCB may thus contribute to stability of the foot arch.

Introduction

The tibialis posterior (TP) plays a very important role during gait as the primary dynamic stabilizer of the medial longitudinal arch [2]. A typical disorder of the tibialis posterior tendon (TPT) is TPT dysfunction (TPTD), which occurs when the TPT becomes inflamed or torn [3]. Previously, although TPTD was thought to be secondary to an inflammatory process resulting in acute and chronic tendinitis, more recent histopathological evidence has revealed this pathology as a degenerative tendinosis with a nonspecific reparative response to tissue injury[4]. TPTD is the prevailing cause of adult acquired flatfoot deformity (AAFD), and it is characterized by collapse of the medial longitudinal arch [5]. An anatomical understanding of the TPT is therefore important not only for understanding the movement and stability of the foot and ankle joints, but also for the prevention of disorders. However, although the anatomical features of TPT have been investigated in various previous studies, no consensus has been obtained regarding the sites of TPT attachment [5–12].

Regarding the sites of TPT attachment, Musial [12] described a permanent, main TPT insertion onto the navicular bone (NB), medial cuneiform bone [1], intermediate cuneiform bone (ICB), lateral cuneiform bone (LCB), and 2nd–3rd metatarsal bones (2–3MB). However, among the 122 feet examined, different sites of attachment were found for the accessory bundles, including the cuboid bone [1] (116 feet), 4th metatarsal bone (4MB) (106 feet), flexor hallucis brevis (104 feet), calcaneus and CB (36 feet), peroneus

longus muscle (20 feet), and 5th metatarsal bone (5MB) (four feet). In addition, Bloome et al. [6] classified TPT into three fibers, anterior, middle, and posterior bundles in an investigation of 11 fresh frozen cadaver feet, and examined the sites of attachment for each bundles. The anterior bund was reported to attach to the navicular tuberosity, inferior capsule of the naviculocuneiform joint, and the inferior surface of the MCB. The middle bund attached to the ICB, LCB, CB, 2nd–5th metatarsal bones, flexor hallucis brevis, and peroneus longus tendon. The posterior bund attached to the sustentaculum tali and spring ligament. Furthermore, in recently, Olewnik [7] investigated the site of TPT attachment in 80 fixed cadaver feet, defining attachment to the NB and MCB as Type I, and categorizing Types II–IV and subtypes A–C according to additional sites of attachment. Willegger et al. [5] showed that the major site of TPT attachment in 41 fixed cadaveric feet was the NB. Branching and attachment to up to eight bones was reported among any of the MCB, ICB, LCB, CB, calcaneus, and 1st–5th metatarsal bones.

No consensus has been reached from previous studies regarding sites of TPT attachment [5–7, 12]. Possible obstacles to development of such a consensus include ethnic differences, differences in laterality, and differences in numbers of samples [5]. While previous studies [5–7, 12] have considered that the NB, MCB, and LCB are the main sites of TPT attachment, the degree of contribution of these attachment sites has not been quantified, and whether they actually contribute significantly to the actions of the TPT remains unknown. Main attachment sites thus need to be clarified by calculating and comparing the surface areas of individual attachment sites.

The purpose of this study was to clarify variations in TPT attachment site using a large sample and to quantify the contribution of each attachment site by examining the surface area of the attachment region.

Methods

Cadavers

We examined 100 feet from 50 Japanese cadavers (mean age at death, 80 ± 11 years; 56 sides from 28 men, 44 sides from 22 women; 50 right sides, 50 left sides) that had been switched to alcohol after placement in 10% formalin. No legs showed any sign of previous major surgery around the ankle. This study was approved by the ethics committee at our institution.

Methods

The procedure for dissecting the TPT is described below. Isolated specimens of the leg were created by transection about 10 cm above the ankle. The skin and subcutaneous tissue were removed and the peroneus longus and the peroneus brevis muscles and TPT were carefully dissected out and inspected. The plantar aponeurosis was carefully dissected from the flexor digitorum brevis and removed. The first, second, and third plantar layers were then dissected and excised. Upon reaching the fourth layer, to clarify sites of attachment to the TPT, the flexor hallucis brevis, flexor digiti minimi brevis, adductor hallucis, opponens digiti minimi, first–fourth dorsal interossei, first–third plantar interossei, part of peroneus

longus, the lateral Lisfranc ligament, and the metatarsal plantar ligament were dissected and excised (Fig. 1A). Based on a previous study [7], the regions of attachment to the NB, MCB, and LCB were set collectively as the main attachment site (Type I). The attachment seen in Type I with addition of one additional site of attachment was defined as Type II, which thus showed attachment at a total of four sites. In the same manner, classification up to Type VII was made according to the number of additional attachment sites. Furthermore, the attachment site area was identified by peeling away any adherent tissue, then coloring the attachment site with a pencil (Fig. 1B). The surface area was then measured using a 3-dimensional (3D) scanner (EinScan Pro HD; SHINING 3D, Hangzhou, China) to make the foot sample 3D (Fig. 1C). The resulting data were read into Geomagic Freeform 2021 design software (3D SYSTEMS), and the boundary of the attachment site was drawn as a curve with a pen-type device (Touch; 3D SYSTEMS) (Fig. 1D). Surface area was then calculated using Rhinoceros7 3D software (McNeel) (Fig. 1E). Each attachment site was measured twice to allow calculation of the mean value and standard deviation. The ratio of each adhered area was calculated so that the sum of adhered areas for each sample as 100%. All measurements were made by the same physical therapist (I.U.).

The reliability of surface area measurement by 3D scanner was calculated using the intraclass correlation coefficient (ICC) (1,2) for 10 of 100 feet, yielding an ICC of 0.993. In this study, measurement of surface area showed almost perfect reliability, consistent with previous results [13].

Statistical analysis

Statistical analyses were performed using SPSS version 24.0 (SPSS Japan, Tokyo, Japan). Pearson’s chi-squared test was used to compare differences in insertion location between sex and laterality. The level of significance was set at 5%.

Results

Sites and ratios of TPT attachment (Table 1)

Table 1
Site of tibialis posterior attachment and ratio

Site of attachment	Ratio (%)	Site of attachment	Ratio (%)
NB	100	1MB	4
MCB	100	2MB	42
ICB	25	3MB	52
LCB	100	4MB	95
CB	66	5MB	15
NB, navicular bone; MCB, medial cuneiform bone; ICB, intermediate cuneiform bone; LCB, lateral cuneiform bone; CB, cuboid bone; 1-5MB, 1st–5th metatarsal bone.			

Attachment to the NB, MCB, and LCB was present in all specimens (100%). Attachment to the ICB was seen in 25 feet (25%), and to the CB in 66 feet (66%). Among 1–5MBs, 4MB was the most commonly attached, at 95 feet (95%).

Type Classification For Site Of Tpt Attachment

With NB, MCB, and LCB considered together as the most basic attachment site (Type I), 7 types were classified according to the number of additional attachment sites, with subtypes A–D defined according to the types of additional attachment sites (Fig. 2, Table 2). Of the seven types, Type IV was the most common, seen in 29 feet (29%), while Type VII was the least common, in 2 feet (2%). No cases of Type I were identified (Table 2). In addition, Types II and III could be classified into three subtypes (A–C), Types IV and V could be classified into four subtypes (A–D), and Type VI could be classified into two subtypes (A and B).

Table 2
Type classification for site of tibialis posterior tendon attachment

Type	Site of attachment		Number of feet	Total
I	NB, MCB, LCB		0	0
II	Type I and 1 site	A 2MB	1	11
		B 3MB	1	
		C 4MB	9	
III	Type I and 2 sites	A Two of ICB, 2MB, 3MB or 4MB	1	26
		B Two of CB, 2MB, 3MB or 4MB	16	
		C Two of 2MB, 3MB, 4MB or 5MB	9	
IV	Type I and 3 sites	A ICB, CB and 4th MB	2	29
		B ICB, two of 2MB, 3MB, 4MB or 5MB	3	
		C CB, two of 2MB, 3MB, 4MB or 5MB	19	
		D Three of 2MB, 3MB, 4MB or 5MB	5	
V	Type I and 4 sites	A ICB, CB and two of 2MB, 3MB, 4MB or 5MB	8	23
		B ICB, 2MB, 3MB and 4MB	3	
		C CB, three of 1MB, 2MB, 3MB, 4MB or 5MB	10	
		D 2MB, 3MB, 4MB and 5MB	2	
VI	Type I and 5 sites	A ICB, CB, 3MB, 4MB and 5MB	8	9
		B CB, four of 1MB, 2MB, 3MB, 4MB or 5MB	1	
VII	Type I and 6 sites	CB, 1MB, 2MB, 3MB, 4MB and 5MB	2	2
NB, navicular bone; MCB, medial cuneiform bone; ICB, intermediate cuneiform bone; LCB, lateral cuneiform bone; CB, cuboid bone; 1MB, 1st metatarsal bone; 2MB, 2nd metatarsal bone; 3MB, 3rd metatarsal bone; 4MB, 4th metatarsal bone; 5MB, 5th metatarsal bone.				

Differences In Laterality And Sex By Type

No significant differences were observed between types (Table 3).

Table 3
Differences in laterality and sex for each type

Type	Male	Female	Right	Left	Total
I	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
II	6 (10.7)	5 (11.4)	6 (12.0)	5 (10.0)	6 (10.7)
III	15 (26.8)	11 (25.0)	13 (26.0)	13 (26.0)	15 (26.8)
IV	17 (30.4)	12 (27.3)	12 (24.0)	17 (34.0)	17 (30.4)
V	13 (23.2)	10 (22.7)	11 (22.0)	12 (24.0)	13 (23.2)
VI	3 (5.4)	6 (13.6)	7 (14.0)	2 (4.0)	3 (5.4)
VII	2 (3.6)	0 (0)	1 (2.0)	1 (2.0)	2 (3.6)
Total	56 (100)	44 (100)	50 (100)	50 (100)	56 (100)
Number (%)					

Surface Area Of Site Of Tibialis Posterior Tendon Attachment

Surface areas were $120 \pm 69.9 \text{ mm}^2$ (25.7%) for NB, $182.4 \pm 50.0 \text{ mm}^2$ (39.0%) for MCB, $48.6 \pm 24.7 \text{ mm}^2$ (10.4%) for LCB, and the three main attachment sites provided a mean of 75.1% of the total attachment (Table 4). The ratio of the three main attachment sites (NB, MCB and LCB) in each type was about 90% in Types II and III, and 70–80% in Types IV–VII (Table 5).

Table 4
Surface areas at sites of tibialis posterior tendon attachment

Attachment site	NB	MCB	ICB	LCB	CB	1MB	2MB	3MB	4MB	5MB
Surface area (mm ²)	120.0 ± 69.9	182.4 ± 50.0	18.4 ± 18.3	48.6 ± 24.7	17.9 ± 15.0	12.1 ± 2.9	19.5 ± 13.8	11.7 ± 9.9	16.6 ± 10.2	20.4 ± 11.6
Ratio (%)	25.7	39.0	3.9	10.4	3.8	2.6	4.2	2.5	3.6	4.4
NB, navicular bone; MCB, medial cuneiform bone; ICB, intermediate cuneiform bone; LCB, lateral cuneiform bone; CB, cuboid bone; 1MB, 1st metatarsal bone; 2MB, 2nd metatarsal bone; 3MB, 3rd metatarsal bone; 4MB, 4th metatarsal bone; 5MB, 5th metatarsal bone.										

Table 5
Percentage surface areas for each type at navicular bone, medial cuneiform bone,
and lateral cuneiform bone

Type	NB	MCB	LCB	Total
II	40.5	43.1	8.7	92.3
III	32.6	38.3	9.8	80.6
IV	22.7	42.6	11.5	76.8
V	27.1	34.1	10.7	71.9
VI	20.5	42.9	14.5	78.0
VII	9.9	60.9	0.7	71.5
NB, navicular bone; MCB, medial cuneiform bone; LCB, lateral cuneiform bone.				

Discussion

In this study, TPT was classified into seven types and four subtypes (A–D) according to the number of attachment sites. A previous study [7] reported four types and three subtypes (A–C), differing from the present. In addition, no significant difference by sex or laterality was seen between types, and we used 100 samples, representing a larger cohort than previous studies [5–7, 12]. The results of this study may thus have yielded different classifications from the previous studies because of differences in the numbers of samples, not factors of sex or laterality.

In this study, attachment to the NB, MCB, and LCB, collectively representing the main site of attachment, was observed in all specimens (100%). Furthermore, the surface area of these main attachment sites (NB, MCB and LCB) accounted for 75.1% of the total, and even among the different types, consistently accounted for more than 70% of the total regardless of the number of additional attachment sites. According to previous studies [5–7, 12], the main attachment sites of the TPT were still the NB, MCB, and LCB, but only the proportion of attachment sites was examined, and how much of the TPT was attached to each site was not examined. The quantitative results obtained in the present study confirmed the NB, MCB, and LCB as the main sites of TPT attachment, broadly supporting the findings of previous studies.

The TPT elevates the medial arch and inverts, adducts, and plantar-flexes the foot [14]. TPTD is the prevailing cause of AAJD, which is characterized by a collapse of the medial longitudinal arch [3, 15]. Swanton et al. [9] reported an extension onto the MCB from the anterior band, naming this as the “navicular cuneiform ligament”. This forms a static restraint between two bony insertions (NB and MCB) and increases the lever arm of the TPT. Gwani et al. [16] also clarified three relationships between the medial and lateral longitudinal arches and the lateral arch. Deformation of the medial longitudinal arch reportedly affects other arches. In addition, the lateral arch has been reported to comprise three cuneiform bones and the CB [8]. From those previous studies and the results of this study, attachment to the NB and

MCB was considered related to the function of the medial longitudinal arch, while attachment to the LCB appears related to the function of the lateral arch.

Some limitations need to be considered when interpreting the findings from this study. First, since only Japanese cadavers were used, potential differences between different ethnicities were not examined. The existence of ethnic differences in foot muscles has been suggested in several papers [5, 17]. Caucasian individuals were found to be nearly three times more likely to show tendinopathic findings when compared to African-American individuals according to a study using ultrasound [18]. Future studies will therefore need to consider comparisons between different ethnicities to clarify the potential for variations in TPT attachment sites. Second, in type classifications for the TPT, only attachments to bone were considered. Previous studies have reported attachments to the abductor hallucis, flexor hallucis brevis, peroneus longus tendon, spring ligament, and plantar calcaneocuboid ligament [6, 7, 12]. Type classification thus needs to be performed with consideration of not only attachment to bone, but also attachment to muscles and ligaments.

In conclusion, the results of this study confirmed TPT attachments to the NB, MCB, and LCB in all specimens, and the surface area of these attachment sites occupied 75.1% of the total attachments to bone. Attachment of the TPT to the NB, MCB, and LCB may thus provide the primary contribution to the stability of the foot arch. In the future, comparisons between races and classification in consideration of attachments to muscles and ligaments will be needed in addition to attachments to bone.

Declarations

Ethical approval and consent to participate

All methods were carried out in accordance with the 1964 Declaration of Helsinki, and all cadavers were legally donated for research purposes to the Dental Sciences at Niigata, Japan. This study was approved by the ethics committee of the Niigata University of Health and Welfare. Informed consent was obtained from the families of all subjects.

Consent for publication

Not Applicable

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to limitations of ethical approval involving the patient data and anonymity but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

None.

Authors' contributions

IU and ME contributed to the study design and data collection, and drafted the manuscript; HY, RH contributed to the data analysis and made critical revisions to the manuscript; CS, SM, MS, RT, and YY made critical revisions to the manuscript; IK supervised the study, contributed to the analysis and interpretation of data, and made critical revisions to the manuscript. All authors read and approved the final manuscript prior to submission.

Acknowledgments

The authors wish to acknowledge and thank the anonymous individuals who generously donated their bodies for medical research, enabling this study to be performed. This study was supported by a Grant-in-Aid for Scientific Research (19K11358) from the Japanese Society for the Promotion of Science (JSPS) and was commissioned by the Japan Sports Agency (Female Athletes Development and Support Projects 2021).

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Figures

Figure 1

Method for measuring site of attachment

A: Site of attachment of the tibialis posterior tendon: right foot, plantar view.

B: The site of attachment was identified by peeling the adherent tissue, then coloring the site with red pencil.

C: The surface area was measured using a 3D scanner to make the foot sample 3-dimensional.

D: Enlarged view of the medial cuneiform bone. A curve is drawn as the boundary of the site of attachment of the navicular bone with a pen-type device.

E: Surface area was calculated using Rhinoceros 3D software.

Figure 2

Type classification of the tibialis posterior tendon

1, Navicular bone; 2, medial cuneiform bone; 3, lateral cuneiform bone; 4, intermediate cuneiform bone; 5, cuboid bone; 6, 1st metatarsal bone; 7, 2nd metatarsal bone; 8, 3rd metatarsal bone; 9, 4th metatarsal bone; 10, 5th metatarsal bone; M, medial; L, lateral.

Type II: In addition to Type I (navicular bone, medial cuneiform bone, and lateral cuneiform bone), one additional site of attachment, with attachment to a total of four sites.

A: 2nd metatarsal bone.

B: 3rd metatarsal bone.

C: 4th metatarsal bone.

Type III: In addition to Type I, two additional sites of attachment, with attachment to a total of five sites.

A: Intermediate cuneiform bone, 4th metatarsal bone.

B: Cuboid bone, 4th metatarsal bone.

C: 3rd metatarsal bone, 4th metatarsal bone.

Type IV: In addition to Type I, three additional sites of attachment, with attachment to a total of six sites.

A: Intermediate cuneiform bone, cuboid bone, 4th metatarsal bone.

B: Intermediate cuneiform bone, 4th metatarsal bone, 5th metatarsal bone.

C: Cuboid bone, 3rd metatarsal bone, 4th metatarsal bone.

D: Third metatarsal bone, 4th metatarsal bone, 5th metatarsal bone.

Type V: In addition to Type I, four additional sites of attachment, with attachment to a total of seven sites.

A: Intermediate cuneiform bone, cuboid bone, 3rd metatarsal bone, 4th metatarsal bone.

B: Intermediate cuneiform bone, 2nd metatarsal bone, 3rd metatarsal bone, 4th metatarsal bone.

C: Cuboid bone, 2nd metatarsal bone, 3rd metatarsal bone, 4th metatarsal bone.

D: 2nd metatarsal bone, 3rd metatarsal bone, 4th metatarsal bone, 5th metatarsal bone.

Type VI: In addition to Type I, five additional sites of attachment, with attachment to a total of eight sites.

A: Intermediate cuneiform bone, cuboid bone, 3rd metatarsal bone, 4th metatarsal bone, 5th metatarsal bone.

B: Cuboid bone, 1st metatarsal bone, 2nd metatarsal bone, 4th metatarsal bone, 5th metatarsal bone.

Type VII: In addition to Type I, six additional sites of attachment, with attachment to a total of nine sites.

Cuboid bone, 1st metatarsal bone, 2nd metatarsal bone, 3rd metatarsal bone, 4th metatarsal bone, 5th metatarsal bone.