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Assessment of tibialis anterior tendon insertion variations in relation to hallux valgus utilizing magnetic resonance imaging

Fatih Uğur[1,5*], Mehmet Albayrak[2], Bedrettin Akar[3] and Bahadir Reis[4]

Abstract

Background Hallux valgus is a deformity characterized by lateral deviation of the big toe and medial deviation of the first metatarsal, causing difficulty in walking and requiring various treatments. Despite its multifactorial etiology, the role of the tibialis anterior tendon in hallux valgus and its variations in the morphology of tibialis anterior tendon distal insertion sites have not been fully explored. This study aimed to evaluate the effect of such variations on hallux valgus using magnetic resonance imaging.

Methods This was a retrospective study and included 115 individuals aged 18 years and older who underwent foot radiographs and MRI. The participants were divided into a hallux valgus group of 53 patients and a control group of 62 people based on radiographic measurements. Tibialis anterior tendon distal attachment was classified into five types according to the attachment morphology. Statistical analyses were performed to evaluate the relationship between the tibialis anterior tendon types and hallux valgus severity.

Results Among the participants, patients who underwent foot radiography and MRI due to any medical indication 70.4% were female, with a mean age of 43.83 ± 15.25 years. In terms of tibialis anterior tendon distal attachment, the most common type was Type 5 (40.9%), followed by Type 2 (34.8%). Type 4 was not observed in any case. In all participants, the mean hallux valgus angle was 20.63 ± 8.42°, and the mean intermetatarsal angle was 9.69 ± 2.68°. Tibialis anterior tendon distal attachment Type 5 was significantly associated with an increased hallux valgus angle but not with the intermetatarsal angle. We found a significant relationship between the diameter of the tibialis anterior tendon and hallux valgus angle.

Conclusions This study revealed a significant association between hallux valgus and Type 5 tibialis anterior tendon distal attachment, suggesting that tibialis anterior tendon morphology influences hallux valgus severity. The findings underscore the importance of considering variations in tibialis anterior tendon distal attachment sites in the etiopathogenesis and treatment planning of hallux valgus.

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Introduction

Hallux valgus (HV) is characterized by lateral deviation of the big toe and medial deviation of the first metatarsal [1]. This condition, which can occur at any age, leads to difficulty walking in shoes rather than barefoot [2, 3]. A recent meta-analysis determined the global prevalence of HV to be 19% [2]. Intrinsic muscle imbalance, genetic conditions, narrow shoes, and flat feet are well-known factors that play significant roles in the development of the deformity [1, 2]. However, the actual trigger for HV remains unknown, and it likely has a multifactorial etiology [1, 2, 4]. Nonsurgical treatment approaches do not correct the deformity but alleviate symptoms [5, 6]. Since HV surgery was first described by Reverdin in 1881 [3], surgical techniques have expanded, and there are now over 100 procedures [2, 3, 5]. Varying complication rates of between 1% and 75% associated with these surgical procedures indicate the absence of a gold standard in treatment [7, 8]. Regardless of the surgical technique used, postoperative recurrence increases with the severity of HV preoperatively and with age [9].

Understanding the etiopathogenesis of HV would enable early and effective treatment [4, 9]. Although metatarsocuneiform joint hypermobility is considered one of the risk factors for HV, a consensus on its role in HV has yet to be reached [1, 10, 11]. The hyperpronation mechanism of the first metatarsal in HV has been evaluated, with significant hyperpronation detected in 31.4% of patients [12]. A cadaver study demonstrated that HV could be induced by a combination of intrinsic hyperpronation of the first metatarsal and medial soft tissue insufficiency at the first metatarsophalangeal joint [13].

Of the foot tendons, the insertion of the abductor hallucis tendon into the first metatarsal has been associated with clinical severity of HV deformity due to abnormal alignment [14]. The distal insertion of the tibialis anterior tendon (TAT), which affects the first metatarsal, is known for its inadequacy that can lead to pronation, a factor demonstrated to influence the etiology of HV. However, the role of the TAT in HV has not been adequately investigated [15–17].

Upon reviewing the literature, a cadaver study was conducted in which the classification of the TAT according to its distal attachment site was evaluated, and this study reported no relationship between TAT and HV [15]. However, the inclusion of elderly cadavers in this study and the significantly different results compared to other studies on TAT classification make it difficult to reach a definitive conclusion, highlighting the need for further research.

In this study, we aimed to evaluate the effect of TAT attachment site type on HV etiology using magnetic resonance imaging (MRI).

Patients and methods

115 patients, who had appropriate MRI and X-ray images, were included in the study. This was a single-center, retrospective study conducted at Kastamonu Education and Research Hospital. Ethical approval was obtained from the local institutional ethics board. The demographic characteristics of the patients, including age and gender, were recorded. Patients were included in the study, regardless of the reason for their condition, as long as they had undergone both foot radiography and MRI. All imaging studies included were conducted within one month of each other. Radiographs obtained between 1 November 2023 and 1 March 2024 were evaluated. All radiological data were obtained from the hospital's Picture Archiving and Communication System database. Patients without full weight-bearing anteroposterior and lateral foot radiographs, as well as those whose TAT distal attachment site could not be classified on MRI, were excluded from the study.

Based on the evaluation of the radiographs, the patients were divided into two groups: a HV group (HV diagnosis) and a control group (no HV diagnosis).

The criteria for a diagnosis of HV were a HVA 16° and above an intermetatarsal angle (IMA) 9 ° and above. The HVA is the angle between the longitudinal axes of the proximal phalanx of the big toe and the first metatarsal, with a normal value between 5° and 15°. The IMA is the angle between the longitudinal axes of the first metatarsal bone and the second metatarsals in the true full weight-bearing anteroposterior (AP) view of the foot, with a normal value of less than 9° [15].

The same radiologist performed the MRI evaluations, and the same orthopedic surgeon performed the measurements of the foot radiographs. All patients who underwent foot MRI and had clear images showing the TAT distal attachment site were included in the study. MR imaging was performed on a 1.5-T scanner (Signa Explorer, General Electric Medical Systems, Milwaukee, Wisconsin, USA). The ankle was placed in a neutral position in a knee coil. Sagittal images along the plane of the TAT and axial images perpendicular to that plane were obtained of both ankles using the following protocol: T1-weighted spin-echo images (TR/TE, 400/10; 3-mm section thickness; 192×256 matrix, 1 signal acquired) and fat-suppressed fast spin-echo T2-weighted images (TR/effective TE, 4000/105; section thickness, 3 mm; echo-train length, 4; matrix, 192×256; signals acquired, 2).

Based on previous studies, the TAT distal attachment site was classified into five types according to attachment morphology. While the Type 5 variation of the TAT distal insertion, consisting of a single band, attaches to the medial cuneiform, other types consist of multiple bands

that attach to the medial cuneiform and proximal phalanx at varying thicknesses [16, 17].

The five types were as follows:

Type 1: A tendon with two equal-sized components attached to the medial cuneiform bone and the base of the first metatarsal.

Type 2: A tendon divided into two components attached to the medial cuneiform bone (larger component) and the base of the first metatarsal (smaller component).

Type 3: A tendon divided into two components attached to the medial cuneiform bone (smaller component) and the base of the first metatarsal (larger component).

Type 4: A tendon divided into three different-sized components, attached to the medial cuneiform bone (smallest component) and the base of the first metatarsal (medium and larger components).

Type 5: A single tendon attached to the medial cuneiform bone.

During the distal attachment site typing of the TAT on MRI, the diameters of the TAT and its various components were recorded for each patient. Tendon thickness was measured using the widest dimensions obtained from axial T1 and fat-suppressed proton density images. The TAT diameter was specifically measured from sections passing through the medial malleolus. Measurements were taken at the thickest points of the TAT, after it had been divided into two or three components: the medial cuneiform component (MCc) and the proximal metatarsal component (PMc) [27].

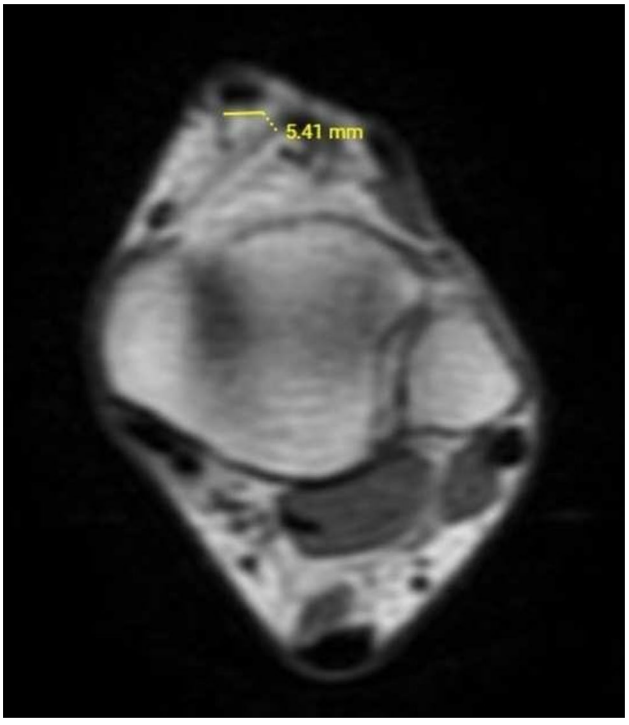

Fig. 1 Measurement location of the tibialis anterior main tendon at the level of the medial malleolus on axial T1-weighted images

In Fig. 1 the location of TAT at medial malleoli level is seen.

In Fig. 2 type 5 tendon (A) and type 2 tendon (B) are seen.

In Fig. 3 TAT is seen as single band or two split bands.

In Fig. 4 with the more distal sections first branch and second branch of TAT is seen.

Statistical analysis

Data distribution was examined with the Shapiro–Wilk test. The Mann–Whitney U test compared two independent groups without normal distribution, while the Kruskal–Wallis test compared three such groups. Significant Kruskal–Wallis results were followed by Dunn's post-hoc test. Categorical variable relationships were analyzed using the Pearson Chi-Square or Fisher-Freeman-Halton test. Linear regression assessed the effects of age and gender on HVA and TAT. Descriptive statistics were given as mean ± standard deviation or median (min-max) for continuous data, and frequency (percentage) for categorical data. Analyses were conducted using IBM SPSS Statistics 26.0, with a significance level of 0.05 and a 95% confidence interval.

Results

Out of the results from 136 patients, 115 were included in the study. The remaining patients were excluded due to insufficient MRI imaging of the TAT tendon making classification impossible and due to foot roentgenographies which are unable to be properly evaluated. Flowchart of the study is seen in Fig. 5.

Of the participants, 81 (70.4%) were female. The HV group comprised 53 patients, including 11 (9.6%) individuals with mild HV, 33 (28.7%) with moderate HV, and 9 (7.8%) with severe HV. The mean age of the participants was 43.83 ± 15.25 years. The mean diameter of TAT was 7.34 ± 0.88 mm, the mean diameter of the MCc was 7.27 ± 2.10 mm, and the mean diameter of the PMc diameter was 4.26 ± 1.01 mm. For all participants, the mean HVA was 20.63 ± 8.42, and the mean IMA was 9.69 ± 2.68. Descriptive values are summarized in Table 1.

The MRI evaluation of the TAT distal attachment sites revealed sufficient representation of the various types: Type 1 (23.4%), Type 2 (34.8%), Type 3 (0.9%), and Type 5 (40.9%). Type 4 was not represented.

As shown in Table 2, there was a statistically significant difference in the incidence of TAT Type 5 (single band) and TAT Types 1–3 (double band) in the HV and control groups ($p = 0.042$), with Type 5 prevalent in the HV group and the other types common in the control group.

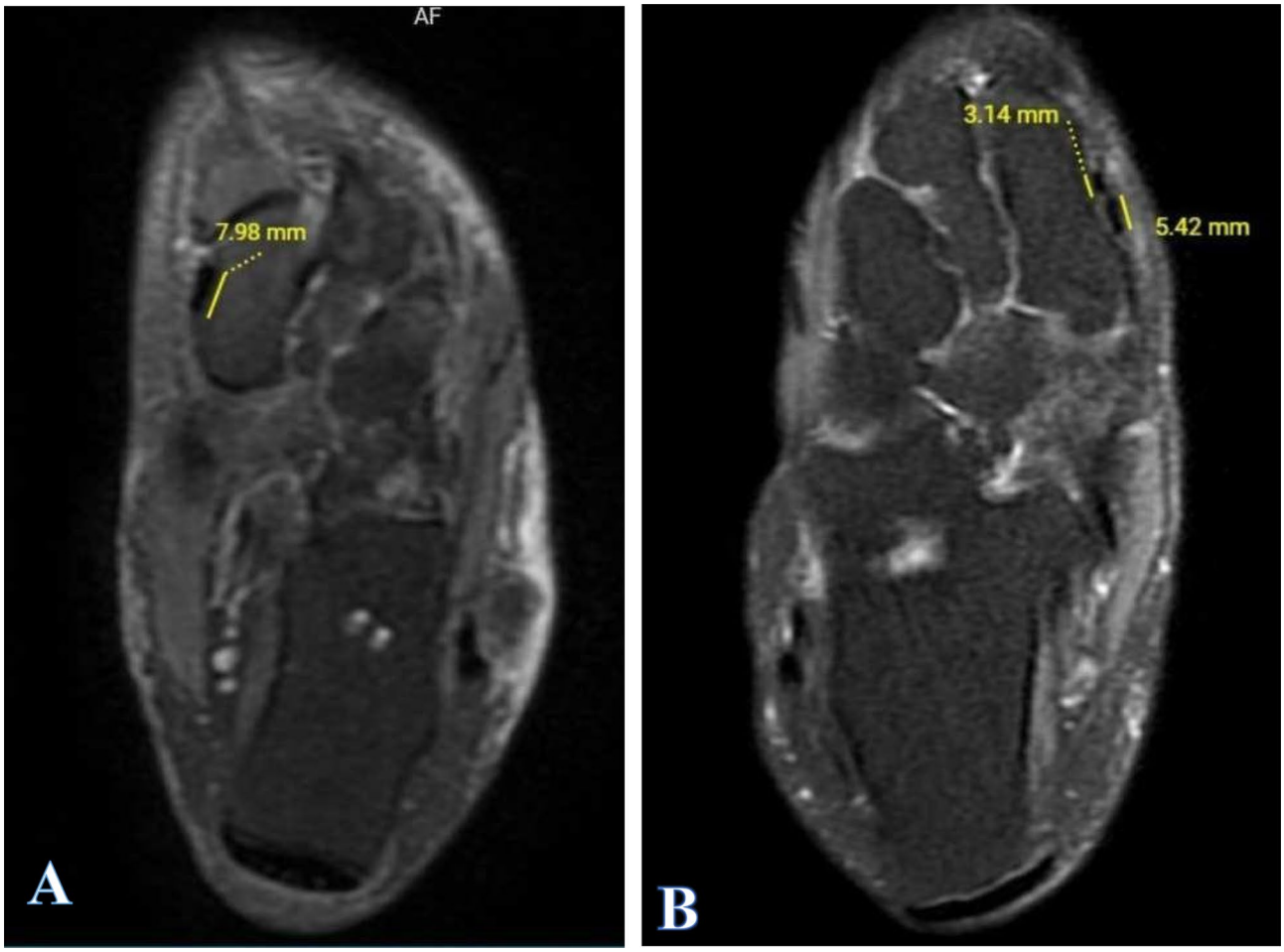

Fig. 2 Measurement locations on axial fat-suppressed proton density images: (**A**) where type 5 tendon is thickest at the level of the medial cuneiform bone, and (**B**) where the two branches of type 2 tendon are thickest after separating from the main tendon

The results of the statistical analysis of the HVA and IMA in Type 5 versus those in Types 1, 2, and 3 based on TAT distal attachment type, because Type 5 consists of a single band, while the others consist of two or three bands, we believe that they function differently, are presented in Table 3. The HVA showed a statistically significant difference according to TAT distal attachment type (i.e., single or double band) ($p=0.002$). Accordingly, the HVA was significantly higher in the single band (Type 5) compared to the double band types. However, there was no statistically significant difference in the IMA based on TAT distal attachment type (i.e., single or double band) ($p=0.272$).

The results of linear regression analysis evaluating the influence of age and gender on the difference between the TAT distal attachment type and HVA are presented in Table 4. The model generated by linear regression analysis evaluating the difference between the TAT type and HVA was statistically significant, indicating that the added variables of age and gender did not have any significant effect ($p=0.313$ and $p=0.062$, respectively).

However, as shown in Table 5, there was a statistically significant poor relationship between the HVA and the TAT diameter and a strong relationship with the MCc diameter. Thus, as the HVA increased, the TAT diameter decreased, and the MCc diameter increased. There was no significant relationship between the PMc diameter and HVA. In addition, there was no significant relationship between the IMA and the TAT diameter, MCc diameter, and PMc diameter.

As shown in Table 6 the results of the analysis of the PMc diameter measurement among the tendon types revealed a statistically significant difference ($p<0.001$), with the PMc diameter being significantly higher in Type 1 tendons compared to Type 2 tendons (Type 1: PMc diameter : 4.85 ± 0.86, Type 2: PMc diameter: 3.85 ± 0.91). When the TAT diameter and MCc diameter was compared based on tendon type, there was a statistically significant difference ($p=0.027$, $p<0.001$). According to the post-hoc analysis, there was a significant difference between the TAT diameter in Type 2 and Type 5, with the TAT diameter being significantly higher in Type 2. As

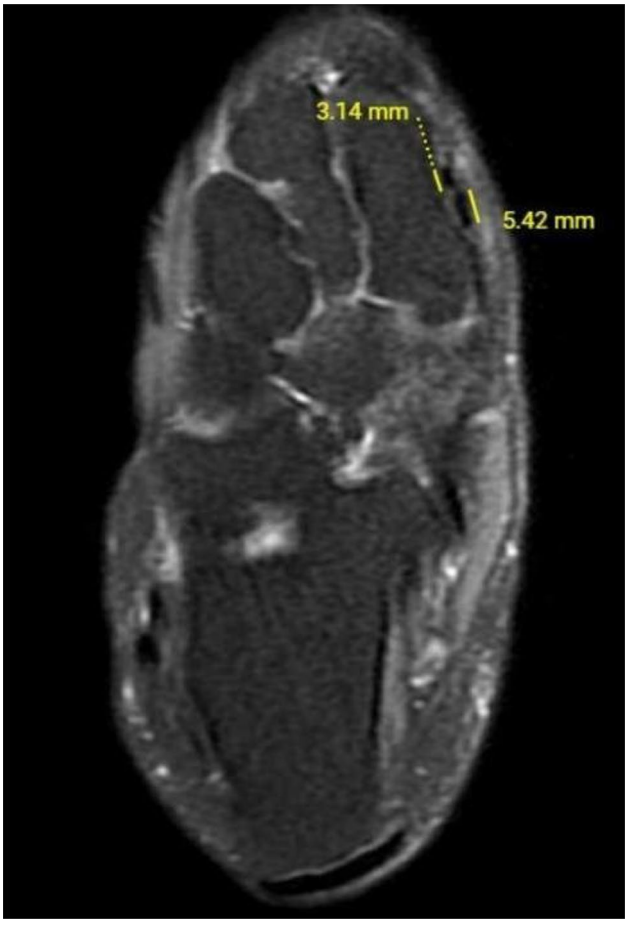

Fig. 3 In axial proton density-weighted images with fat suppression, (**A**) shows the tibialis anterior main tendon (thick arrow), and (**B**, **C**) depict the tendon splitting into two equal thickness tendons in consecutive sections (thin arrows)

seen in Table 6 the MCc diameter was significantly lower in Type 1 compared to Type 2 and 5 and significantly lower in Type 2 compared to Type 5.

Discussion

This study demonstrates for the first time a statistically significant association between HV and Type 5 TAT distal attachment types. Specifically, HVA was significantly higher in the single band (Type 5) compared to the double band type. No relationship with the IMA was observed. Our findings indicate a strong positive correlation between the increase in MCc diameter and HVA, and a negative correlation between the TAT diameter and HVA. Specifically, as HVA increases, TAT diameter decreases, and MCc diameter increases. This study is the first to demonstrate a relationship between HV and TAT distal attachment type.

The incidence of Type 1 in our study was 23.4%, similar to the 20% reported in an ultrasound study by Olewnik et al. [17]. Other studies have reported a range from 7.3 to 56.5% [18]. The incidence of Type 2 in our study was 34.8%, closely aligning with the 35% reported by Olewnik et al. [18] with other studies reporting variations between 24% and 56.5% [18]. However, the incidence of Type 3 in our study was 0.9%, which differed from other studies where Brenner et al. [19] reported an incidence of 1.7% and Olewnik et al. [17] reported an incidence of 11% a high incidence of 25.6% [17,18.19]. We found no cases of Type 4, consistent with findings from other studies, except for Musial et al. [18] who reported an incidence of 4.1% and Olewnik et al. [17] who reported 2% in their cadaver studies. In Olewnik's study [17], 32% of cases were identified as Type 5, while in our study, the control group comprised 32.3%, indicating very similar rates. In our study, the incidence of Type 5 was 40.9%, higher than reported in other studies, except for a study by Karau et al. [16] on fetal cadavers, which reported an incidence of 60%. In contrast, Brenner et al. [19] reported a markedly

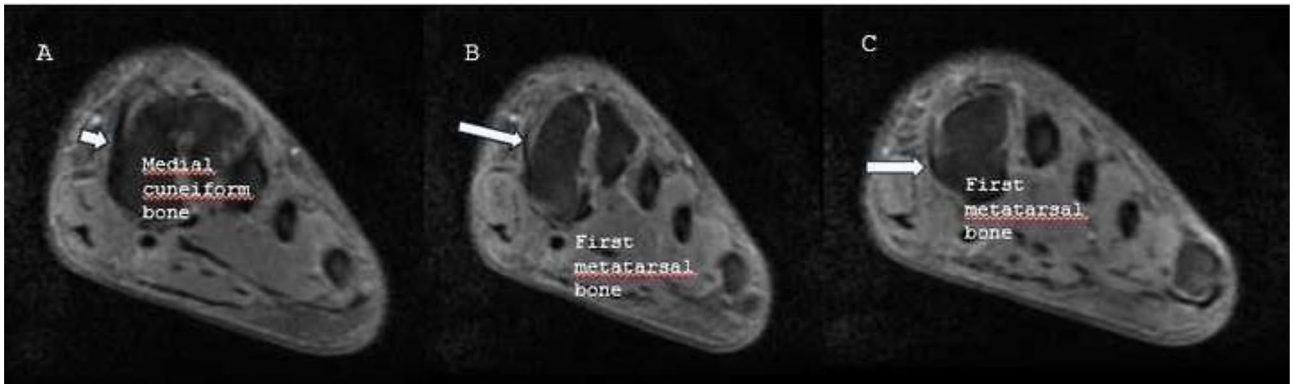

Fig. 4 Demonstration of tendon insertions on coronal fat-suppressed proton density images. The first branch (short arrow) attaching to the medial cuneiform bone (**A**), and the second branch (long arrows) attaching to the first metatarsal head in consecutive sections (**B**, **C**)

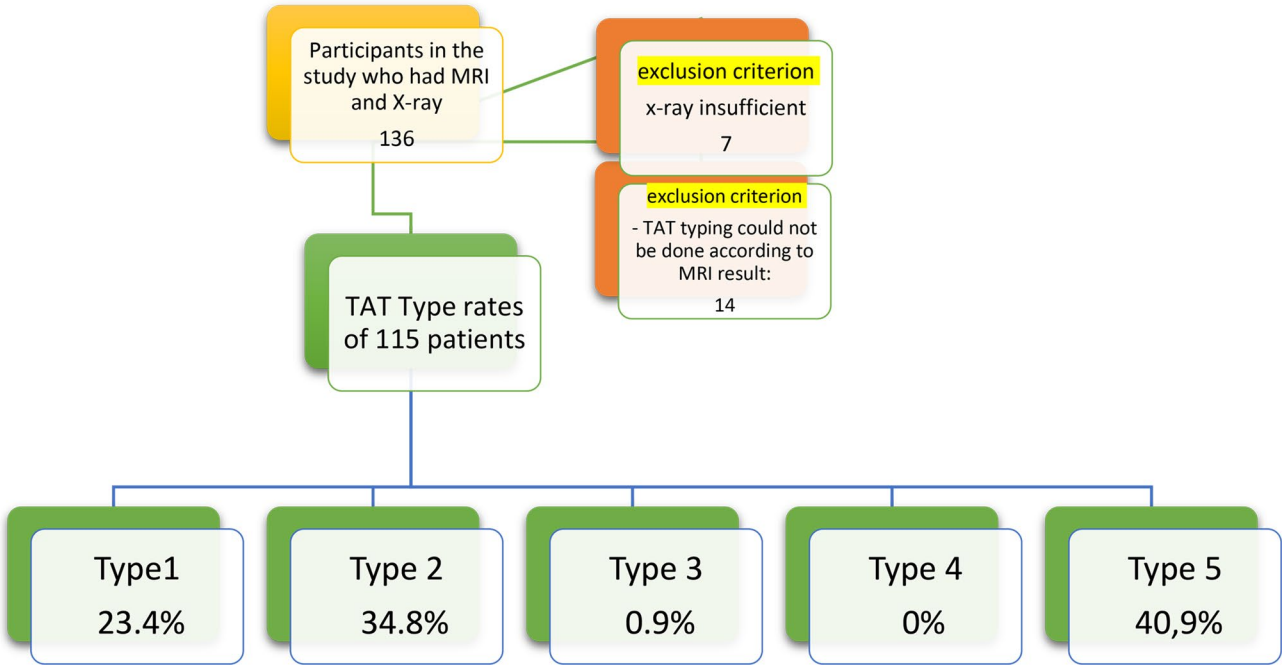

Fig. 5 Flowchart of the study

Table 1 Descriptive statistical distributions of the data

	Descriptive Statistics
Sex	
Female	81 (%70.4)
Male	34(%29.6)
Age	43.83 ± 15.25
TAT Diameter (mm)	7.34 ± 0.88
MCc Diameter (mm)	7.27 ± 2.10
PMc Diameter (mm)	4.26 ± 1.01
HVA (°)	20.63 ± 8.42
IMA (°)	9.69 ± 2.68
Group	
HV group	53(%46.1)
Control group	62(%53.9)

Categorical data are presented as frequency (percentage), and numerical data are presented as mean ± standard deviation

TAT: Tibialis anterior tendon, MCc: Medial cuneiform component, PMc: Proksimal metatarsal component, HVA: Hallux valgus angle, IMA: Intermetatarsal angle, HV: Hallux Valgus

Table 3 Comparison of HVA and IMA between type 5 and types 1 + 2 + 3.

	Type 5	Type 1 + 2 + 3	*p*-value
HVA	25(8–47)	18(7–42)	**0.002**[a]
IMA	10(5–19)	9(5–15)	0.272[a]

[a]:Mann Whitmey U test

Data are presented as median (min-max)

Table 2 Evaluation of the relationship between tat type and groups

	Control Group	HV Group	*p* value
TAT			
Type 1	15(%24.2)	12(%22.6)	0.119*
Type 2	26(%41.9)	14(%26.4)	
Type 3	1(%1.6)	0(%0)	
Type 4	0(%0)	0(%0)	
Type 5	20(%32.3)	27(%51)	
TAT			
Type 5 (Single band)	20(%32.3)	27(%50.9)	**0.042***
Type 1 + 2 + 3 (Double band)	42(%67.7)	26(%49.1)	

*Chi-Square test

Data are presented as n (%)

TAT: Tibialis anterior tendon

Table 4 Evaluation of the effect of age and gender on the difference between TA typing and HVA

	β	S.E	%95 CI	*p*-value
Age	-0.050	0.049	(10.146 – 0.047)	0.313
Gender	-3.306	1.754	(-6.782-0.170)	0.062
TA	1.217	0.468	(0.289–2.144)	**0.011**

Model general significance: $p = 0.001$, adj. R^2 = 0.369

β: It is the change observed in the dependent variable based on the change in the independent variable

S.E: Standart error

C.I: Confidence Interval

low incidence of Type 5 in a cadaver study (1.3%). In another study, a single-band Type 5, as described by Olewnik, was identified in 0% of cases. This suggests a possibility of regional influences or ethnic differences in TAT attachment types, as highlighted in a study conducted in Japan [25]. The discrepancies in the literature emphasize the need for further research into the association of these types with HV and other conditions. The

Table 5 The correlation of HVA and IMA angles with TAT diameter, MCc diameter, and PMc diameter

	HVA		IMA	
	r	*p*-value	*r*	*p*-value
TAT Diameter(mm)	-0.193	**0.039**	-0.131	0.162
MCc Diameter(mm)	0.273	**0.003**	0.073	0.438
PMc Diameter(mm)	0.006	0.958	0.076	0.536

r: Spearman Correlation Coefficient

Table 6 Comparison of TAT diameter and MCc diameter across tendon types

	TAT Type				
	Type 1	Type 2	Type 5	*p*-value	Post-hoc *p*-value
TAT Diameter (mm)	7.53 ± 0.85	7.53 ± 0.75	7.40 ± 0.94	**0.015**	**2–5: 0.032**
MCc Diameter (mm)	4.91 ± 0.87	6.57 ± 1.08	9.22 ± 1.38	**< 0.001**	1–2, 1–5, 2–5 :**<0.001**

One-way ANOVA test was conducted, followed by post-hoc Bonferroni test. Data are presented as mean ± standard deviation

differences observed in our study should be attributed to the MRI results of patients who were scanned for various foot issues. When examining the control group without HV, it is evident that the proportions are quite similar to those reported in Olewnik's study. This research demonstrates for the first time that classification of TAT using MRI is feasible.

Furthermore, regional variations in the prevalence rates of HV should also be considered.There are widely varying prevalence rates of HV in countries and continents, with rates in Africa and Asia of 3% and 21.96%, respectively, and rates in Europe, North America, and Oceania of 18.35%, 16.10%, and 29.2%, respectively in general population [2]. In a previous study conducted in Turkey, the prevalence of HV in the general population was 54.3% [20]. In our study, also conducted in Turkey, the HV rate was 46,1% in patients with foot disorders. As is well known, HV is particularly prevalent in females [2]. In one of the studies, all patients with foot disorders were included, and 61% were female [20]. In our study, 70.4% were female. Similarly, in the study by Lopez and colleagues [21], 73.7% of the group with foot problems were female, like in our study.

Considering that the prevalence of HV increases with age, it should not be overlooked that the adjusted prevalence of HV in the Japanese population may be lower in global prevalence calculations [2, 28]. Additionally, it is noteworthy that the prevalence of HV is significantly lower in the male population of this community: 24.9% in women compared to 7.6% in men [29, 30]. In light of this information, the fact that Hirai et al. [25] reported no observations of Type 5 TAT suggests the significance of the relationship between HV and Type 5 identified in our study, highlighting the need for broader research in this area.

The etiology of HV is multifactorial. An effect of footwear, particularly ill-fitting shoes that place external pressure on the forefoot, has been shown, but a consensus for such an effect has yet to be reached [22, 23]. However, poor-fitting shoes have been shown to play a significant role in accelerating the process [24]. Despite numerous studies, its etiology remains unclear and understanding the etiology of HV will aid understanding of this deformity and contribute to treatment success by identifying the most appropriate approach [4, 9]. Attempts have been made to demonstrate a genetic effect in HV, consistent with an autosomal dominant inheritance model, with potential contributions of immunity/inflammation and cytochrome P450 metabolism to the etiology of HV [23]. However, research conducted on twins has not supported a genetic basis for HV [25]. The concept of first ray rotation in HV was first described by Hicks J.H in 1953 [26]. The shape and length of the first metatarsal have been proposed as etiological factors in HV [27]. Although detecting first ray rotation has been challenging, recent technological advancements have facilitated this process and suggested its role in the pathogenesis of HV. While its role in HV etiology remains uncertain, evidence indicates it may be a contributing factor. Pronation, associated with hypermobility and torsional changes, can lead to laxity and force redistribution along the first tarsometatarsal joint. Despite studies showing a link between first ray motion and HV [28, 29], with some reporting pronation in up to 87% of cases, the prevalence remains debated [30] as evidenced by Najefi et al. [31] finding of hyperpronation in only 31.4% of HV patients.

Many aspects of the etiology of HV are linked to the TAT attachment site and effect. When considering the involvement of the TAT in the supination-pronation mechanism, especially in cases of insufficiency or inadequate function, it should be considered that it may increase foot pronation [32–34]. Particularly, the association of Type 5 distal attachment with HV and a high Angle (HVA) demonstrated in this study, compared to other types, suggests an association with the etiologies of HV, as indicated by first ray rotation or pronation mechanisms. This underscores the potential role of Type 5 distal attachment of TAT as one of the etiological factors for HV.

Maintaining alignment of the first ray relies on a delicate balance between static (capsule, ligaments, and plantar fascia) and dynamic stabilizers (peroneus longus and small foot muscles), constituting inherently an unstable axial array [24]. With this study, the effect of the TAT has been demonstrated for the first time, particularly its impact on HV, especially for Type 5.

Previous research demonstrated a relationship between significant displacement in the position of the abductor hallucis tendon at the first metatarsophalangeal joint and HV [14]. Other research pointed to a relationship between Achilles tendon contracture and HV [35], Better outcomes in HV surgery with proximal gastrocnemius release have been reported [36]. Olgunus et al. [37] revealed an association between the length of tendons (extensor hallucis longus and brevis, abductor hallucis, and flexor hallucis longus) and moderate-to-severe HV. In our study, Type 2 had a significantly higher TAT diameter compared to Type 5. We found a negative and low relationship between the diameter of the TAT and a positive and strong relationship with the MCc diameter. Accordingly, as the HVA increased, diameter of TAT decreased, and the MCc diameter increased.

In this study, MRI images taken due to foot problems show a relationship with HV and reveal its association with type 5 foot problems. In Brenner's study [15] the incidence of type 5 was 1.3%, which did not associate it with HV. This finding is quite contradictory to the incidence of type 5 reported in other studies. Additionally, considering that TAT is the foot tendon most significantly affected by age among those impacting the and given that the majority of cases in Brenner's study [19, 38]. A cadaver study involving individuals of advanced age (primarily in their 80s) found that fibers attached to the first metatarsal were present in all feet with HV, suggesting a lack of etiopathological significance [19]. The prevalence of HV increases with age [8], accompanied by changes in tendon structure [17–20]. The most significant age-related morpho-structural changes in the TAT occur at the ankle [21], the failure to demonstrate the relationship between TAT and HV cases should be considered a limitation of the study. The relationship between the TAT and the first ray rotation cannot be ignored [32, 33, 38]. This study has shown that the type 5 variation, where the tendon attaches exclusively to the medial cuneiform, is associated with HV, and a significant statistical relationship was found between this variation and the HVA. The underlying reason may be that types not attaching to the first metatarsal influence hyperpronation due to their attachment site on the first ray. This does not explain the entire etiology of HV and does not disregard the fact that it is multifactorial.

The findings point to an undeniable relationship between the TAT and first ray, which necessitates surgical planning considering its distal variations and diameters, along with the effects of other tendons [37]. After resolving the complex pathogenesis of variations in TAT distal attachment sites, a more scientific approach to HV treatment will be possible, allowing for personalized treatment (conservative or surgical) [24].

The limitations of our study include its retrospective nature, and due to this no clinical examination of the TAT was undertaken, and joint mobilities were not assessed, furthermore inclusion of patients with diagnoses other than HV, as they presented to orthopaedic and physical therapy and rehabilitation outpatient clinics or emergency departments for various reasons. A study specifically addressing isolated cases of HV would be valuable. Moreover, the assessment was confined to examining only the diameter of the TAT, without conducting cross-sectional measurements to evaluate its length and width. The potential for degeneration or dysfunction at the TAT distal attachment site was also not investigated. The use of MRI only to assess TAT distal attachment sites may also explain the differences in our findings compared to those of studies using other evaluation methods.

Conclusions

This study identified a significant association between Type 5 TAT distal attachment and increased HVA, suggesting that TAT anatomical variations may influence HV development. The lack of correlation with IMA underscores the multifactorial nature of HV. Clinically, these results highlight the value of MRI in assessing TAT morphology for better diagnostics and customized surgical strategies. Early identification of Type 5 TAT as a risk factor for severe HV can improve patient management and surgical outcomes.

Abbreviations

HV	Hallux valgus
TAT	Tibialis anterior tendon
MRI	Magnetic resonance imaging
IMA	Intermetatarsal angle
HVA	Hallux valgus angle
AP	Anteroposterior
MCC	Medial cuneiform component
PMC	Proximal metatarsal component

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Author contributions

F.U. and M.A. wrote the main manuscript; B.A. and B.R. prepared the figures; F.U and B.A. made the interpretation of data; M.A. and B.A. substantively revised it. All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from Kastamonu University Clinical Research Ethics Committee on February 7, 2024, (no. 2024-KAEK-19). All methods were performed in accordance with the 1964 Declaration of Helsinki and its later amendments, and the ethical standards of the institutional research committee.

Consent for publication
Written informed consent for publication was obtained from all participants.

Competing interests
The authors declare no competing interests.

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