Exploring the Link Between Calcaneal Apophysis Maturation and Heel Pain in Youth Baseball Players

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Investigation performed at Waseda University, Saitama, Japan

Background: Calcaneal apophysitis is the most common cause of heel pain in children and adolescents. However, the relationship between skeletal maturity and heel pain in the specific youth cohort is unclear.

Purpose: To clarify the relationship between the maturity stages of the calcaneal apophysis and heel pain in youth baseball players.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A total of 336 youth male baseball players participated in this study. Ultrasound scanning of the calcaneal apophysis was performed along the longitudinal line connecting the middle of the Achilles tendon, the middle of the calcaneus, and the second toe, between the proximal calcaneal edge and the medial calcaneal tubercle. The authors classified the maturity of the calcaneal apophysis into 5 stages, from nonpresence of the apophysis (stage 1) to complete fusion (stage 5). The diagnosis of heel pain was based on subjective report of feeling pain on the squeeze test. The relationship between the maturity stages and physical characteristics was investigated using 1-way analysis of variance or the Kruskal-Wallis test, and the relationship between the maturity stages and heel pain was investigated using the chi-square test.

Results: Of the 336 players, 49 had heel pain, for a prevalence of 14.6%. Eighteen (5.4%) players had unilateral heel pain, and 31 (9.2%) players had bilateral heel pain. There were no significant differences in the maturity stages of the calcaneal apophysis between the players with no heel pain and those with heel pain. However, no players had heel pain during stage 5, when the calcaneus had completed its maturation.

Conclusion: The prevalence of heel pain was 14.6% in Japanese youth male baseball players. There was no relationship between the maturity stages of the calcaneal apophysis and heel pain. Heel pain that could be associated with calcaneal apophysitis did not occur during stage 5, when maturation of the calcaneal apophysis was complete.

Keywords: heel; Sever disease; overuse injury; injury prevention; youth; ultrasonography

Calcaneal apophysitis, also known as Sever disease, is the most common cause of heel pain in children and adolescents. Generally, this condition is believed to be caused by repeated traction loading of the Achilles tendon and plantar fascia, inserted in the calcaneus, and compression loading against the calcaneal apophysis. The incidence of calcaneal apophysitis is approximately 0.4% to 16.3% of musculoskeletal injuries in children and adolescents and is higher in children who participate in sports that include running and jumping, such as soccer, basketball, gymnastics, and track and field.‖ Calcaneal apophysitis tends to occur in boys aged 7 to 15 years, particularly in active boys aged 10 to 12 years, and in girls aged 5 to 13 years.[23] However, researchers have reported that calcaneal apophysitis occurs more frequently during the prepeak height velocity period (<88% of adult height) in youth soccer players.[15]

Apophyseal overuse injuries in children and adolescents occur during the skeletal immature period when the apophysis is unfused.[8,12,13] Previous studies have shown

The Orthopaedic Journal of Sports Medicine, 12(10), 23259671241253861
DOI: 10.1177/23259671241253861

‖References 1, 3, 10, 14, 19, 20, 23, 26, 28.

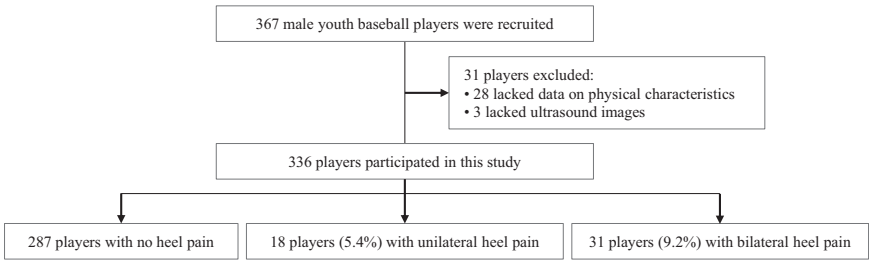

Figure 1. Flowchart of exclusion criteria and the outcomes.

the relationship between skeletal maturity and lumbar bone stress injury, which is thought to occur in the early stage of lumbar spondylolysis, and Osgood-Schlatter disease.[9,17,24,25,29] In particular, Tsutsui et al[25] and Takei et al[24] showed that immature epiphyses were a risk factor for bilateral lumbar bone stress injury and Osgood-Schlatter disease, respectively. The relationship between calcaneal apophysitis and skeletal maturity has been reported using radiography.[4] Duong et al[4] reported that calcaneal apophysitis tended to occur at stage 2 (where stages are indicated from 0 to 5), defined as when the apophysis covers >50% of the metaphysis but does not extend to the plantar edge. However, no studies have reported the relationship between skeletal maturity of the calcaneal apophysis and calcaneal apophysitis in a specific youth cohort.

The aim of this study was to clarify the relationship between the maturity stages of the calcaneal apophysis and heel pain. Previous studies have evaluated the development of the calcaneal apophysis using radiography, computed tomography (CT), and magnetic resonance imaging.[2,4,6,16,21,22,27] However, the maturity stages of the tibial tuberosity have previously been evaluated using ultrasonography based on the 4 maturity stages created by Ehrenborg and Lagergren[5] (cartilaginous stage, apophyseal stage, epiphyseal stage, and bony stage).[9,17,18,24,29] Therefore, in this study, we used ultrasound to investigate the maturity stages of the calcaneal apophysis.

METHODS

Study Design

The protocol for the current study was approved by the ethics committee of our institution, and all participants and their parents provided informed consent before measurements were obtained. We followed the guidelines of the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement. This was a cross-sectional study of Japanese youth male baseball players. Based on a power analysis (SPSS Version 28; IBM), a minimum sample size of 144 would have an assumed type 1 error of 0.05 and statistical power of 0.80. The prevalence of each group was set at 0.1 and 0.3 based on a previous study of Osgood-Schlatter disease by Takei et al.[24]

Participants

For this study, we recruited 367 youth male baseball players between January and March 2023. All participants belonged to regional league baseball teams in Tokyo, Japan, and practiced 2 days per week for 3 to 6 hours per day on average. We focused on male baseball players between the ages of 7 and 15 years because they are more susceptible to developing calcaneal apophysitis. We based the diagnosis of heel pain on the participant's subjective report of feeling pain on the squeeze test.[7] The squeeze test is the most common examination for diagnosing calcaneal apophysitis (Sever disease) and is conducted by compressing the medial and lateral aspects of the calcaneus. Other diagnoses for lower limbs were not explored. Participants were asked to complete a questionnaire to obtain relevant personal information (age, sex, height, and weight).

Of the 367 initially recruited participants, 31 were excluded (28 for lack of information on physical characteristics and 3 for lack of ultrasound images), leaving 336 participants for analysis. Of the 336 players, 49 had heel pain, for a prevalence of 14.6%. Of the 49 players with heel pain, 18 (5.4%) players had unilateral heel pain and 31 (9.2%) players had bilateral heel pain (Figure 1).

Ultrasonography

Participants were asked to lie in the prone position with the knee fully extended and ankle joint kept in the neutral

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Final revision submitted October 24, 2023; accepted December 5, 2023.
The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.
Ethical approval for this study was obtained from Waseda University (ref No. 2021-218).

position (Figure 2A). The skeletal maturity of the calcaneal apophysis was examined using an ultrasound device (Noblus; Hitachi) and the linear probe (L55, 7.5 MHz; Hitachi). An examiner (Y.H.), who is an experienced user of the ultrasound device and specializes in sports medicine as a graduate student, conducted the ultrasound measurements in all participants. The calcaneal apophysis was scanned along the longitudinal line connecting the middle of the Achilles tendon, the middle of the calcaneus, and the second toe (Figure 2, B and C), between the proximal calcaneal edge and the medial calcaneal tubercle. We measured the consecutive ultrasound images of the calcaneal apophysis, attaching 2 polypropylene strings to the linear probe as a landmark. In addition, after attaching the electronic angle meter (PT180; R&D Instrument Services) to the probe and defining the probe angle at the measurement starting point on the sagittal plane as the standard point (0°), we recorded the probe angle from the standard point on the sagittal plane at each image measurement (Figure 2A). During analysis, each image was trimmed based on 2 landmarks. After trimming, we created the calcaneal outline image by joining each image together based on the probe angle at the measurement. The same examiner (Y.H.) created all calcaneal outline images.

Maturity Stages of the Calcaneal Apophysis

We created 5 maturity stages of the calcaneal apophysis. Stage 1 was characterized by the nonpresence of the apophysis (Figure 3). Stage 2 was characterized by the presence of several small secondary ossification centers of the calcaneus or the apophysis covering <50% of the metaphysis. Stage 3 was characterized by the apophysis covering ≥50% of the metaphysis. Stage 4 was characterized by complete fusion of the apophysis of the Achilles tendon side but incomplete fusion of apophysis of the plantar fascia side. Stage 5 was characterized by complete fusion of the apophysis.

In participants with a discrepancy in maturity stage between the left and right sides (n = 32), we used the side with the more advanced maturity stage. However, in the group with unilateral heel pain, when clarifying the relationship between maturity stages and heel pain, we used the stage of the side with heel pain in the analysis (2 participants in this group had a discrepancy in maturity stage between the left and right sides).

Statistical Analysis

All statistical analyses were performed using SPSS software (Version 28; IBM). The intrarater and interrater reliabilities were examined using quadratically weighted kappa (κ) coefficients. To assess the intrarater reliability of the maturity stage classifications, the examiner (Y.H.) reclassified a random 10% (65 images) of all ultrasound images at least 1 month after the first evaluation. To assess interrater reliability, another examiner (A.H.), an experienced physical therapist, classified a random 10% of all ultrasound images. The intrarater reliability was κ = 0.980, and the interrater reliability was κ = 0.814; both indicated almost perfect agreement.[11] Therefore, the results of the first classification by the examiner (Y.H.) who conducted the ultrasound measurements were used in the analysis.

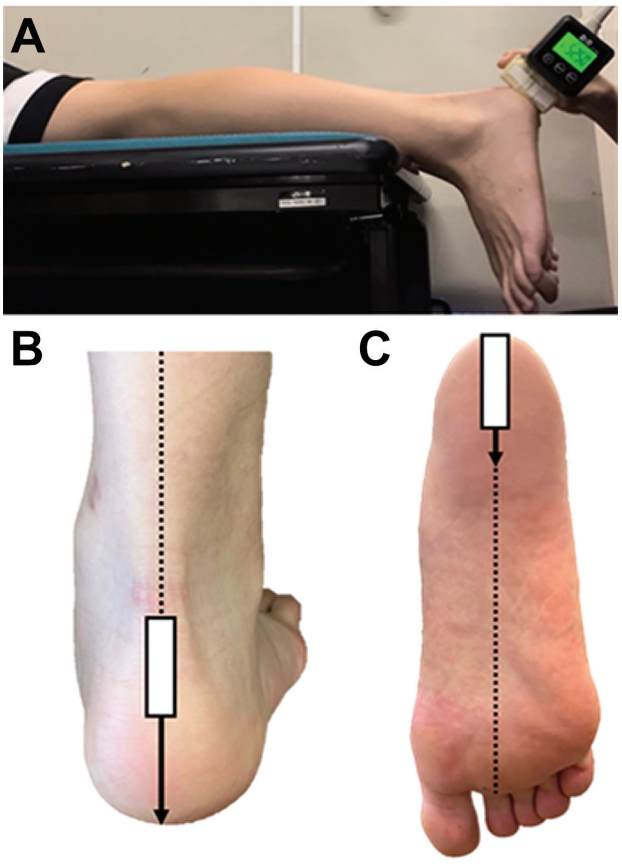

Figure 2. (A) Participant position during ultrasound measurement. (B and C) Probe position of the calcaneal apophysis at the ultrasound measurement. The black solid line represents the measurement section; the black dotted line represents the longitudinal line for measurement.

We investigated the relationship between the maturity stages of the calcaneal apophysis and the physical characteristics of the players using 1-way analysis of variance or the Kruskal-Wallis test with a Dunn-Bonferroni post hoc test. To compare the differences among the 3 study groups (no heel pain, unilateral pain, and bilateral pain), we used 1-way analysis of variance or the Kruskal-Wallis test. We investigated the relationship of heel pain to maturity stage of the calcaneal apophysis and age using the chi-square test. The level of significance was defined as $P < .05$.

RESULTS

Table 1 shows the physical characteristics of each maturity stage. There was a significant difference in participant age, height, and weight among the maturity stages ($P < .001$). The results of the Dunn-Bonferroni post hoc test revealed

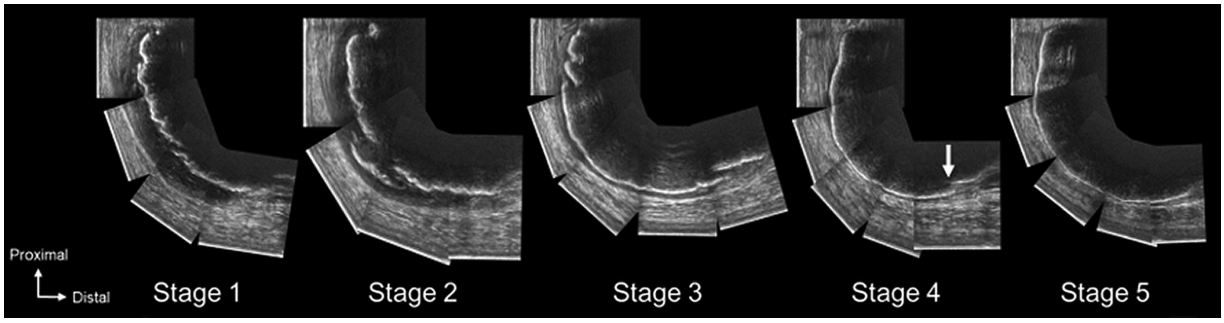

Figure 3. The 5 maturity stages of the calcaneal apophysis as shown on sagittal plane ultrasound images. Stage 1: nonpresence of the apophysis; stage 2: several small secondary ossification centers of calcaneus present or apophysis covering <50% of the metaphysis; stage 3: apophysis covering ≥50% of the metaphysis; stage 4: complete fusion of the apophysis of the Achilles tendon side but incomplete fusion of the apophysis of the plantar fascia side (arrow); stage 5: complete fusion of the apophysis.

TABLE 1
Physical Characteristics of Players by Maturity Stage of the Calcaneal Apophysis[a]

	Overall (N = 336)	Stage 1 (n = 12)	Stage 2 (n = 86)	Stage 3 (n = 202)	Stage 4 (n = 32)	Stage 5 (n = 4)
Age, y						
Median (IQR)	10.8 (9.6-12.0)	7.3 (7.2-8.4)	9.3 (8.7-9.9)	11.4 (10.3-12.1)	12.2 (11.8-12.5)	12.5 (12.3-14.8)
Range	7.0-15.5	7.0-9.7	7.3-11.1	8.0-12.8	10.7-15.3	12.3-15.5
Significant difference[b]	—	Stages 3, 4, 5	Stages 3, 4, 5	Stages 1, 2, 4	Stages 1, 2, 3	Stages 1, 2
Height, cm						
Median (IQR)	142.0 (134.0-151.0)	121.9 (117.1-123.6)	132.0 (128.0-136.9)	145.0 (140.0-151.7)	160.0 (150.2-163.8)	163.4 (161.2-164.6)
Range	115.0-173.0	115.0-130.0	118.0-152.0	129.0-170.0	142.0-175.0	160.5-165.0
Significant difference[c]	—	Stages 2, 3, 4, 5	Stages 1, 3, 4, 5	Stages 1, 2, 4, 5	Stages 1, 2, 3	Stages 1, 2, 3
Weight, kg						
Median (IQR)	37.8 (30.6-45.0)	24.1 (21.2-27.0)	29.0 (26.0-32.0)	40.0 (35.4-45.4)	52.1 (46.5-58.8)	63.3 (60.6-73.0)
Range	20.0-77.5	20.3-30.0	20.0-51.0	24.5-75.0	38.0-77.5	60.5-75.5
Significant difference[b]	—	Stages 3, 4, 5	Stages 3, 4, 5	Stages 1, 2, 4	Stages 1, 2, 3	Stages 1, 2

[a]Dashes indicate not applicable. IQR, interquartile range.
[b]Kruskal-Wallis test.
[c]One-way analysis of variance.

significant differences between each maturity stage (Table 1).

Table 2 shows the physical characteristics of the 3 study groups. There were no significant differences in any of the physical characteristics among the groups. Figure 4 displays the percentage and number of players for each group according to maturity stage. No players had unilateral heel pain or bilateral heel pain during stage 5. There were no significant differences in maturity stage or age between the players with no heel pain and those with unilateral heel pain (Table 3). In addition, maturity stage and age were not significantly different between the no heel pain group and bilateral group (Table 4).

DISCUSSION

In this study, we evaluated the relationship between the maturity stages of the calcaneal apophysis and heel pain using ultrasound, with high intrarater and interrater reliability, and found that age and height were higher and weight was heavier as the maturity of the calcaneal apophysis advanced. This indicates that the maturity stages of the calcaneal apophysis we created may reflect skeletal maturity. Moreover, none of the participants experienced heel pain during stage 5, when the calcaneus had completed its maturation.

Of the 336 Japanese youth male baseball players included in this study, 49 had unilateral or bilateral heel pain, and the prevalence of heel pain was 14.6%. The incidence of calcaneal apophysitis has been reported to be between 0.4% and 16.3% of musculoskeletal injuries in children and adolescents.[¶] The prevalence of heel pain in our study is consistent with these data, although it could not be diagnosed as calcaneal apophysitis. A previous study showed that the incidence of calcaneal apophysitis was higher in children playing sports that included running and jumping, such as soccer, basketball, gymnastics, and track and field.[14] The findings of our study suggest

[¶]References 1, 3, 10, 14, 19, 20, 23, 26, 28.

TABLE 2
Comparison of Physical Characteristics Between the 3 Groups[a]

Variable	No Heel Pain (n = 287)	Unilateral Heel Pain (n = 18)	Bilateral Heel Pain (n = 31)	*P*
Age, y	10.8 (9.5-12.0)	11.6 (9.5-11.9)	10.4 (9.8-11.3)	.547[b]
Height, cm	142.3 (134.9-151.0)	141.8 (133.0-153.1)	141.0 (133.0-146.0)	.518[c]
Weight, kg	38.0 (30.5-45.8)	39.5 (30.8-45.0)	35.9 (30.0-42.0)	.639[b]

[a]Data are presented as median (interquartile range).
[b]Kruskal-Wallis test.
[c]One-way analysis of variance.

TABLE 3
Comparison of Maturity Stage and Participant Age Between Players With No Heel Pain Versus Unilateral Heel Pain[a]

Variable	n	Unilateral Heel Pain, n (%)	RR (95% CI)	*P*
Maturity stage				
Stage 1	10	0 (0.0)	—	.421
The others	295	18 (6.1)		
Stages 1, 2	89	5 (5.6)	0.933 (0.343-2.541)	.893
The others	216	13 (6.0)		
Stages 1, 2, 3	273	17 (6.2)	1.993 (0.274-14.480)	.481
The others	32	1 (3.1)		
Stages 1, 2, 3, 4	301	18 (6.0)	—	.614
The others	4	0 (0.0)		
Age, y				
<9.0	48	1 (2.1)	0.315 (0.043-2.311)	.221
≥9.0	257	17 (6.6)		
<10.0	100	7 (7.0)	1.305 (0.521-3.264)	.570
≥10.0	205	11 (5.4)		
<11.0	156	7 (4.5)	0.608 (0.242-1.526)	.283
≥11.0	149	11 (7.4)		
<12.0	226	15 (6.6)	1.748 (0.520-5.878)	.357
≥12.0	79	3 (3.8)		

[a]RR, relative risk.

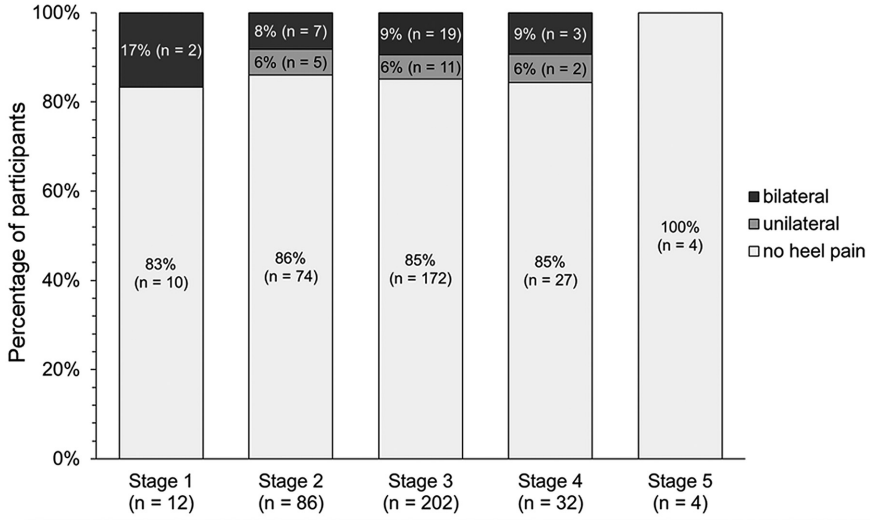

Figure 4. Percentage of participants in each study group according to maturity stage.

TABLE 4
Comparison of Maturity Stage and Participant Age Between Players With No Heel Pain Versus Bilateral Heel Pain[a]

Variable	n	Bilateral Heel Pain, n (%)	RR (95% CI)	*P*
Maturity stage				
Stage 1	12	2 (16.7)	1.759 (0.474-6.529)	.410
The others	306	29 (9.5)		
Stages 1, 2	93	9 (9.7)	0.990 (0.474-2.068)	.978
The others	225	22 (9.8)		
Stages 1, 2, 3	284	28 (9.9)	1.117 (0.359-3.481)	.847
The others	34	3 (8.8)		
Stages 1, 2, 3, 4	314	31 (9.9)	—	.508
The others	4	0 (0.0)		
Age, y				
<9.0	50	3 (6.0)	0.574 (0.182-1.817)	.330
≥9.0	268	28 (10.4)		
<10.0	105	12 (11.4)	1.281 (0.647-2.539)	.478
≥10.0	213	19 (8.9)		
<11.0	170	21 (12.4)	1.828 (0.890-3.756)	.093
≥11.0	148	10 (6.8)		
<12.0	237	26 (11.0)	1.777 (0.706-4.474)	.209
≥12.0	81	5 (6.2)		

[a]RR, relative risk.

that calcaneal apophysitis is also more likely to occur in youth baseball players.

In this study, the mean age of the participants in the unilateral heel pain group was 11.6 years (interquartile range [IQR], 9.5-11.9 years), whereas in the bilateral heel pain group, it was 10.4 years (IQR, 9.8-11.3 years). The time at which calcaneal apophysitis frequently occurs is usually described using chronological age in the literature. As calcaneal apophysitis occurs in boys aged 7 to 15 years and is more likely to occur in active boys aged 10 to 12 years,[23] the participants in the heel pain group in the current study may have had calcaneal apophysitis.

Participant age was higher as the maturity stages of the calcaneal apophysis advanced. In this study, the 4 stages of calcaneal apophysis maturity we defined using ultrasound—stages 1, 2, 3, and 5—were similar to those in a previous study in which the authors created 6 maturity stages using radiography.[16] Of the maturity stages of the calcaneal apophysis defined similarly to the previous study, the minimum age of each maturity stage, except for stage 1, was 7.3 years in stage 2, 8.0 years in stage 3, and 12.3 years in stage 5. In contrast, Nicholson et al[16] reported that the minimum age of boys was 7.9 years in stage 1, 10.0 years in stage 2, and 13.9 years in stage 5, which corresponds to stage 2, stage 3, and stage 5 in our study, respectively. The study by Nicholson et al was a 10- to 15-year longitudinal evaluation of 94 American children (49 girls and 45 boys) aged 3 to 18 years using radiography. The study design, age range of the players, and race differed between the current research and the study by Nicholson et al. Despite differences in imaging equipment, it is possible that Japanese boys may be earlier than Americans in the maturation of the calcaneal apophysis. Moreover, in Japanese boys, the maturation of the calcaneal apophysis may be completed by approximately 12 years of age.

Of the maturity stages of the calcaneal apophysis we created in this study, stage 4 was defined by complete fusion of the apophysis of the Achilles tendon side but incomplete fusion of the apophysis of the plantar fascia side. In all study participants, at stage 4, the fusion of the apophysis proximally (on the Achilles side) always preceded distal (plantar fascia side) fusion. In contrast, a study by Blythe et al[2] using a CT device and an 11-stage maturity classification of the calcaneal apophysis showed that the fusion of the calcaneal apophysis of the Achilles tendon side occurred after the fusion of the calcaneal apophysis of the plantar fascia side. In our study, we created the maturity stages of the calcaneal apophysis using ultrasound images scanned in a specific cross section, whereas Blythe et al created the maturity stages using CT images scanning multiple cross sections. Therefore, the fusion process of the calcaneal apophysis may differ depending on the imaging section of the calcaneus.

We found no relationship between the maturity stages of the calcaneal apophysis and heel pain in Japanese youth male baseball players. In this study, heel pain that could be associated with calcaneal apophysitis occurred during stages 1 to 4, when the calcaneal apophysis is immature, and it did not occur during stage 5, when maturation of the calcaneal apophysis was complete. Calcaneal apophysitis is cured by fusion of the apophysis with the calcaneal metaphysis,[10] which could be consistent with our results. Calcaneal apophysis is subjected to traction, compression, and impact loading from the ground, resulting in loads from multiple directions compared with the tibial tuberosity. The mechanism of heel pain in children and adolescents is multifaceted, and it is possible that there was no relationship between maturity stages of the calcaneal apophysis and heel pain in this study.

Limitations

This study has several limitations. First, we did not examine the reproducibility of scanning the calcaneal outline image using ultrasound. All ultrasound images of calcaneal outline were scanned by a single examiner. Therefore, the reproducibility of scanning the calcaneal outline image using ultrasound needs to be investigated. In addition, we classified the maturity stages of the calcaneal apophysis using ultrasound images that scanned a specific cross section. The study by Blythe et al[2] using CT showed that the medial calcaneal apophysis ossified before the lateral process, and the lateral calcaneal apophysis started fusion before the medial process. Therefore, the process of ossification and fusion of the calcaneal apophysis may differ depending on the imaging section of the calcaneus. Finally, the number of players per maturity stage was highly skewed. Therefore, it may have been difficult to determine the statistical significance of each of the different maturity groups.

CONCLUSION

The prevalence of heel pain was 14.6% in this study. There was no relationship between maturity stages of the calcaneal apophysis and heel pain. However, heel pain that could be associated with calcaneal apophysitis occurred during maturity stages 1 to 4, when the calcaneal apophysis was immature, and it did not occur during stage 5, when maturation of the calcaneal apophysis was complete.

ACKNOWLEDGMENT

The authors sincerely thank the players who participated in this study as well as their parents and coaches.

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REFERENCES

1. Belikan P, Färber LC, Abel F, Nowak TE, Drees P, Mattyasovszky SG. Incidence of calcaneal apophysitis (Sever's disease) and return-to-play in adolescent athletes of a German youth soccer academy: a retrospective study of 10 years. *J Orthop Surg Res*. 2022;17(1):83.
2. Blythe CS, Reynolds MS, Gregory LS. Quantifying the ossification and fusion of the calcaneal apophysis using computed tomography. *J Anat*. 2022;241(2):484-499.
3. Ceylan HH, Caypinar B. Incidence of calcaneal apophysitis in northwest Istanbul. *BMC Musculoskelet Disord*. 2018;19(1):267.
4. Duong MM, Nicholson AD, Li SQ, Gilmore A, Cooperman DR, Liu RW. Relationship between Sever disease and skeletal maturity. *J Pediatr Orthop*. 2020;40(2):93-96.
5. Ehrenborg G, Lagergren C. Roentgenologic changes in the Osgood-Schlatter lesion. *Acta Chir Scand*. 1961;121:315-327.
6. Ekizoglu O, Hocaoglu E, Can IO, Inci E, Aksoy S, Bilgili MG. Magnetic resonance imaging of distal tibia and calcaneus for forensic age estimation in living individuals. *Int J Legal Med*. 2015;129(4):825-831.
7. Fares MY, Salhab HA, Khachfe HH, Fares J, Haidar R, Musharrafieh U. Sever's disease of the pediatric population: clinical, pathologic, and therapeutic considerations. *Clin Med Res*. 2021;19(3):132-137.
8. Gerrard DF. Overuse injury and growing bones: the young athlete at risk. *Br J Sports Med*. 1993;27(1):14-18.
9. Kaneuchi Y, Otoshi K, Hakozaki M, et al. Bony maturity of the tibial tuberosity with regard to age and sex and its relationship to pathogenesis of Osgood-Schlatter disease: an ultrasonographic study. *Orthop J Sports Med*. 2018;6(1):2325967117749184.
10. Kvist MH, Heinonem OJ. Calcaneal apophysitis (Sever's disease)—a common cause of heel pain in young athletes. *Scand J Med Sci Sports*. 1991;1(4):235-238.
11. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.
12. Longo UG, Ciuffreda M, Locher J, Maffulli N, Denaro V. Apophyseal injuries in children's and youth sports. *Br Med Bull*. 2016;120(1):139-159.
13. McKay D, Broderick C, Steinbeck K. The adolescent athlete: a developmental approach to injury risk. *Pediatr Exerc Sci*. 2016;28(4):488-500.
14. Micheli LJ, Ireland ML. Prevention and management of calcaneal apophysitis in children: an overuse syndrome. *J Pediatr Orthop*. 1987;7(1):34-38.
15. Monasterio X, Gil SM, Bidaurrazaga-Letona I, et al. Injuries according to the percentage of adult height in an elite soccer academy. *J Sci Med Sport*. 2021;24(3):218-223.
16. Nicholson AD, Liu RW, Sanders JO, Cooperman DR. Relationship of calcaneal and iliac apophyseal ossification to peak height velocity timing in children. *J Bone Joint Surg Am*. 2015;97(2):147-154.
17. Ohtaka M, Hiramoto I, Minagawa H, Matsuzaki M, Kodama H. Screening of the maturity status of the tibial tuberosity by ultrasonography in higher elementary school grade schoolchildren. *Int J Environ Res Public Health*. 2019;16(12):2138.
18. Omodaka T, Ohsawa T, Tajika T, et al. Relationship between lower limb tightness and practice time among adolescent baseball players with symptomatic Osgood-Schlatter disease. *Orthop J Sports Med*. 2019;7(5):2325967119847978.
19. Orava S, Puranen J. Exertion injuries in adolescent athletes. *Br J Sports Med*. 1978;12(1):4-10.
20. Price RJ, Hawkins RD, Hulse MA, Hodson A. The Football Association medical research programme: an audit of injuries in academy youth football. *Br J Sports Med*. 2004;38(4):466-471.
21. Rossi I, Rosenberg Z, Zember J. Normal skeletal development and imaging pitfalls of the calcaneal apophysis: MRI features. *Skeletal Radiol*. 2016;45(4):483-493.
22. Saint-Martin P, Rérolle C, Dedouit F, et al. Age estimation by magnetic resonance imaging of the distal tibial epiphysis and the calcaneum. *Int J Legal Med*. 2013;127(5):1023-1030.
23. Scharfbillig RW, Jones S, Scutter SD. Sever's disease: what does the literature really tell us? *J Am Podiatr Med Assoc*. 2008;98(3):212-223.
24. Takei S, Torii S, Taketomi S, et al. Developmental stage and lower quadriceps flexibilities and decreased gastrocnemius flexibilities are predictive risk factors for developing Osgood–Schlatter disease in adolescent male soccer players. *Knee Surg Sports Traumatol Arthrosc*. 2023;31(8):3330-3338.
25. Tsutsui T, Iizuka S, Takei S, Maemichi T, Torii S. Risk factors for symptomatic bilateral lumbar bone stress injury in adolescent soccer players: a prospective cohort study. *Am J Sports Med*. 2023;51(3):707-714.
26. Valasek AE, Young JA, Huang L, Singichetti B, Yang J. Age and sex differences in overuse injuries presenting to pediatric sports medicine clinics. *Clin Pediatr (Phila)*. 2019;58(7):770-777.
27. Volpon JB, de Carvalho Filho G. Calcaneal apophysitis: a quantitative radiographic evaluation of the secondary ossification center. *Arch Orthop Trauma Surg*. 2002;122(6):338-341.
28. Wiegerinck JI, Yntema C, Brouwer HJ, Struijs PAA. Incidence of calcaneal apophysitis in the general population. *Eur J Pediatr*. 2014;173(5):677-679.
29. Yanagisawa S, Osawa T, Saito K, et al. Assessment of Osgood-Schlatter disease and the skeletal maturation of the distal attachment of the patellar tendon in preadolescent males. *Orthop J Sports Med*. 2014;2(7):2325967114542084.