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Prevalence of flatfoot among young Korean males and the correlation among flatfoot angles measured in weight-bearing lateral radiographs

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Abstract

Flatfoot causes significant fatigue and pain while walking, and even asymptomatic flatfoot may increase the risk of metatarsal stress fracture during long-distance walking. While most studies have used physical examination or plantar footprints to diagnose flatfoot, a weight-bearing radiograph of the foot provides more objective data. However, data on the prevalence of flatfoot in Asian populations gathered in a nationwide cohort of a specific age group is lacking. We examined the prevalence of flatfoot among 19-year-old male Korean army recruits using a weight-bearing lateral radiograph and evaluated the correlation among flatfoot angles. A total of 560,141 19-year-old Korean males were examined at the regional Military Manpower Administration offices between April 2018 and April 2020. Weight-bearing lateral radiographs of the foot were obtained using an X-ray system while the subjects were standing on a table with their feet in a neutral position. Based on these radiographs, military orthopedic surgeons and radiologists measured the talo-first metatarsal angle (TMA) and calcaneal pitch angle (CPA) for flatfoot diagnosis. Mild flatfoot was diagnosed when the TMA ranged from 6 to 15° or the CPA was <17°, and moderate-to-severe flatfoot was diagnosed when the TMA was 15° or greater or the CPA was <10°. Pearson correlation coefficients and scatter plot matrix were used to evaluate the correlation among the flatfoot angles. Finally, we evaluated the relationship between body mass index (BMI) and flatfoot angles and compared the BMI in subjects with or without self-checked foot deformities including flatfoot and pes cavus. Of the 560,141 subjects, 16,102 (2.9%) were diagnosed as flatfoot, and 5265 (0.9%) were diagnosed with moderate-to-severe flatfoot. The coefficients between TMA and CPA ranged from 0.342 to 0.449 (all P values < 0.001), and those between the 2 sides of TMA and CPA were 0.709 and 0.746 (all P values < 0.001), respectively. BMI had a significant correlation with both TMA and CPA in subjects with flatfoot, and those with self-checked foot deformities had a significantly higher BMI than the group without foot deformities. The prevalence of total flatfoot and moderate-to-severe flatfoot in 19-year-old Korean males based on a weight-bearing lateral radiograph was 2.9% and 0.9%, respectively. The correlation coefficients between TMAs and CPAs showed a low degree of positive correlation. Higher BMI was associated with the likelihood of the presence of flatfoot.

Abbreviations: ANOVA = one-way analysis of variance, BMI = body mass index, CI = confidence interval, CPA = calcaneal pitch angle, MLA = medial longitudinal arch, MMA = Military Manpower Administration, TMA = talo-first metatarsal angle.

Keywords: calcaneal pitch angle, conscription, diagnosis, flatfoot, prevalence, Meary angle

1. Introduction

Adult flatfoot is generally characterized by the collapse of the medial longitudinal arch (MLA), forefoot abduction, and valgus alignment of the hindfoot.[1–3] Collapse of the MLA results in the loss of elasticity of the medial side of the foot while walking.[4,5] As a result, the foot is prone to tiredness and pain may occur if the degree of collapse is severe. Accordingly, it has been suggested that many patients with foot pain may be suffering from neglected flatfoot.[6]

Flexible flatfoot occurs largely due to general joint flexibility, and rigid flatfoot is mainly caused by the tarsal coalition in children.[4,5,7–9] Adult flatfoot typically occurs due to posterior tibial tendon dysfunction, and other causes include rheumatoid arthritis, Charcot neuropathy, trauma, and tumor.[10] Most cases of childhood flexible flatfoot improve with age; however, some of those cases develop into adult flatfoot, which causes fatigue and significantly hinders long-distance walking.[11] Furthermore, some researchers suggested that even patients

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with asymptomatic flatfoot are more likely to develop a metatarsal stress fracture during long-distance walking.[12] Therefore, individuals with flatfoot are not fit for active military duty and should be screened appropriately.

Adult flatfoot is generally diagnosed through patient history, physical examination, and standing radiographs of the foot and ankle.[13] Among them, a weight-bearing lateral radiograph is considered the gold standard for diagnosing adult-acquired flatfoot deformity[3] and for assessing the characteristics of the MLA.[14] Flatfoot can be diagnosed by various radiographic angles, but the talo-first metatarsal angle (TMA)[15] and calcaneal pitch angle (CPA)[16] are the most commonly used angles; however, no studies to date have examined the correlation between TMA and CPA.

A self-reported questionnaire-based study on adult flatfoot reported that the prevalence of flatfoot in Asians, African-Americans, and Caucasians was 1%, 3%, and 2%, respectively.[17] The prevalence of flatfoot among 2100 male Saudi Arabian army recruits aged 18 to 21 was 5% using plantar footprints.[18] In a study from Israel, the prevalence of mild and severe flatfoot diagnosed through physical examination by military doctors in 17-year-olds before military service was 12.4% and 3.8% in males and 9.3% and 2.4% in females, respectively.[19] However, the diagnostic methods used in previous studies (e.g., plantar footprints, physical examination) are relatively subjective than weight-bearing radiographs.

There are no nationwide data on the prevalence of flatfoot in Asian populations gathered in a specific age group. Therefore, we examined the prevalence of flatfoot among 19-year-old male Korean army recruits using a weight-bearing lateral radiograph and evaluated the correlation among flatfoot angles. In addition, we examined the correlation between body mass index (BMI) and foot deformities including flatfoot and pes cavus.

2. Methods

2.1. Subject selection

This research has been approved by the Public Institutional Review Board designated by the Ministry of Health and Welfare (2020-2585-001). South Korea enforces the conscription system; thus, all men are examined for conscription at the Military Manpower Administration (MMA) when they reach 19 years of age. The data for this study were collected from the Korean National portal of information disclosure (open.go.kr), which was gathered by the regional MMAs in South Korea from April 2018 to April 2020. The 15 regional MMAs in Korea are shown in Fig. 1. A total of 560,141 Korean males were examined for conscription during this period, which covers 97.5% of the total 19-year-old Korean male population; the remaining 2.5% of the population were excluded for the following reasons: imprisoned, missing, staying abroad, and the presence of disabilities and inability to move.

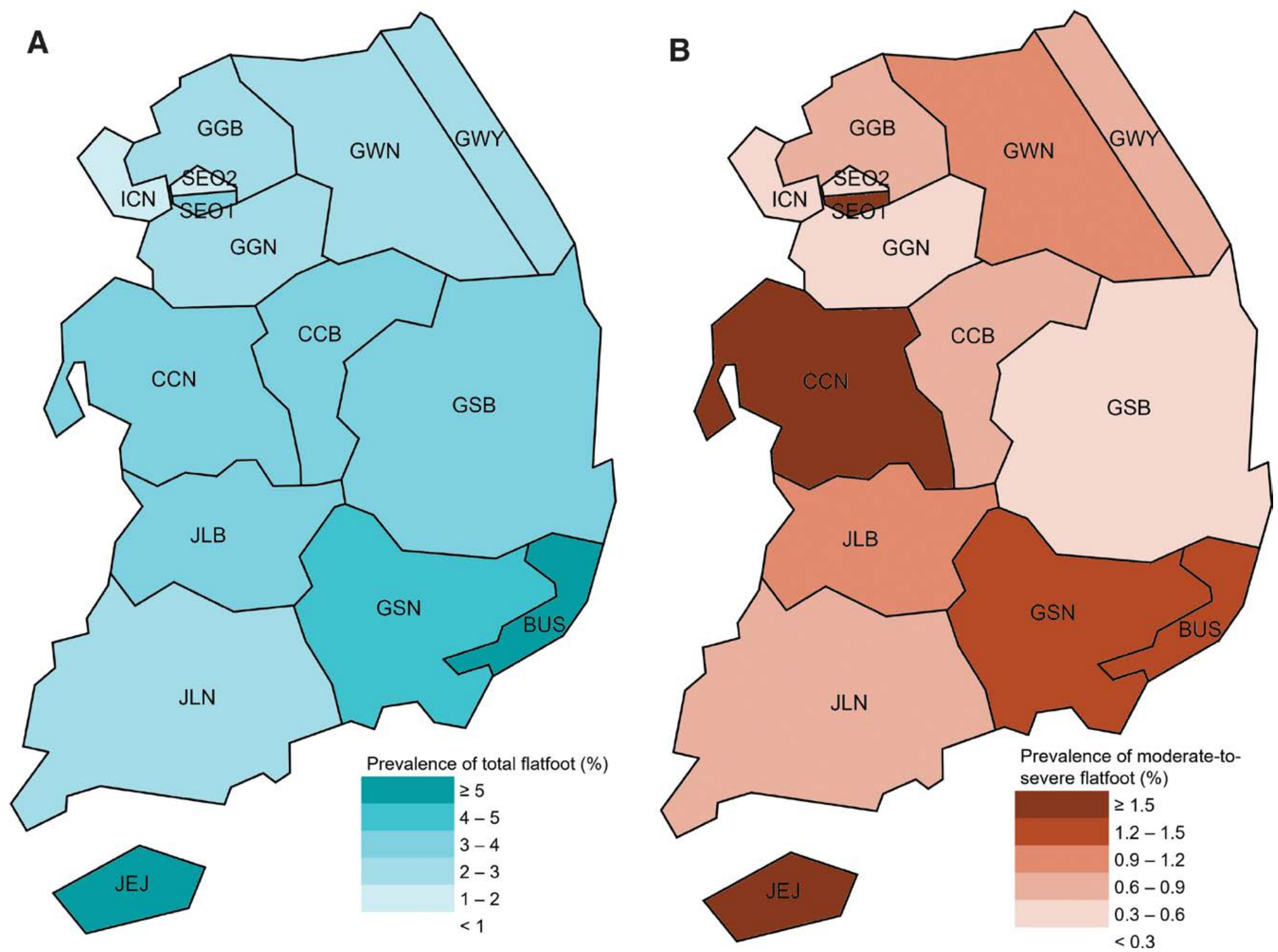

Figure 1. Prevalence of (A) total and (B) moderate-to-severe flatfoot diagnosis according to the regional jurisdiction of the Military Manpower Administration of South Korea. BUS, Busan; CCB, Chungcheongbuk-do; CCN, Chungcheongnam-do; GGB, Northern Gyeonggi-do; GGN, Southern Gyeonggi-do; GSB, Gyeongsang-buk-do; GSN, Gyeongsangnam-do; GWN, Gangwon-do; GWY, Yeongdong region, Gangwon-do; ICN, Incheon; JEJ, Jeju-do. JLB, Jeollabuk-do; JLN, Jeollanam-do; SEO, Seoul.

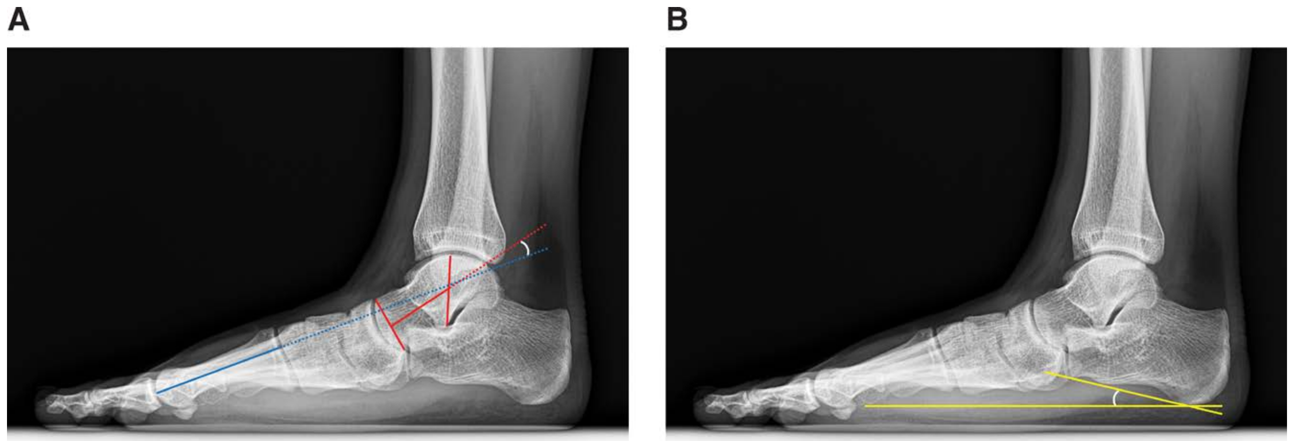

Figure 2. Standard weight-bearing lateral radiograph angle measurements of the foot. (A) Talo-first metatarsal angle. (B) Calcaneal pitch angle.

2.2. Data collection

All subjects at the draft physical examination were assessed with a questionnaire, in which the subjects checked the item for foot deformity, if they had been diagnosed with flatfoot, or if they thought they had foot deformity. The subjects who checked any of those items underwent an X-ray examination by the military orthopedic surgeons. Specifically, a weight-bearing lateral radiograph of the foot was acquired using an X-ray system (R225ACS, DK Medical system, Gyeonggi-do, South Korea) with subjects standing on a table with their feet in a neutral position. Based on these radiographic tests, military orthopedic surgeons and radiologists of each regional MMA measured the TMA and the CPA (Fig. 2). In addition, the information on the height and weight of all subjects was also collected.

2.3. Radiographic angle measurement and diagnosis of flatfoot

TMA of 0° ± 6° was regarded as normal, and TMA 15° or greater was considered as moderate-to-severe flatfoot according to the guidelines of the Ministry of Defense of South Korea (Table 1).[20–22] As for CPA, angles <17° were classified as mild flatfoot[22] and those <10° were considered as moderate-to-severe flatfoot.[23] If either the TMA or the CPA was abnormal, the subjects were categorized as abnormal.

For the management of military service resources, the Ministry of Defense of South Korea classifies an individual with a moderate-to-severe flatfoot into supplementary service. An experienced military orthopedic surgeon and a radiologist evaluate the radiographic angles using a Picture Archiving and Communication System (PACS, ViewRex, TechHeim Co., Ltd. Seoul, South Korea). Depending on the radiographic angle, subjects are classified as Supplementary Service or Active Service by a military orthopedic surgeon (Table 2).

2.4. Body mass index as a risk factor for flatfoot

We evaluated the correlation between body mass index (BMI) and flatfoot angles. Furthermore, we compared the mean and 95% confidence interval (CI) of flatfoot angles between those with self-checked foot deformities such as flatfoot and pes cavus, those without self-checked foot deformities, and normal groups. Between the angles of the left and right foot, the more severe angle was chosen for correlation analysis with BMI.

2.5. Statistical analysis

All statistical analyses were performed using IBM SPSS version 25.0 (IBM Corp., Armonk, NY, USA). A P value < 0.05 was considered statistically significant. Pearson correlation coefficient and scatter plot matrix were used to evaluate the correlations among the flatfoot angles. To compare the BMI according to the presence of self-checked foot deformities, a one-way analysis of variance (ANOVA) was performed. In addition, a Bonferroni correction was applied to the post hoc analysis of the between-group or within-group comparisons to correct for the number of comparisons performed.

3. Results

3.1. Nationwide prevalence

Table 3 shows the demographic data and the prevalence of flatfoot among 19-year-old Korean males according to the geographic regions of South Korea. Of the 560,141 subjects at the draft physical examination, a total of 20,989 (3.7%) subjects checked the item for flatfoot and were thus examined by the military orthopedic surgeons with weight-bearing lateral radiograph; as a result, 16,102 (76.7%) subjects were finally diagnosed with flatfoot. Of them, 5265 (32.7%) subjects were

Table 1

Proposed classification of flatfoot according to the talo-first metatarsal angle and calcaneal pitch angle.

	Talo-first metatatarsal angle	Calcaneal pitch angle
Moderate-to-severe flatfoot	15° or larger	<10°
Mild flatfoot	6° ≤, <15°	10° ≤, <17°
Normal	−6° ≤, <6°	17° ≤, <25°
Pes cavus	<−6°	25° or larger

Table 2

Physical status grade according to the guidelines of the Ministry of Defense of South Korea and the corresponding role according to the angle of flatfoot.

Grade	Flatfoot angle	Classification	Role
1	Others	Normal	Active service
3	6° ≤ TMA < 15°	Mild flatfoot	Active service
4	TMA ≥ 15° or CPA < 10°	Moderate-to-severe flatfoot	Supplementary service

CPA = calcaneal pitch angle; TMA = talo-first metatarsal angle.

Table 3

Demographic data of flatfoot according to severity and proportion of Supplementary Services due to flatfoot in 19-year-old Korean males.

	Total	GGN	ICN	SEO2	SEO1	GSB	BUS	GGB	CCN	JLN	GSN	JLB	CCB	GWN	GWY	JEJ
① Total number of subject for draft physical examination	560,140	65,492	60,270	57,232	56,094	55,158	52,687	49,797	45,214	39,684	29,857	15,840	14,297	9874	5505	3139
Number of individuals with flatfoot																
② Moderate-to-severe	5265	347	354	310	963	267	685	440	738	292	395	148	128	91	46	61
③ Mild	10,837	975	770	386	877	1469	2073	823	772	794	791	341	427	138	84	117
④ Total (=②+③)	16,102	1322	1124	696	1840	1736	2758	1263	1510	1086	1186	489	555	229	130	178
Prevalence of flatfoot (%)																
Moderate-to-severe (=②/①×100)	0.9	0.5	0.6	0.5	1.7	0.5	1.3	0.9	1.6	0.7	1.3	0.9	0.9	0.9	0.8	1.9
Mild (=③/①×100)	1.9	1.5	1.3	0.7	1.6	2.7	3.9	1.7	1.7	2.0	2.6	2.2	3.0	1.4	1.5	3.7
Total (=④/①×100)	2.9	2.0	1.9	1.2	3.3	3.1	5.2	2.5	3.3	2.7	4.0	3.1	3.9	2.3	2.4	5.7
Supplementary Service (SS)																
⑤ Classified as SS due to all orthopedic problems	19,079	2255	1785	1735	2301	1590	2161	1531	1729	1404	1029	648	424	258	112	117
Percentage (%) of SS due to only flatfoot (=②/⑤×100)	27.6	15.4	19.8	17.9	41.9	16.8	31.7	28.7	42.7	20.8	38.4	22.8	30.2	35.3	41.1	52.1

BUS, Busan; CCB, Chungcheongbuk-do; CCN, Chungcheongnam-do; GGB, Northern Gyeonggi-do; GGN, Southern Gyeonggi-do; GSB, Gyeongsang-buk-do; GSN, Gyeongsangnam-do; GWN, Gangwon-do; GWY, Yeongdong region, Gangwon-do; ICN, Incheon; JEJ, Jeju-do. JLB, Jeollabuk-do; JLN, Jeollanam-do; SEO1, Seoul-South; SEO2, Seoul-North.

diagnosed with moderate-to-severe flatfoot. Therefore, the prevalence of total flatfoot and moderate-to-severe flatfoot among 19-year-old males in South Korea was 2.9% and 0.9%, respectively.

3.2. Geographic prevalence

Table 3 and Fig. 1 show the geographic prevalence of flatfoot. Among the regions with more than 10,000 subjects, Busan showed the highest prevalence of total flatfoot (5.2%), while Seoul 2 (Seoul-North) showed the lowest prevalence of flatfoot (1.2%). The prevalence of total flatfoot ranged from 1.2 to 5.7%, and the prevalence of moderate-to-severe flatfoot ranged from 0.5 to 1.7%.

3.3. Fluctuation of geographic prevalence

Between the first year (April 2018–March 2019) and the second year (April 2019–April 2020), the annual prevalence of total flatfoot increased from 2.8 to 3.0% (Table 4); of the 15 regions, 10 regions showed increases in the prevalence of total flatfoot. In contrast, the annual prevalence of moderate-to-severe flatfoot decreased from 1.0 to 0.8%, with 9 out of the 15 regions showing decreases in the prevalence of moderate-to-severe flatfoot.

3.4. Correlation analysis between angles

In the weight-bearing lateral radiographs of the total subjects, the coefficients between TMA and CPA ranged from 0.342 to 0.449 (Table 5, Fig. 3; all P values < 0.001). The coefficients between the 2 sides of TMA and CPA were 0.709 and 0.746 (all P values < 0.001), respectively.

3.5. BMI as a risk factor for flatfoot

The Pearson correlation coefficient between flatfoot angles and BMI was −0.124 ($P < .001$) for TMA and 0.019 ($P < .05$) for CPA, indicating significant but low degrees of correlation. Fig. 4 shows the mean and 95% CI of BMI in the normal and flatfoot groups as determined by flatfoot angles TMA and CPA. There were significant differences in one-way ANOVA analysis among normal and diseased groups as determined by TMA or CPA (both $P < .001$). Moreover, those with foot deformities including flatfoot and pes cavus according to TMA or CPA had a significantly higher BMI than those without foot deformities in a post hoc analysis of the one-way ANOVA analysis.

4. Discussion

In this study, we examined the prevalence of flatfoot among 19-year-old Korean males and assessed the correlations among flatfoot angles. According to the diagnosis made based on weight-bearing lateral radiographs, the prevalence of total flatfoot and moderate-to-severe flatfoot was 2.9% and 0.9%, respectively. The correlation coefficients between flatfoot angles (i.e., TMAs and CPAs) ranged from 0.342 to 0.449.

Clinical classification of flatfoot is based on the function of posterior tibial tendon, deformity of the foot, pain, single-limb heel-rise, "too many toes" sign, valgus deformity, and arthritis of the ankle.[24] As diagnosing flatfoot through physical examination or plantar footprints can be a subjective matter, examination of the deformity of the foot and weight-bearing radiographs is regarded as the most appropriate mode of screening for flatfoot before conscription. In line with the research by Chi et al, the Ministry of Defense of South Korea classifies individuals into Supplementary Service if their TMAs are 15° or greater.[20,21] Flatfoot can also be diagnosed if CPA is <18° or 17°[23,25]; however, the Ministry of Defense of South Korea classifies an individual into Supplementary Service if the CPA is <10°. Occasionally, the guidelines set by the Ministry of Defense are changed to meet the demand of the military troops.

The MLA of the foot spontaneously develops around ten years of age; however, 10 to 20% show no development of the arches until adulthood and result in flatfoot.[26] There is a significant difference in the flatfoot prevalence between children and adults,[27,28] and the conscription data of each country are gathered between adolescence and adulthood; therefore, the prevalence of flatfoot during this period is important. For example, a study of Saudi Arabian army recruits with ages ranging from 18 to 21 years showed a flatfoot prevalence of 5% using plantar footprints.[18] In a study from Israel in which flatfoot was diagnosed through physical examination by military doctors, the prevalence of mild flatfoot was 12.4% and

Table 4

Geographical prevalence of total flatfoot and moderate-to-severe flatfoot among Korean 19-year-old males.

	Total	GGN	ICN	SEO2	SEO1	GSB	BUS	GGB	CCN	JLN	GSN	JLB	CCB	GWN	GWY	JEJ
Total # of subjects	560,140	65,492	60,270	57,232	56,094	55,158	52,687	49,797	45,214	39,684	29,857	15,840	14,297	9874	5505	3139
April 2018–March 2019	307,115	35,946	33,369	31,220	30,478	30,363	28,882	28,486	24,434	16,943	16,031	13,518	6975	4678	2653	3139
April 2019–April 2020	253,025	29,546	26,901	26,012	25,616	24,795	23,805	21,311	20,780	22,741	13,826	2322	7322	5196	2852	0
Moderate-to-severe flatfoot																
April 2018–March 2019	3147(1.0%)	167 (0.5%)	190 (0.6%)	147 (0.5%)	717 (2.4%)	169 (0.6%)	264 (0.9%)	250 (0.9%)	497 (2.0%)	144 (0.8%)	273 (1.7%)	134 (1.0%)	55 (0.8%)	51 (1.1%)	28 (1.1%)	61 (1.9%)
April 2019–April 2020	2118(0.8%)	180 (0.6%)	164 (0.6%)	163 (0.6%)	246 (1.0%)	98 (0.4%)	421 (1.8%)	190 (0.9%)	241 (1.2%)	148 (0.7%)	122 (0.9%)	14 (0.6%)	73 (1.0%)	40 (0.8%)	18 (0.6%)	0 (0%)
Total flatfoot																
April 2018–March 2019	8536(2.8%)	755 (2.1%)	538 (1.6%)	389 (1.2%)	1154(3.8%)	1020(3.4%)	1111(3.8%)	768 (2.7%)	813 (3.3%)	441 (2.6%)	602 (3.8%)	415 (3.1%)	158 (2.3%)	135 (2.9%)	59 (2.2%)	178 (5.7%)
April 2019–April 2020	7566(3.0%)	567 (1.9%)	586 (2.2%)	307 (1.2%)	686 (2.7%)	716 (2.9%)	1647(6.9%)	495 (2.3%)	697 (3.4%)	645 (2.8%)	584 (4.2%)	74 (3.2%)	397 (5.4%)	94 (1.8%)	71 (2.5%)	0 (0%)

BUS = Busan, CCB = Chungcheongbuk-do, CCN = Chungcheongnam-do, GGB = Northern Gyeonggi-do, GGN = Southern Gyeonggi-do, GSB = Gyeongsang-buk-do, GSN = Gyeongsangnam-do, GWN = Gangwon-do, GWY = Yeongdong region = Gangwon-do, ICN = Incheon, JEJ = Jeju-do, JLB = Jeollabuk-do, JLN = Jeollanam-do, SEO1 = Seoul-South, SEO2 = Seoul-North.

Table 5

Pearson's correlation coefficients among the flatfoot angles.

	TMAR	TMAL	CPAR	CPAL
TMAR	–	0.709	0.357	0.377
TMAL	0.709	–	0.342	0.449
CPAR	0.357	0.342	–	0.746
CPAL	0.377	0.449	0.746	–

All P values < 0.001.

CPAL = calcaneal pitch angle, left, CPAR = calcaneal pitch angle, right, TMAL = talo-first metatarsal angle, left, TMAR = talo-first metatarsal angle, right.

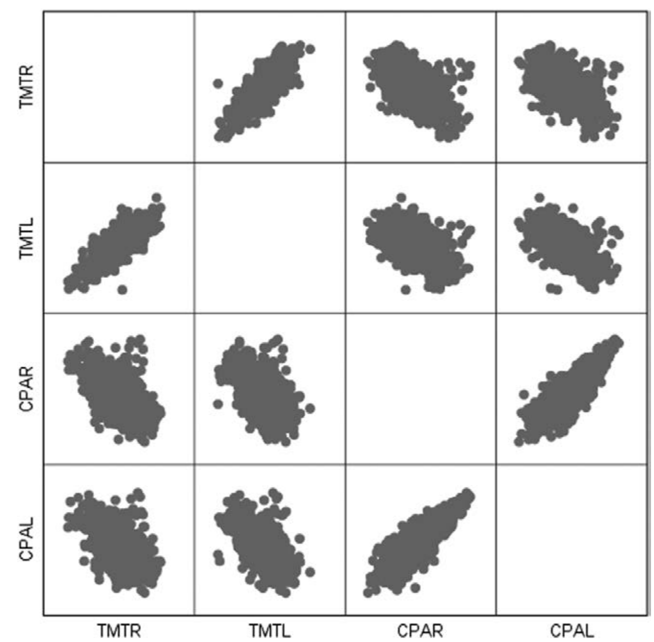

Figure 3. Scatterplot matrix of the flatfoot angles.TMAR, Talo-first metatarsal angle, right; TMAL, Talo-first metatarsal angle, left; CPAR, Calcaneal pitch angle, right; CPAL, Calcaneal pitch angle, left.

9.3% in males and females, respectively, and that for severe flatfoot was 3.8% and 2.4% in males and females, respectively.[19] In our study, the prevalence of flatfoot as diagnosed by weight-bearing lateral radiographs in the Korean 19-year-old male population was 2.9%. We assume that the prevalence of flatfoot in South Korea was lower than those in Saudi Arabia and Israel because South Korea is the only country that evaluates the flatfoot angle based on radiographs. Our current results may be appropriate considering that the flatfoot prevalence in our study is greater than that of Asians in the United States.[17] There was a fluctuation in the geographical prevalence between 2018 and 2019, but the average total prevalence showed a modest degree of change from 2.8 to 3.0%. Notably, there were no cases of flatfoot in the JEJ (Jeju-do) area in the second year (April 2019–April 2020), which was because physical examinations were suspended in the area due to the spread of COVID-19.

To the best of our knowledge, there has been no study that directly assessed the correlation between the TMA and CPA. Furthermore, only a few studies have indirectly compared the flat foot indices, TMA and CPA.[29,30] In our study, the coefficients between TMA and CPA ranged from 0.342 to 0.449. We expected that talar declination would naturally increase by anatomy as calcaneal inclination increases. However, the correlation was less than what we expected, which we assume to be due to the fact that TMA is affected by the first metatarsal bone. Future studies analyzing the correlations among each bone in the foot are needed.

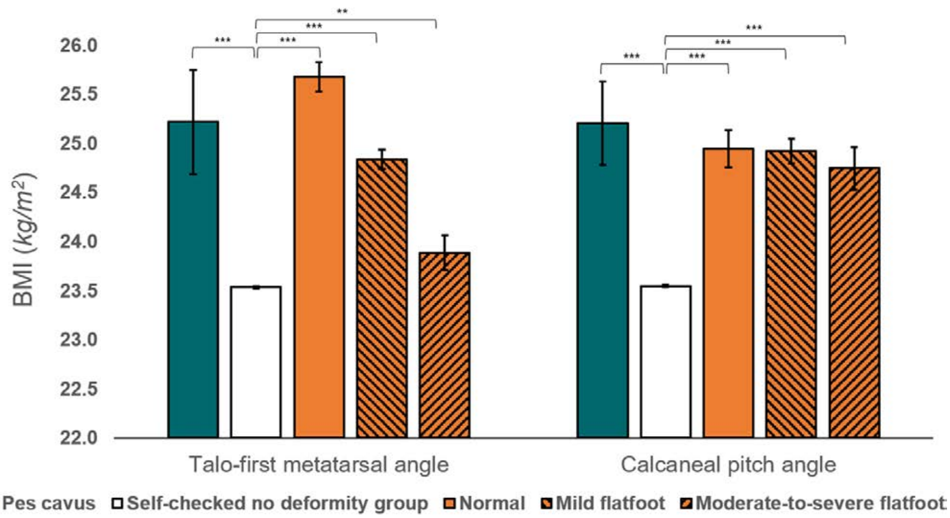

Figure 4. Mean values and 95% confidence intervals of body mass index (BMI) according to disease severity. The numbers of examinees classified by the talo-first metatarsal angle and the calcaneal pitch angle are as follows: Pes cavus (n = 337 and 595), Not checked the questionnaire (n = 533,321 and 538,238), Normal (n = 4247 and 2722), Mild flatfoot (n = 8712 and 5804), and Moderate-to-severe flatfoot (n = 2650 and 1908). Asterisks represent the statistical significance in post hoc analysis between the Normal group and the diseased groups. $^*P < .05$, $^{**}P < .01$, $^{***}P < .001$, n.s. = not significant.

In this study, those with self-checked foot deformity groups had a significantly higher BMI than the self-checked no deformity group in a post hoc analysis (Fig. 4). According to a systematic review by Butterworth et al, there were strong associations between high BMI and nonspecific foot pain in the general population and chronic plantar heel pain in a nonathletic population.[31] In line with the fact that the self-checked foot deformity groups have a high tendency to have foot pain, our results also showed that higher BMI was associated with a higher tendency to deem oneself as having foot deformities such as flatfoot and pes cavus.

Since the study data were collected from military conscription examinations, the symptoms may have been overestimated, and false-negative examinees may not be substantially high. There may be both symptomatic and asymptomatic cases in the flatfoot group because the examinees checked the "flatfoot" box in the self-questionnaire. Also, symptomatic and asymptomatic flatfoot are difficult to be discriminated using flatfoot angles in radiographs. Moraleda et al reported that among many relative alignments between symptomatic and asymptomatic pediatric flexible flatfoot, the only difference was in the lateral displacement of the navicular as measured by the anteroposterior talonavicular coverage, which seems to be related to the onset of symptoms among patients with flexible flatfoot.[32]

There are several limitations to this study. Inter-observer bias may have occurred because different orthopedic surgeons and radiologists assessed the radiographs at each regional MMA. Also, radiographic evaluation was performed in 20,989 (3.7%) subjects out of the total 560,141 subjects who checked the questionnaire item for "flatfoot". However, the number of mild flatfoot cases that were missed may not be substantially high considering that subjects at the mandatory draft physical examination are likely to check all health-related items that may be even remotely associated with themselves.

In conclusion, the overall prevalence of flatfoot diagnosed using a weight-bearing lateral radiograph was 2.9% in the 19-year-old Korean male population, while the prevalence of moderate-to-severe flatfoot was 0.9%. The correlation coefficients among flatfoot angles in radiographs (i.e., TMAs and CPAs) showed a low degree of positive correlation.

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Author contributions

S.M.R. and S.H.L. designed the study, T.K.L. conducted image and statistical analysis, S.M.R. and S.H.L. supervised the present study, S.M.R., T.K.L., and S.H.L. writed, edited and approved the manuscript.

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