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Effects of wearing shoes on the feet: Radiographic comparison of middle-aged partially shod Maasai women's feet and regularly shod Maasai and Korean women's feet☆

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ABSTRACT

Background: Maasai tribe members walk long distances daily either barefoot or wearing traditional shoes made from recycled car tires, without any foot ailments. To figure out the characteristic of their feet, we designed a radiographic comparative study of middle-aged partially shod Maasai women's feet and regularly shod Maasai and Korean women's feet.
Methods: Weight bearing radiographs of bilateral foot and ankle joints from 20 healthy middle-aged bush-living partially shod (PS) Maasai women were obtained. Same number of radiographs from 20 urban-living regularly shod (RS) Maasai and 20 Korean women were obtained and compared. The hallux valgus angle, the first to second intermetatarsal angle, talonavicular coverage angle, talo-first metatarsal angle, Meary angle, naviculo-cuboidal overlap, and the medial cuneiform height were measured to establish the degree of pes plano-valgus and hallux valgus deformity.
Results: On comparing PS and RS Maasai groups radiographically, the talonavicular coverage angle, talo-first metatarsal angle, and naviculo-cuboidal overlap were significantly greater in the PS Maasai group, whereas hallux valgus angle, the first and second intermetatarsal angle, Meary angle, and the medial cuneiform height were greater in the RS Maasai and Korean group.
Conclusions: Regularly wearing shoes would protect the feet from pes plano-valgus deformity, despite potentially contributing to hallux valgus deformity.

1. Introduction

The Maasais are a globally known African indigenous ethnic group, with the majority living in northern Tanzania. They are well known for living a semi-nomadic lifestyle and walking barefoot or in a pair of traditional shoes made from recycled car tires imitating a rocker bottom shape (Fig. 1). It is particularly unique that they do not generally suffer from low back pain and foot ailments despite walking long distances of up to 60 km daily. Although several studies have been performed since MBT (Masai Barefoot Technology, Masai Marketing & Trading AG, Winterthur, Switzerland) was invented focusing on their traditional shoes' design for the reason of this specialty, the positive effects of MBT on the foot and ankle joint still remain unclear [1–4].

A previous report [5] revealed that middle-aged partially shod Maasai women have a higher prevalence of abducted midfeet, everted hindfeet, and fallen medial longitudinal arches than Korean women do, while Korean women have a higher prevalence of hallux valgus, a preserved medial longitudinal arch, and toes that are free from claw deformity. However, this previous study was limited in that data from Maasai women who wear shoes regularly were not collected and compared; therefore, genetic and ethnic factors might not have been ruled out to understand the effect of wearing shoes. To overcome limitations of the previous studies, we designed a new study that compared radiographs of the feet of middle-aged Maasai women dwelling partially shod in the bush and those of middle-aged Maasai and Korean women living in the modernized ready-made shoe-wearing society.

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Fig. 1. Maasai traditional shoes made from recycled car tires (A) are characterized by a rounded sole in the anterior-posterior direction (B). The Maasai tribe spends their life barefoot or in the traditional shoes (C).

We hypothesized that partially shod (PS) Maasai women would be more likely to have pes plano-valgus and claw toe deformities than regularly shod (RS) Maasai and Korean women, whereas RS Maasai and Korean would have larger hallux valgus deformity. In designing this study, we assumed that the feet of middle-aged women would reflect their lifestyle rather than a result of the aging process. A previous report revealed that the incidence of foot diseases due to shoe wearing such as hallux valgus is high in the third through fifth decade [6] or at 60 years of age [7]. Some studies have demonstrated that the incidence of osteoarthritis of the ankle increases with age [8,9]. Thus, we decided to survey middle aged women to rule out the aging effect on the foot and ankle joint.

2. Materials and methods

2.1. Participants

Forty feet from 20 healthy PS Maasai women aged 46–55 years in various rural villages around Arusha, northern Tanzania, were selected from volunteers who participated in this study from September 2012 to March 2013. Among volunteers, participants without predisposing trauma, history of rheumatoid disease, leg length discrepancy, excessive genu valgus or varus deformity, or limping gait were selected.

From June 2014 to December 2014, using the same selection criteria, a similar study with the same number of healthy Korean women wearing ready-made shoes was conducted in Seoul. For RS Maasai women who live in modernized society and wore the same ready-made shoes as did the Koreans in Arusha urban area, another study was performed from May 2016 to October 2016.

Informed consent was obtained from all participants before commencing the investigation, and this study was approved by the ethical review committee of Inje University Ilsan Paik Hospital (IB-1410-047).

2.2. Measuring surface anatomy and gait related parameter

First, body height and weight were measured and body mass index (BMI) was calculated. Second, the length of both feet, which was defined as the distance from the most posterior part of the heel to the longest toe, with the participant in a standing position, was measured; the width of both feet, defined as the shortest perpendicular distance to the heel bisecting from the most medial part of the forefoot, was also measured [10]. The foot width divided by the length was then calculated. Third, a single, trained orthopedic surgeon examined the feet for any mallet or claw toe deformities. We defined mallet toe deformity as a flexion of the distal interphalangeal (DIP) joint with hyperextension of the proximal interphalangeal (PIP) joint. Claw toe deformity was defined as a flexion of the PIP and DIP joints with hyperextension of the metatarsophalangeal joint.

To measure step length, walking velocity, and count cadence, each participant was requested to walk barefoot on a flat surface for 1 min. While they walked, the number of steps per minute (cadence) was counted and the entire distance (walking velocity) was measured. Step length was defined as the distance from the heel of one foot to the heel of the other.

2.3. Radiological evaluation

Radiographs in the anteroposterior (AP) view of the weight-bearing foot, AP view of the ankle, and foot and ankle lateral view

were obtained bilaterally. On weight-bearing ankle AP radiographs, the tibial anterior surface angle (TAS) [11] and talar tilt were measured to assess the alignment of the ankle joint. The hallux valgus angle (HVA) and the first to second intermetatarsal angle (IMA) were measured on the weight-bearing foot AP radiographs to determine the degree of hallux valgus. HVA was defined as the angle between the longitudinal axes of the first metatarsal and the proximal phalanx, and the IMA was defined as the angle between the longitudinal axes of the first metatarsal and the second metatarsal.

Since obtaining a hindfoot alignment view [12] is infeasible in Africa, we decided to measure naviculo-cuboid overlap (NCO), talonavicular coverage angle (TNCA), and talo-first metatarsal angle (T1MTA) alternately based on the study by Lee et al. [13]. Normally, TNCA and T1MTA represent the degree of midfoot abduction or adduction; TNCA, T1MTA and NCO are reported to be reliable and valid measures for the evaluation of hindfoot valgus and varus deformities. Using weight bearing foot AP radiographs, TNCA was defined as the angle between a bisecting line of the anterior talar articular surface and another bisecting line of the proximal navicular articular surface. T1MTA on weight-bearing foot AP radiographs was defined as the angle between a line bisecting the anterior talar articular surface and the long axis of the first metatarsal. On lateral weight-bearing ankle radiographs, the tibial lateral surface angle (TLS) [11] was measured to evaluate the ankle alignment. Additionally, the talo-first metatarsal angle (Meary angle) and calcaneal pitch angle (CPA) were measured to evaluate the degree of pes planus or cavus. The Meary angle was defined as the angle between the long axis of the first metatarsal bone and a line drawn through the midpoints of the talar head and neck. CPA was defined as the angle between a line drawn along the edge of the plantar soft tissue shadow and a line drawn along the calcaneal lower margin. NCO was measured to obtain the degree of hindfoot valgus or varus as mentioned above. NCO was defined as the portion of the navicular bone divided by the cuboid vertical height using weight-bearing foot lateral radiographs.

Finally, medial cuneiform height, defined as the length from the ground to the lowest point of the medial cuneiform bone, was measured on weight-bearing foot lateral radiographs.

Schematic measurements for radiological parameters are shown as Fig. 2.

2.4. Statistical analysis

SPSS version 18 (SPSS Inc., Chicago, IL, USA) was used to calculate mean values and standard deviations for all parameters. A one-way ANOVA test was used to compare clinical and radiographic parameters among three groups. Statistical significance was determined at a p-Value of less than 0.05 for all analyses. Post-hoc analysis was performed by using independent t-test.

3. Results

3.1. Demographic data of the participants

The mean age of the PS, RS Maasai and Korean groups were 48.55 ± 3.76 years, 48.90 ± 2.92 years, and 49.1 ± 3.28 years, respectively. The results of each group are summarized in Table 1. Demographic parameters showed no significant differences among the groups.

3.2. Surface anatomy and gait related parameters (Table 2)

Mean foot length was significantly longer in PS Maasai than in Koreans ($p = 0.009$), Mean foot length of RS Maasai was not significantly different from that of others (vs. PS Maasai: $p = 0.183$, vs. Koreans: $p = 0.383$). Mean foot width was significantly narrower in Koreans than in others (vs. PS Maasai: $p = 0.0001$, vs. RS Maasai: $p = 0.007$), while PS and RS Maasai showed no significant difference ($p = 0.187$). The values of foot width divided by length were not significantly different among three groups. Regarding toe deformity, 38 (95%) and 32 feet (80%) in PS and RS Maasai, respectively, showed claw deformity of at least one toe. The highest incidence was seen for the fifth toe in both PS and RS Maasai (100% in each).

Step length was significantly longer in PS Maasai than in Koreans ($p = 0.0076$), while RS Maasai showed no differences vs. others (vs. PS Maasai: $p = 0.174$, vs. Koreans: $p = 0.265$). The cadence

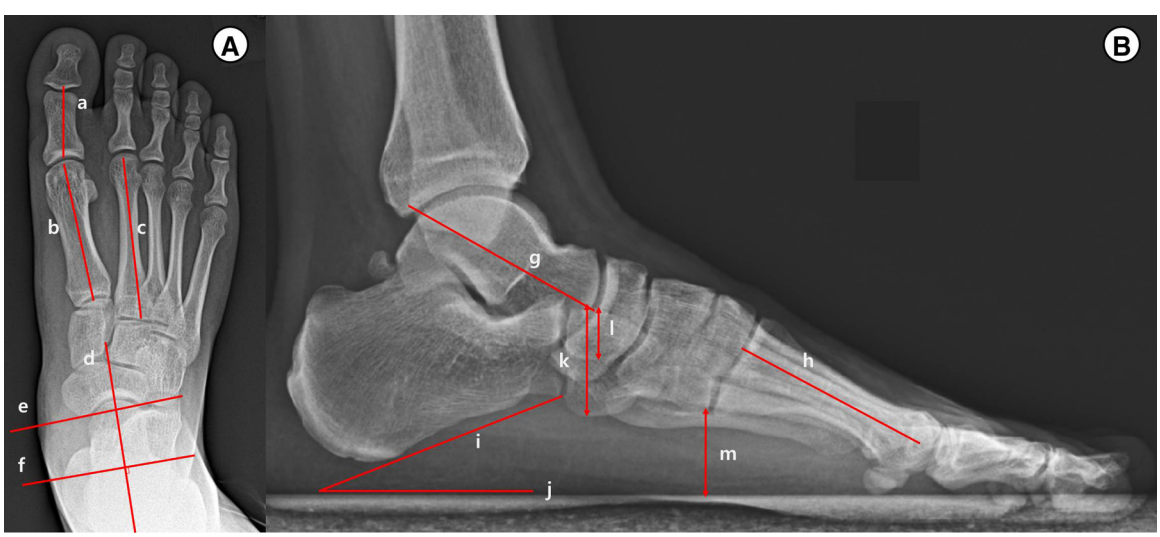

Fig. 2. Schematic measurements for radiological parameters are shown. With weight-bearing foot AP (A), angle between a and b (hallux valgus angle), b and c (the first to second intermetatarsal angle), b and d (talo-first metatarsal angle) and e and f (talonavicular coverage angle) were measured. With lateral (B) radiograph, angle between g and h (Meary angle), i and j (calcaneal pitch angle), the ratio of l divided by k (naviculo-cuboid overlap) and the length of m (medical cuneiform height) were measured.

Table 1
Participant demographic characteristics.

	Partially shod Maasai	Regularly shod Maasai	Korean	*p*-Value
Age (years)	48.55 ± 3.76	48.90 ± 2.92	49.1 ± 3.28	0.489
Body weight (kg)	57.3 ± 12.03	54.25 ± 10.92	62.0 ± 8.91	0.096
Body height (cm)	159.55 ± 5.60	156.15 ± 6.37	160.7 ± 3.91	0.287
BMI (kg/m^2)	22.44 ± 4.30	22.27 ± 4.42	24.06 ± 3.72	0.108

BMI, body mass index.

Table 2
Surface anatomy and gait related parameters of each group.

	Partially shod Maasai	Regularly shod Maasai	Korean	*p*-Value
Foot length (mm)	243.5 ± 12.15	238.5 ± 12.72	234.75 ± 6.78	0.014
Foot width (mm)	99.73 ± 5.02	98.21 ± 5.48	95.59 ± 4.53	0.0001
Foot width/foot length	0.41 ± 0.01	0.41 ± 0.04	0.41 ± 0.02	0.677
Step length (cm)	43.35 ± 6.94	40.48 ± 7.01	36.83 ± 11.46	0.031
Cadence	95.1 ± 3.39	95.45 ± 4.00	114.8 ± 12.45	0.0001
Walking velocity (m/min)	41.17 ± 6.48	38.22 ± 6.72	42.81 ± 15.16	0.755

was the highest in Koreans (vs. PS Maasai: $p = 0.0001$, vs. RS: $p = 0.0001$), whereas PS and RS Maasai were not significantly different ($p = 0.678$). As a result, walking velocity was not statistically different among three groups.

3.3. Radiological evaluation (Table 3)

On the weight-bearing ankle AP and lateral images, TAS and TLS were significantly lower in Koreans (**TAS**: vs. PS Maasai: $p = 0.0001$, vs. RS Maasai: $p = 0.003$; **TLS**: vs. PS Maasai: $p = 0.0001$, vs. RS Maasai: $p = 0.0001$), while the PS and RS Maasai showed no significant differences (**TAS**: $p = 0.51$; **TLS**: $p = 0.12$). Talar tilts were not significantly different among three groups.

The TNCA and T1MTA were greatest in PS Maasai followed by RS Maasai and Koreans on weight-bearing foot AP images, indicating more midfoot abduction related to hindfoot valgus (**TNCA**: vs. RS Maasai: $p = 0.025$, vs. Koreans: $p = 0.0001$, RS Maasai vs. Koreans: $p = 0.004$; **T1MTA**: vs. RS Maasai: $p = 0.003$, vs. Koreans: $p = 0.0001$, RS Maasai vs. Koreans: $p = 0.0001$).

HVA and IMA were significantly greatest in Koreans, followed by RS and PS Maasai (**HVA**: vs. RS Maasai: $p = 0.002$, vs. PS Maasai: $p = 0.0001$, RS Maasai vs. PS Maasai: $p = 0.047$; **IMA**: vs. RS Maasai: $p = 0.007$, vs. PS Maasai: $p = 0.0001$, RS Maasai vs. PS Maasai: $p = 0.005$). On weight-bearing foot lateral images, the Meary angle and MCH were significantly lower in PS Maasai vs. others (Meary angle: vs. RS Maasai: $p = 0.043$, vs. Koreans: $p = 0.0001$; **MCH**: vs. RS Maasai: $p = 0.0001$, vs. Koreans: $p = 0.0001$), while RS Maasai and Koreans showed no differences (Meary angle: $p = 0.067$; **MCH**: $p = 0.693$). NCO was the greatest in PS Maasai (vs. RS Maasai: $p = 0.014$, vs. Korean: $p = 0.0001$), while RS Maasai and Koreans showed no significant difference ($p = 0.384$). CPAs were not significantly different among three groups (Fig. 3).

4. Discussion

A previous study described the characteristics of the Maasai feet by analyzing 1096 bush-dwelling Maasai people's footprints grouped by age and sex [14]. That study reported that 5.84% of Maasai participants had bilateral flat foot and 1.92% had unilateral flat foot. Additionally, 98.79% of Maasai participants had a claw deformity of at least one toe.

To the best of our knowledge, this is the first study to elucidate the effect of wearing shoes by comparing foot and ankle radiographic parameters of PS with RS Maasai and Korean women. We used the data from the same ethnic group living in different areas with different shoe wearing habits. Additionally, we placed the Korean women's data for the comparison with a different ethnic group.

Regarding ankle alignment, the TAS and TLS in both PS and RS Maasai were significantly higher than those in Koreans. The TAS and TLS of the Koreans were similar to that in previous reports from Korea [15] and Japan [11]. We concluded that the TAS and TLS were not affected by wearing shoes, but by the characteristics of the ethnic group. Talar tilts were maintained constantly regardless of ethnic group and shoe-wearing status.

Table 3
Radiologic parameters of the three groups.

		Partially shod Maasai	Regularly shod Maasai	Korean	*p*-Value
Weight-bearing ankle AP & lateral	TAS (°)	91.67 ± 1.65	90.56 ± 2.59	88.85 ± 2.21	0.0001
	TLS (°)	83.97 ± 1.96	83.31 ± 2.93	79.7 ± 2.27	0.0001
	Talar tilt (°)	1.58 ± 0.63	1.48 ± 0.78	1.47 ± 1.06	0.201
Weight-bearing foot AP	TNCA (°)	31.95 ± 10.23	21.95 ± 10.04	15.60 ± 7.06	0.0001
	T1MTA (°)	26.53 ± 5.42	19.82 ± 10.55	11.70 ± 6.25	0.0001
	HVA (°)	7.57 ± 4.43	10.15 ± 5.62	13.99 ± 4.88	0.0001
	IMA (°)	7.59 ± 2.17	9.29 ± 2.69	10.86 ± 2.19	0.0001
Weight-bearing foot lateral	Meary angle (°)	−15.55 ± 6.46	−11.65 ± 7.65	−9.08 ± 7.08	0.0001
	CPA (°)	15.98 ± 3.81	16.84 ± 4.37	17.19 ± 5.31	0.388
	MCH (mm)	15.55 ± 2.31	17.78 ± 2.95	17.75 ± 3.03	0.0001
	NCO (ratio)	0.54 ± 0.12	0.47 ± 0.15	0.44 ± 0.14	0.001

TAS, talar anterior surface angle; TLS, talar lateral surface angle; TNCA, talo-navicular coverage angle; T1MTA, talo-1st metatarsal angle; HVA, hallux valgus angle; IMA, 1st to 2nd intermetatarsal angle; CPA, calcaneal pitch angle; TCA, talo-calcaneal angle; MCH, medial cuneiform height; NCO, naviculo-cuboid overlap.

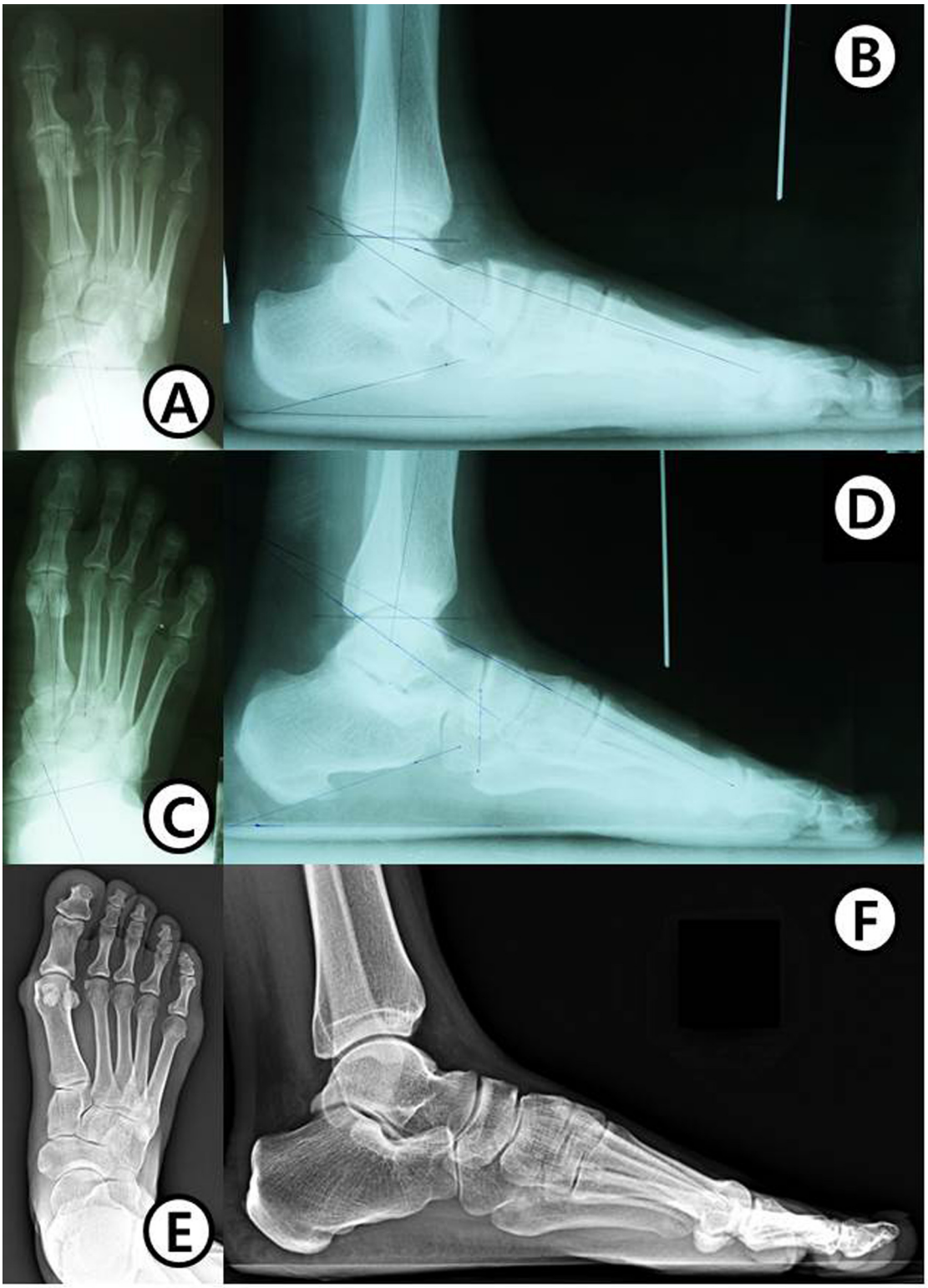

Fig. 3. Weight-bearing foot AP and lateral radiographs of 3 different groups (A,B: partially shod (PS) Maasai, C,D: regularly shod (RS) Maasai, E,F: Korean). The talonavicular coverage angle and talo-1st metatarsal angle were greatest in the PS Maasai group followed by RS Maasai and Koreans on the weight-bearing foot AP radiographs. Hallux valgus angle and the first to second intermetatarsal angle were significantly greatest in the Korean group followed by the RS and PS Maasai group. On the lateral weight-bearing foot radiographs, the Meary angle and medial cuneiform height were significantly lowest in the PS Maasai group. Naviculo-cuboid overlap was greatest in the PS Maasai group, while RS Maasai and Koreans showed no significant difference. Calcaneal pitch angle was not significantly different among groups.

Regarding midfoot and hindfoot alignment, Castro-Aragon et al. [16] concluded that African Americans had a lower CPA and a higher incidence of flat feet reporting the differences in radiographic morphology among African Americans, Caucasians, and Hispanics. In our study, the NCO, TNCA, and T1MTA were significantly greatest in PS Maasai followed by RS Maasai and Koreans; however, NCO was not significantly different between RS Maasai and Koreans. Meary angle and MCH were significantly

Fig. 4. Claw toe deformities are commonly shown in the Maasai tribe, regardless of shoe-wearing habits.

lower in the PS Maasai group, whereas RS Maasai and Koreans showed no significant differences. CPA was not significantly different among three groups. Consequently, PS Maasai showed more abducted midfoot and greater degree of pes plano-valgus deformity than RS Maasai and Koreans. On comparing RS Maasai and Koreans, TNCA, and T1MTA were significantly greater in RS Maasai, while Meary angle, MCH, and NCO were not significantly different. We report that RS Maasai have more abducted midfeet, but an insignificantly different degree of pes plano-valgus deformity compared to that in Korean women.

Regarding forefoot deformity, hallux valgus deformity is known to occur more frequently in people who wear shoes, but occasionally in unshod people [17]. Sim-Fook and Hogdson [18] reported that some degree of hallux valgus deformity was found in 33% of shod individuals compared with 2% of unshod individuals. Kato and Watanabe [19] also mentioned that the incidence of hallux valgus deformity in Japanese women substantially increased with the use of fashionable leather shoes, while the deformity was extremely rare in those wearing traditional shoes. Zipfel and Berger [20] also reported that the pathological lesions found in the metatarsals of the recent rural and urban shod populations generally appeared to be more severe than those found in the pre-pastoral group. Our results show that HVA and IMA significantly increased in RS Maasai and Koreans who have spent their entire lives wearing ready-made shoes. However, on comparing the RS Maasai and Korean groups in our study, HVA and IMA were significantly lower in the RS Maasai group despite both groups wearing the same type of ready-made shoes; this was considered an ethnic difference.

The prevalence of claw toe deformity (Fig. 4) was expected to be the highest in PS Maasai, but incidences were great in both PS and RS Maasai than in the Koreans (95% and 80% vs. 0%). Choi et al. [14] revealed claw toe deformity to exist in 98.79% of 1096 partially shod Maasai people, with the fifth (62.34%) being the most frequently affected toe. Another report [5] concluded that living barefoot in the bush could contribute to claw toe deformity, but we report that claw toe deformity is very common in the Maasai tribe regardless of shoe wearing habits.

The main limitation of this study was the small sample. As the participants were extremely reluctant to appear in the urban areas, the biggest obstacle was in bringing the rural living Maasai women to the urban area to examine the radiographs. To validate these results, further studies with a larger number or comparing with the different ethnic group such as Caucasians are necessary.

In modern society, we cannot imagine living without shoes. Shoes can protect the feet from detrimental objects on the ground surface that may be encountered during walking. However, we must remember that shoes can also bring about many kinds of foot and ankle problems.

5. Conclusions

In conclusion, regularly wearing shoes would protect the feet from pes plano-valgus deformity, despite increasing the risk for hallux valgus deformity. Claw toe deformity was found frequently in the Maasai tribe, regardless of shoe-wearing habits.

Conflict of interest

The authors declare that they have no conflict of interest.

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