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Salient Features of the Maasai Foot: Analysis of 1,096 Maasai Subjects

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Background: The Maasai are the most widely known African ethnic group located in Kenya and northern Tanzania. Most spend their days either barefoot or in their traditional shoes made of car tires. Although they walk long distances of up to sixty kilometers a day, they do not suffer from any foot ailments. Little is known about their foot structure and gait. The goal of this investigation was to characterize various aspects of Maasai foot in standing and walking.

Methods: Foot length, calf circumference, hindfoot alignment, step length, cadence, and walking velocity were obtained from 1,096 adult Maasai people (545 males and 551 females; mean age, 40.28 ± 14.69 years; age range, 16 to 65 years). All included subjects were from rural areas, where the primary terrain was sandy soil, who spend most of their lifetime barefoot, walking. They all denied any medical history or previous symptoms related to foot problems. A trained clinician scanned all feet for deformities. Static (standing) and dynamic (walking) Harris mat footprints were taken to determine the distribution of forefoot pressure patterns during walking.

Results: The average foot length was 250.14 ± 18.12 mm (range, 210 to 295 mm) and calf circumference was 32.50 ± 3.22 cm (range, 25 to 41 cm). The mean hindfoot alignment was 6.21° ± 1.55° of valgus. Sixty-four subjects (5.84%) had bilateral flat-shaped feet with a low medial longitudinal arch that exactly matched the broad pattern of their static footprints. Step length, cadence, and walking velocity were 426.45 ± 88.73 cm (range, 200 to 690 cm), 94.35 steps/min (range, 72 to 111 steps/min), and 40.16 ± 8.36 m/min (range, 18.20 to 63.36 m/min), respectively. A total of 83.39% subjects showed unilateral or bilateral deformities of multiple toes regardless of age. The most frequent deformity was clawing (98.79%) of which the highest incidence occurred with the fifth toe (93.23%). Dynamic footprints showed even pressure patterns throughout the forefoot (64.87%), followed by lateral forefoot pressure concentration patterns (21.81%).

Conclusions: Our study shows the distinct parameters that provide more insight into the Maasai foot.

Keywords: *Maasai, Maasai foot, Surface anatomy*

The Maasai, the most widely known African ethnic group, are located in Kenya and northern Tanzania. They migrated south from the lower Nile Valley around the 15th century. They have continued their old customs for years, despite government programs to encourage them to abandon their traditional semi-nomadic lifestyle. Most of them still spend their days either barefoot or in their traditional shoes made of car tires (Fig. 1). Although they walk long distances of up to sixty kilometers a day, they do not suffer from any foot aliments. MBT (Masai Barefoot Technology, Masai Marketing & Trading AG, Winterthur, Switzerland) footwear was born in 1996 when it was discovered that natural rolling gait can have positive effects on the human body. Based on Maasai traditional footwear design, MBT introduced shoes are characterized by a rounded sole in

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Fig. 1. Maasai traditional shoes made of car tires.

the anterior-posterior direction, imitating a rocker shape of the foot, with a cushioned sensor underneath the rear of the foot. The invention has been commercialized. Several studies on MBT shoes have focused on the ankle, knee, and hip joint relationships. Roberts et al.[1] found that MBT sandals increased the range of motion of the ankle and subtalar joint complex in the frontal and sagittal planes. Nigg et al.[2] found that an increase in the angle of ankle dorsiflexion in MBT shoes compared to a standard training shoe was evident. Vernon et al.[3] also reported that subjects exhibited significantly higher maximum dorsiflexion at the ankle joint when wearing MBT shoes. Buchecker et al.[4] have stated that the use of MBT shoes might reduce the risk of developing knee and hip osteoarthritis in the elderly and might play an important role in pain prevention and disability. However, it should be noted that these studies were based on the assumption that the parameters for Maasai foot anatomy and gait arae the same as other ethnic groups. For this reason, the aim of current study was to characterize various aspects of the Maasai foot in standing and walking.

METHODS

Subjects

A total of 1,096 healthy Maasai people between the ages of 16 and 65 years (545 males and 551 females) from various rural villages around Arusha, Tanzania voluntarily participated in this study from September 2012 to March 2013. All volunteers were well informed about the process and consented before the investigation. At first, participants without any type of neuromuscular dysfunction in walking a long distance as part of their daily lives were chosen. Among them, those who denied any medical history, trauma history, or previous symptoms that could be related to foot problems were ultimately included. Participants were excluded from the study if they had any kind of lower extremity malalignment or gait abnormality. The mean age of the subjects was 40.28 ± 14.69 years and they were divided into five age groups to investigate any age-related changes and compare each parameter between the age groups. There were five groups: group 1 (n = 225; range, 16 to 25 years), group 2 (n = 200; range, 26 to 35 years), group 3 (n = 245; range, 36 to 45 years), group 4 (n = 218; range, 46 to 55 years), and group 5 (n = 208; range, 56 to 65 years). The mean and standard deviation (SD) for height, body weight, and body mass index (BMI) of each group is shown in Table 1. Group 5 showed a significant difference in body weight and BMI both overall and in both gender groups. The peak overall height was highest in group 4, but it was not statistically significant.

Table 1. Height, Body Weight, and BMI of Each Group

Variable	Height (cm)	Body weight (kg)	BMI
Group 1 (16–25 yr)			
Overall (n = 225)	160.01 ± 7.89	49.68 ± 8.59	19.55 ± 3.03
Male (n = 125)	162.26 ± 8.93	50.44 ± 9.11	19.00 ± 2.16
Female (n = 100)	157.20 ± 5.15	48.74 ± 7.84	20.23 ± 3.75
Group 2 (26–35 yr)			
Overall (n = 200)	164.70 ± 9.77	55.36 ± 9.09	20.48 ± 3.39
Male (n = 100)	170.84 ± 9.58	58.77 ± 5.75	19.47 ± 1.24
Female (n = 100)	158.57 ± 4.91	53.95 ± 11.36	21.48 ± 4.41
Group 3 (36–45 yr)			
Overall (n = 245)	163.00 ± 7.48	56.77 ± 10.53	21.25 ± 3.53
Male (n = 112)	169.19 ± 5.09	61.94 ± 10.00	21.65 ± 3.47
Female (n = 133)	158.30 ± 5.20	52.42 ± 8.91	20.92 ± 3.55
Group 4 (46–55 yr)			
Overall (n = 218)	165.89 ± 11.13	59.49 ± 12.90	21.00 ± 3.83
Male (n = 108)	175.92 ± 3.60	68.33 ± 10.99	22.05 ± 3.42
Female (n = 110)	156.05 ± 6.05	50.80 ± 7.70	21.07 ± 4.16
Group 5 (56–65 yr)			
Overall (n = 208)	164.62 ± 11.79	63.25 ± 17.82	23.11 ± 5.22
Male (n = 100)	174.80 ± 6.77	71.80 ± 15.06	23.44 ± 4.52
Female (n = 108)	155.19 ± 6.30	55.33 ± 16.53	22.81 ± 5.79

Values are presented as mean ± SD.
BMI: body mass index.

Procedure

Measuring surface anatomy

The lengths of both feet were taken from the most posterior part of heel to the most anterior part of the longest toe in a full weight-bearing position. Then, calf circumference was taken at the widest point in the middle of calf using a flexible tape measure. A series of measurements were taken repeatedly by a single, trained person to minimize inter- and intraobserver errors.

The static measurement of the hindfoot alignment involved goniometric measurements of motion in the frontal plane between the calcaneus and the lower third of the leg. Weight-bearing measurement of the hindfoot has been described as an important feature in the evaluation of fuction.[5-8] The subject was positioned with his or her feet flat, in a weight-bearing position, and the clinician stood behind the patient. The clinician then positioned the patient in a subtalar neutral position as determined by talar head palpation, which was where the head of the talus was felt to be equally on both the medial and lateral sides, and the angle between bisecting lines of calcaneus and the lower third of the leg was measured with a protractor.[9]

Arch height has been defined as the highest point on the soft tissue margin of the medial longitudinal arch.[10] Measurements were taken while the right foot was in a full weight-bearing position, with the left foot resting lightly on the floor. The ankle joint was placed in a neutral position, with the body in a normal upright posture.[11] A series of measurements were taken to determine the highest point along the soft tissue margin of the medial plantar curvature.

Next, all feet were investigated by a single, trained clinician to detect any sorts of toe deformities such as mallet or claw and accompanying soft or hard corn formation. Mallet toe deformity is defined as a flexion of the distal interphalangeal (DIP) joint, accompanied by hyperextension of the proximal interphalangeal (PIP) joint, whereas claw toe deformity is defined as a hyperextension of the metatarsophalangeal joint and flexion of the PIP and DIP joints.

Measuring step length, cadence, and walking velocity

To measure the step length, cadence, and walking velocity, the subjects walked barefoot on a flat surface for one minute. During their walk, the number of steps per minute (cadence) and distance walked in the given time (walking velocity) were measured. Step length was measured from the heel of a footprint of one foot to the heel print of the other foot, or the distance traveled forward by a single leg (stride).

Harris and Beath foot printing technique

Prior to use, the Harris mat was lightly and evenly inked on its ridged side with water-soluble printing ink and a printer's roller. It is very important that a light, even coat of ink be present on the mat. Standing (static) prints are made with the subject looking ahead with hands by his or her sides and the feet comfortably together, with a small gap between medial malleoli. When a walking (dynamic) print is taken, the subject is asked to walk normally for a couple of steps before and after contact with the mat. As the subject steps on the smooth surface of the mat, the ridged, inked side is face down on the recording paper, creating a print.

Several prints of each foot were made until the investigator was satisfied by the reproducibility and is confident that the dynamic and static characteristics are truly represented.

Data Analysis

The mean values and SDs for all dependent parameters were calculated using MedCalc. The relationship between each age group was compared with a paired t-test. A significance level of p-value less than 0.05 was used for all analyses.

RESULTS

Surface Anatomy

The overall mean foot length and calf circumference were 250.14 ± 18.12 mm (range, 210 to 295 mm) and 32.50 ± 3.22 cm (range, 25 to 41 cm), respectively. The results of each individual age and gender group are summarized in Table 2. Foot length showed no significant differences among age groups, whereas calf circumference had a significant increasing tendency throughout groups 1, 2, 3, and 4. Sixty-four subjects (5.84%) showed an excessive valgus alignment (> 10°), which matched the excessively low arch height of 43 subjects (< 0.5 cm; mean, 0.51 ± 0.16 cm) bilaterally and 21 subjects (1.92%) on unilateral side exactly. The mean hindfoot alignment degree of the excessive valgus was 12.27° ± 1.19° (range, 11° to 17°). Six subjects (0.55%) showed a hindfoot varus alignment of 2°–5° and excessively high arches (> 3 cm; mean, 3.58 ± 0.19 cm) bilaterally (Fig. 2). The mean hindfoot alignment degree of varus was 3.17° ± 1.11° (Table 3). The mean hindfoot alignment degree and arch height without those exceptions were 6.21° ± 1.55° (range, 1° to 10°) of valgus and 1.75 ± 0.48 cm (range, 0.5 to 3 cm), respectively.

A total of 746 subjects (68.06%) showed a deformity of one or more toes bilaterally and 168 subjects (15.33%)

Table 2. Foot Length and Calf Circumference

Group	Foot length (mm)	Calf circumference (cm)
Group 1 (16–25 yr)		
Overall	243.40 ± 13.38	31.07 ± 2.79
Male	247.70 ± 13.53	31.44 ± 2.64
Female	238.03 ± 11.07	30.06 ± 2.90
Group 2 (26–35 yr)		
Overall	251.90 ± 19.26	31.72 ± 2.41
Male	264.95 ± 16.27	31.64 ± 1.88
Female	238.85 ± 11.71	31.80 ± 2.83
Group 3 (36–45 yr)		
Overall	248.16 ± 14.75	32.60 ± 3.20
Male	257.19 ± 13.66	33.06 ± 2.91
Female	240.56 ± 10.84	32.21 ± 3.38
Group 4 (46–55 yr)		
Overall	252.52 ± 18.56	33.39 ± 3.09
Male	268.33 ± 3.74	34.00 ± 3.06
Female	237.00 ± 13.48	32.80 ± 3.00
Group 5 (56–65 yr)		
Overall	255.58 ± 21.76	33.72 ± 3.69
Male	273.00 ± 16.04	35.70 ± 1.72
Female	239.44 ± 11.48	31.89 ± 4.05

Values are presented as mean ± SD.

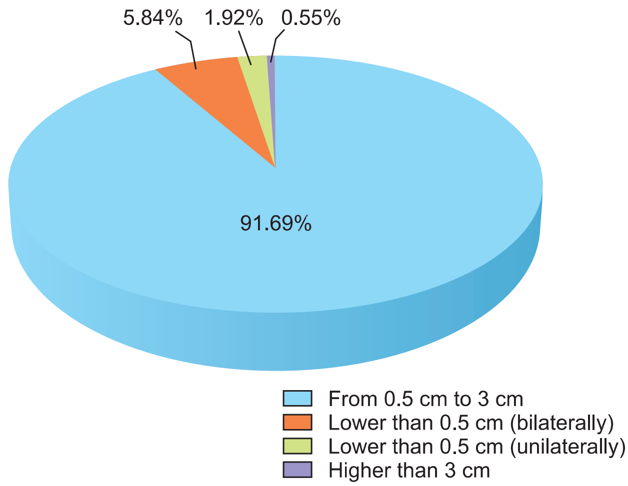

Fig. 2. Frequency distribution of subjects with regard to arch height.

Table 3. Degree of Hindfoot Valgus and Varus

Variable (n)	Degree (°)
0°–10° of valgus (1,005)	6.21 ± 1.55
> 10° of valgus (bilateral 64, unilateral 21)	12.27 ± 1.19
Varus (6)	3.17 ± 1.11

Values are presented as mean ± SD.

Table 4. Frequencies of Claw and Mallet Toe Deformities with Respect to Age Group

Group	Claw toe deformity (%)	Mallet toe deformity (%)
1 (16–25 yr)	70.44	1.78
2 (26–35 yr)	69.75	3.00
3 (36–45 yr)	74.90	0
4 (46–55 yr)	77.06	0
5 (56–65 yr)	83.65	1.92

on a unilateral foot, regardless of gender and age. Frequencies of each deformity regarding the age groups are summarized in Table 4. Groups 1 and 2 showed no significant difference, while there was a significant increasing tendency throughout the other groups. Among them, claw toe deformity occurred most frequently (98.79%), followed by mallet toe deformity (1.69%). Only four subjects (0.48%) showed both claw and mallet toe deformities in different toes of the same foot. Frequencies of each toe for multiple claw and mallet toe deformity are shown in Figs. 3 and 4. The fifth and third toes had the most frequent claw and mallet deformities. Additionally, 42.26% of claw toe deformities were accompanied by a soft corn lesion on the prominent surface (Fig. 5). Frequencies of a soft corn lesion of each toe for claw and mallet toe deformities are listed in Table 5. Claw toe deformities occurred most frequently in the fifth PIP joint (62.34%), followed by the fourth PIP (18.47%), second PIP (7.99%), and third PIP (5.63%). Mallet toe deformities had accompanying soft corn lesions as well, 21.43% showed a soft corn lesion on the fourth DIP joint and 14.29% on the third DIP joint. No subjects showed gross valgus or varus deformity of the great toe, while two subjects showed a slightly valgus deformity (< 10°) on the PIP joint of second toe bilaterally.

Step Length, Cadence, and Walking Velocity

The mean and SD for step length, cadence, and walking

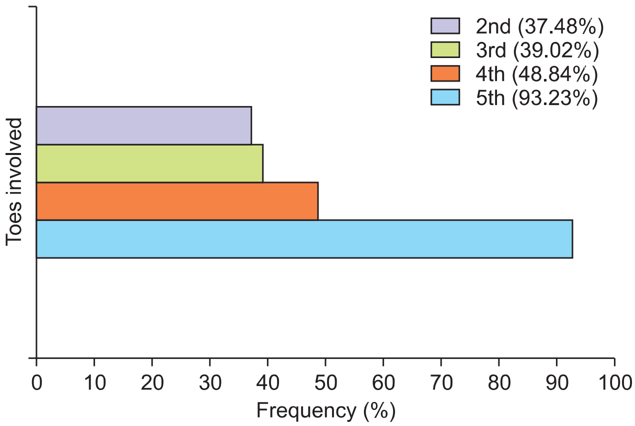

Fig. 3. Frequency distribution of claw toes in the Maasai population.

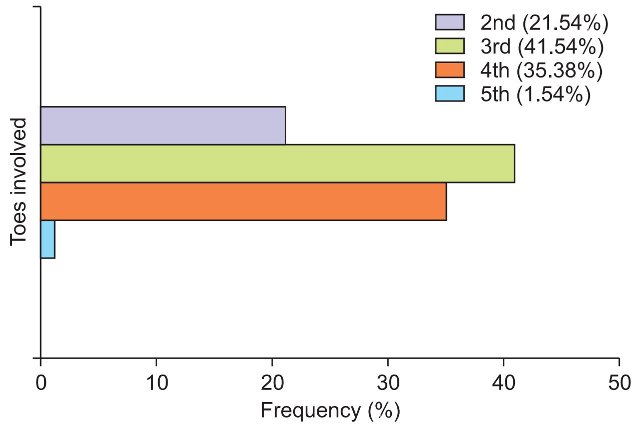

Fig. 4. Frequency distribution of mallet toes in the Maasai population.

Fig. 5. Anterior (A) and lateral (B) aspects of multiple claw toe deformity show soft corn lesion on the 5th proximal interphalangeal joint.

velocity were 426.45 ± 88.73 cm (range, 200 to 690 cm), 94.35 steps/min (range, 72 to 111 steps/min), and 40.16 ± 8.36 m/min (range, 18.20 to 63.36 m/min), respectively. Whole parameters for each gender and age group are listed in Table 6. The peak overall step length and walking velocity were shown in group 1 (441.27 ± 90.32 cm and 41.80 ± 8.48 m/min, respectively), whereas group 4 showed the peak overall cadence (97.11 ± 6.86 steps/min). Step length and walking velocity in the male group showed a significantly higher value than the female group throughout all age groups (Fig. 6A and C). In the male group, group 2 showed the peak step length (475.00 ± 61.54 cm) and group 4 showed the peak walking velocity (44.96 ± 6.11 m/min). In the female group, group 1 showed the peak step length and walking velocity (415.10 ± 88.90 cm and 40.04 ± 8.45 m/min, respectively). Group 4 showed the peak cadence in both the male and female groups (Fig. 6B).

Footprint Analyses

The footprints were analyzed subjectively for the following components by a single observer and correlated with the examination findings: static and dynamic foot shape, dynamic heel shape and bisecting line, and dynamic forefoot pressure concentration. With static footprints, 64 and 21 subjects showed a broad foot footprint pattern (Fig. 7A), which exactly matches the low arch height (< 0.5 cm) on the bilateral and unilateral sides respectively. In contrast, six subjects showed a high arched footprint pattern[12] (Fig. 7B) with an anthropometically excessive high arch (> 3 cm) bilaterally. On the whole, the dynamic shape was identical to the static shape.

The heel shape, normally ovalular, bisected by a line

Table 5. Frequencies of Soft Corn Lesion of Each Toe for Claw and Mallet Toe Deformities

Deformity	Toe	PIP joint (%)	DIP joint (%)
Claw toe	2nd	7.99	0
	3rd	5.63	0
	4th	18.47	2.50
	5th	62.34	1.31
Mallet toe	2nd	0	0
	3rd	0	14.29
	4th	0	21.43
	5th	0	0

PIP: proximal interphalangeal, DIP: distal interphalangeal.

Table 6. Step Length, Cadence, and Walking Velocity of Each Group

	Step length (mm)	Cadence (steps/min)	Walking velocity (m/min)
Group 1 (16–25 yr)			
Overall	441.27 ± 90.32*	94.85 ± 4.53	41.80 ± 8.48*
Male	462.20 ± 88.05	93.48 ± 3.27	43.20 ± 8.25
Female	415.10 ± 88.90†	96.62 ± 5.23	40.04 ± 8.45†
Group 2 (26–35 yr)			
Overall	433.23 ± 80.33	91.98 ± 5.64	39.74 ± 7.20
Male	475.00 ± 61.54‡	89.74 ± 5.01	42.58 ± 5.65
Female	391.45 ± 75.11	94.21 ± 5.36	36.89 ± 7.46
Group 3 (36–45 yr)			
Overall	420.39 ± 91.99	93.33 ± 5.75	39.17 ± 8.59
Male	449.06 ± 101.22	91.81 ± 6.19	41.16 ± 9.53
Female	396.24 ± 75.58	94.61 ± 5.01	37.49 ± 7.33
Group 4 (46–55 yr)			
Overall	425.25 ± 62.03	97.11 ± 6.86*	41.34 ± 7.06
Male	461.67 ± 53.48	97.33 ± 6.20‡	44.96 ± 6.11‡
Female	389.50 ± 47.35	96.90 ± 7.47†	37.80 ± 6.07
Group 5 (56–65 yr)			
Overall	412.31 ± 109.55	94.37 ± 5.73	38.75 ± 9.72
Male	462.00 ± 114.55	93.00 ± 3.36	42.87 ± 9.95
Female	366.30 ± 81.21	95.63 ± 7.05	34.93 ± 7.76

Values are presented as mean ± SD.
*Peak value among overall. †Peak value among female group. ‡Peak value among male group.

projected forward, can be related to the toes. All subjects showed an oval-shaped heel, of which the bisecting line was directed between second and fourth toes. The detailed ratio regarding the relationship between each toe and the heel bisecting line is listed in Table 7. The heel bisecting line was directed between the second and third toes in a statistically significant frequency ($p < 0.05$).

The dynamic forefoot pressure concentration was divided into four groups according to the maximal pressure concentration point. The four groups were as follows: even, even pressure throughout the forefoot; medial, pressure under the first metatarsal head; middle, pressure under the second and third metatarsal heads, spreading to include the fourth metatarsal head; and lateral, the fifth metatarsal head spreading to include the fourth metatarsal head (Fig. 8). The distribution of a dynamic forefoot pressure concentration according to gender and age is shown in Fig. 9. The even pressure pattern showed a significant difference in frequency (64.87%, $p < 0.05$), followed by the lateral concentration pattern (21.81%). Males in group 2 showed a significantly higher ratio in the medial forefoot area throughout the whole subgroups (26%, $p < 0.05$) and females in group 2 showed a significantly higher ratio in the lateral forefoot area (35%, $p < 0.05$).

DISCUSSION

It is significant that this investigation was the first trial to examine the secret behind the structure of the Maasai foot within an African population group. Subjects showed a higher medial longitudinal arch (1.75 ± 0.48 cm) than a previous report, in which Young et al.[13] described that a normal medial longitudinal arch was approximately 1 cm when the patient was weight-bearing. The longitudinal arch of the sole usually develops during childhood. Harris and Beath,[14] in a study of subjects from the Canadian Army, concluded that flexible flat feet resulted in a disability only they occurred in combination with a contracture of the triceps surae. They described low arches as "the normal contour of a strong and stable foot, rather than the result of weakness in foot structure or weakness of the muscles which motivate the foot."[15] In our study, no subject with unilateral/bilateral flat foot deformity complained of any disability or pain.

Murray et al.[16,17] suggested that mean step length, cadence, and walking velocity differed in men and women.

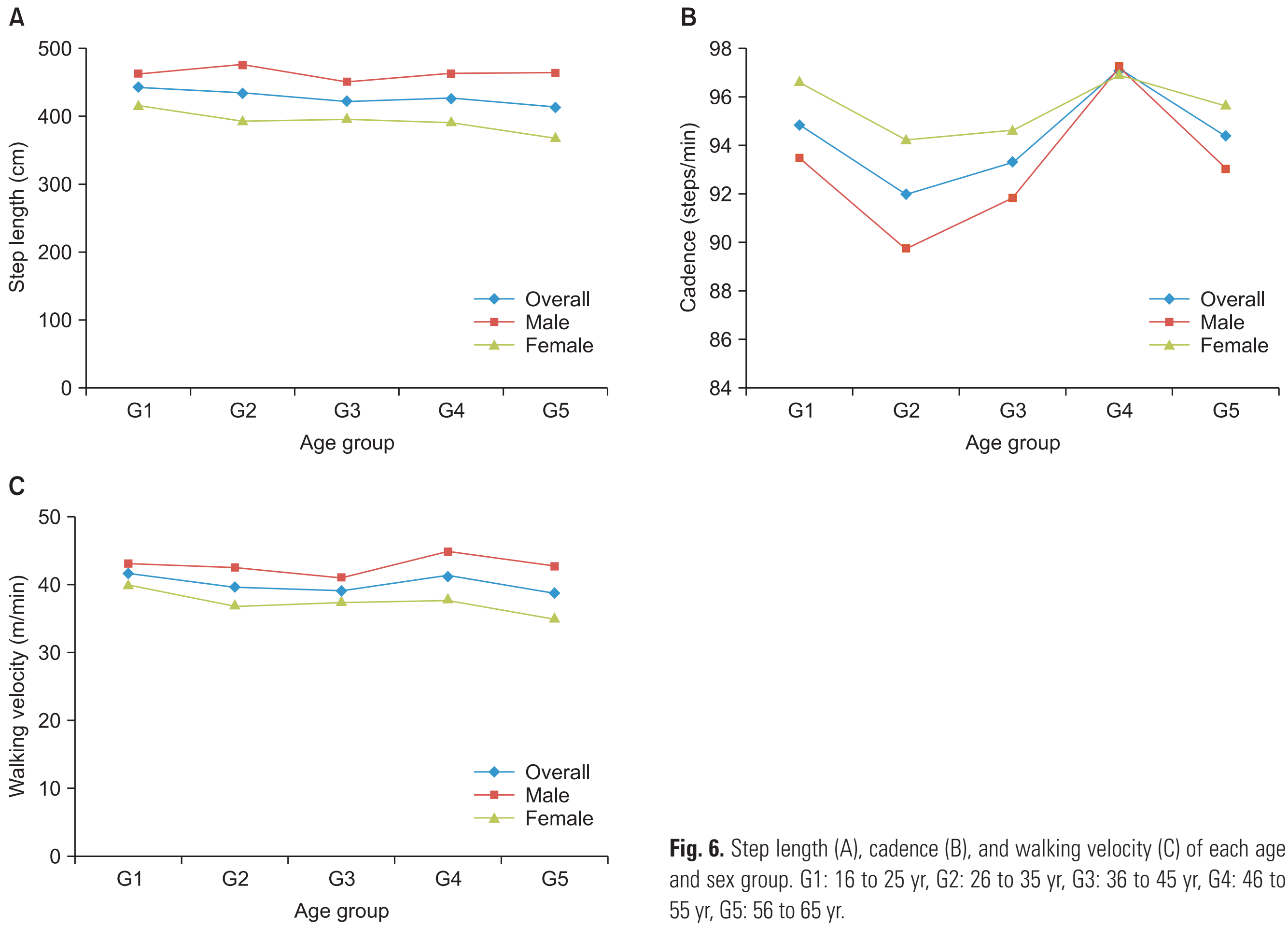

Fig. 6. Step length (A), cadence (B), and walking velocity (C) of each age and sex group. G1: 16 to 25 yr, G2: 26 to 35 yr, G3: 36 to 45 yr, G4: 46 to 55 yr, G5: 56 to 65 yr.

According to their results, mean step length, cadence, and walking velocity for men were 79 cm, 117 steps/min, and 1.54 m/sec, respectively. The same parameters for women were 66 cm, 117 steps/min, and 1.31 m/sec, respectively. Compared to our study, the mean step length and cadence were significantly lower while the walking velocity was almost half of that in Murray's subjects.

The high incidence of the clawing deformity in multiple toes (especially the 5th) is considered to result from the bush life and barefoot status, though the exact cause is still unclear. These deformities showed no attenuation with direct pressure on the metatarsal necks using the radial edge of both index fingers. Irreducibility of the deformity contraindicates an orthopaedic insole with a support behind the metatarsal heads, as the risk of worsening the dorsal impingement with the shoe by increasing the thickness of the foot.[15]

The results demonstrated no significant difference in step length in between the age groups ($p < 0.05$) except group 5, but the peak walking velocity in group 4 revealed a significantly higher cadence. Walking activity is thought to be maintained up through the mid-50s, followed by an abrupt decline in the Maasai.

The biggest obstacle of this study was encouraging the subjects to move out of their territory for an X-ray scan because they were reluctant to visit urban areas. Other portable ways to measure their feet during our visits to their tribe and in their boma (Maasai traditional mud hut) was necessary. The Harris mat was first demonstrated by Harris and Beath[14] in 1947 and has been used to aid clinical diagnosis, decision-making, and long-term follow-up for since then. The mat has a rough side, which consists of ridges of three different heights lined up in two planes. A light pressure is indicated by only the large ridges printing, whereas a heavier pressure will progressively print the smaller and then the smallest ridges in addition to the large ridges. The major drawback noted for the Harris mat is that, although it records the shape of the contact area, it can only provide qualitative information regarding the pressure involved. But it is an inexpensive, noninvasive method and many parameters from the footprints have been used to assess foot characteristics.[18] Welton[12] stated

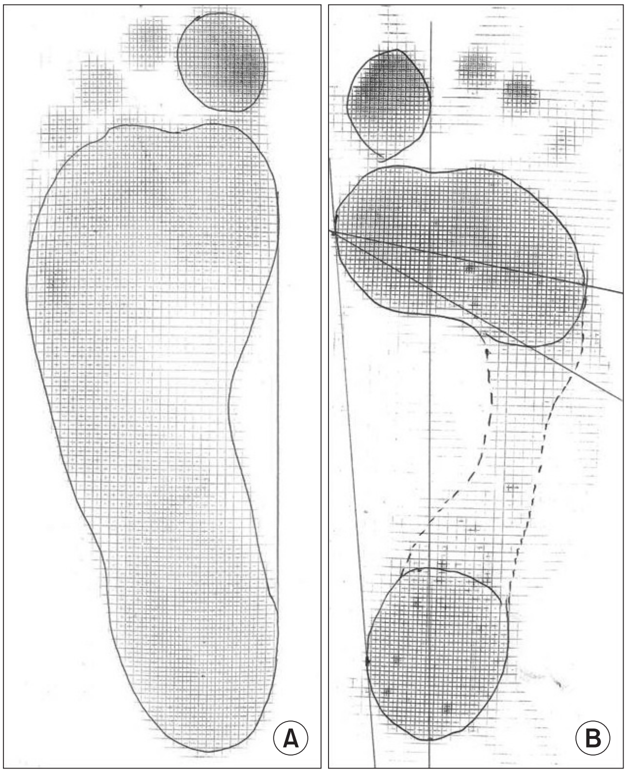

Fig. 7. (A) Broad footprint pattern. (B) High arched footprint pattern.

that the Harris mat provided a noninvasive, inexpensive, safe, and permanent record of foot/ground pressure patterns, which could be used to guide the clinician and to benefit children, who frequently require encouragement in continuing what might appear to be a long and fruitless course of treatment.

Young et al.[13] stated that examining the patient's shoes for wear pattern might give clues about overpronation and oversupination. Shoes of overpronators showed more medial wear, whereas those of oversupinators showed a more lateral wear pattern. Based on this idea, footprints were used to determine whether subjects were oversupinators or overpronators. Supination allows foot

Table 7. Frequencies of Heel Bisecting Line Direction

Variable	No. (%)
Between great and 2nd toe	95 (8.67)
Toward 2nd toe	114 (10.40)
Between 2nd and 3rd toe	817 (74.54)
Toward 3rd toe	70 (6.39)

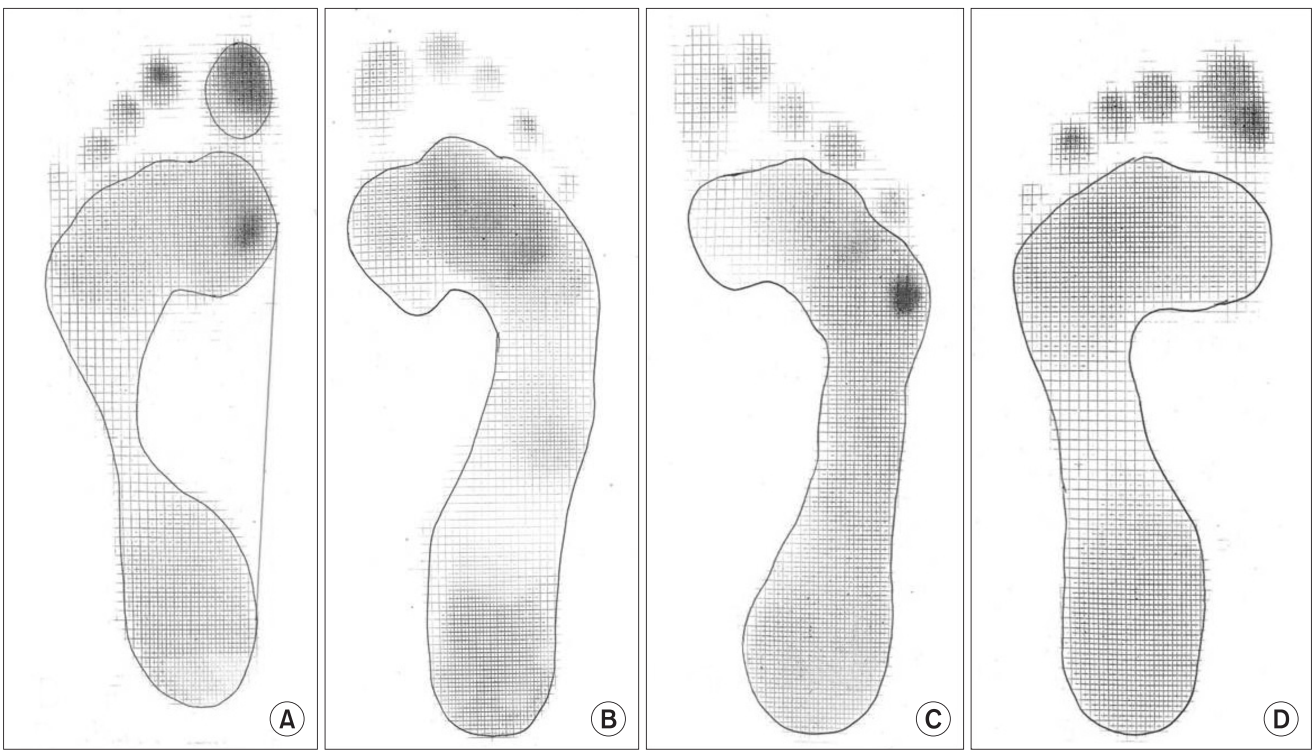

Fig. 8. Medial (A), middle (B), lateral (C), and even (D) dynamic forefoot pressure concentration.

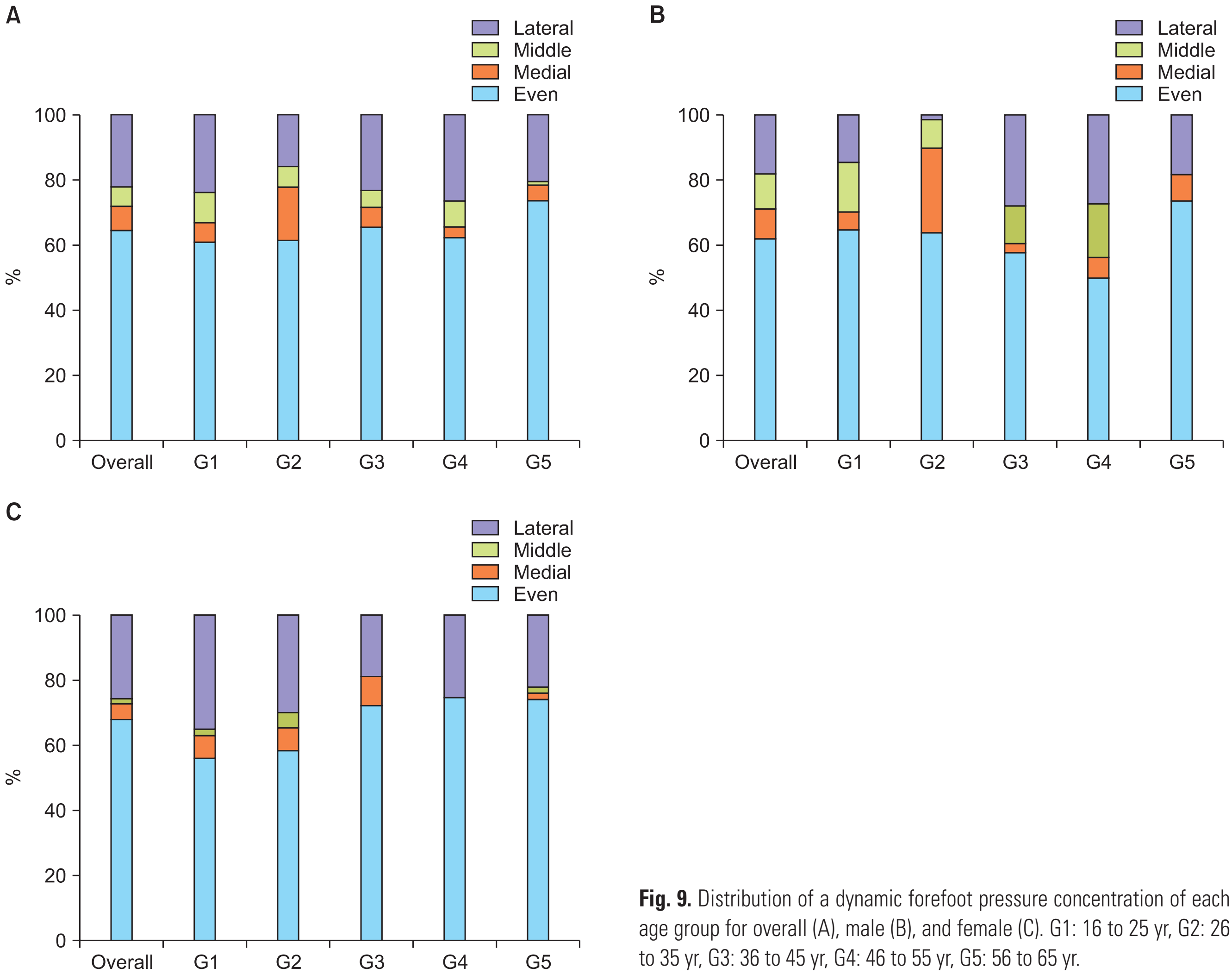

Fig. 9. Distribution of a dynamic forefoot pressure concentration of each age group for overall (A), male (B), and female (C). G1: 16 to 25 yr, G2: 26 to 35 yr, G3: 36 to 45 yr, G4: 46 to 55 yr, G5: 56 to 65 yr.

and ankle joints to move into a relatively closed packed or locked position, and gives the foot rigidity to transfer energy efficiently during ambulation. Pronation allows the foot and ankle complex to form a more flexible configuration to absorb shocks and adapt to the terrain.

According to results of dynamic footprints, 21.81% of the subject showed a dynamic forefoot pressure concentration on the lateral area without any sort of forefoot deformity, such as metatarsal adductus of abductus, indicating that their ankle joints tend to be mildly oversupinated. This ratio was higher than Welton[12] demonstrated in his study, finding that 15.8% of adults who had asymptomatic feet and no history of foot problems showed a dynamic forefoot pressure concentration on lateral side. These findings were in contrast to the results of Woodburn and Helliwell,[19] who found that highest peak pressures occurred over the central metatarsal heads, followed by a medial to lateral distribution in healthy adults with no history of organic disease likely to affect foot posture or gait, and who on examination, had no significant foot pathology, while in the rheumatoid valgus heel group, peak pressures followed a medial to lateral distribution in order of magnitude.

Although valgus heel alignment is thought to redistribute the load medially to the forefoot, altering the normally even pressure distribution pattern, no direct relation between the distribution of peak pressure and valgus heel alignment was found. Cavanagh et al.[20] concluded that, in normal subjects, only about 35% of the variance in dynamic plantar pressure could be explained by the measurements of foot structure derived from radiographs. This implies that the dynamics of gait likely exert major influences on plantar pressure during walking.

In conclusion, we found numerous parameters to reveal the secret behind the Maasai foot. However, because our current investigation consisted of a surface anatomy examination, further studies, including X-rays, and other comparative studies with other ethnic groups will be necessary.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Roberts S, Birch I, Otter S. Comparison of ankle and subtalar joint complex range of motion during barefoot walking and walking in Masai Barefoot Technology sandals. J Foot Ankle Res. 2011;4:1.
2. Nigg B, Hintzen S, Ferber R. Effect of an unstable shoe construction on lower extremity gait characteristics. Clin Biomech (Bristol, Avon). 2006;21(1):82-8.
3. Vernon T, Wheat J, Naik R, Pettit G. Changes in gait characteristics of a normal healthy population due to an unstable shoe construction. Sheffield: Sheffield Hallam University Centre for Sports and Exercise Science; 2004.
4. Buchecker M, Lindinger S, Pfusterschmied J, Muller E. Effects of age on lower extremity joint kinematics and kinetics during level walking with Masai barefoot technology shoes. Eur J Phys Rehabil Med. 2013;49(5):675-86.
5. Elveru RA, Rothstein JM, Lamb RL, Riddle DL. Methods for taking subtalar joint measurements: a clinical report. Phys Ther. 1988;68(5):678-82.
6. Michaud TC. Foot orthoses and other forms of conservative foot care. New York: Lippincott Williams & Wilkins; 1997.
7. Phillips RD, Christeck R, Phillips RL. Clinical measurement of the axis of the subtalar joint. J Am Podiatr Med Assoc. 1985;75(3):119-31.
8. Root ML, Orien WP, Weed JH. Clinical biomechanics. Vol. 2. Normal and abnormal function of the foot. Los Angeles: Clinical Biomechanics Co.; 1977.
9. Keenan AM, Bach TM. Clinicians' assessment of the hindfoot: a study of reliability. Foot Ankle Int. 2006;27(6):451-60.
10. Queen RM, Mall NA, Hardaker WM, Nunley JA 2nd. Describing the medial longitudinal arch using footprint indices and a clinical grading system. Foot Ankle Int. 2007;28(4):456-62.
11. Hawes MR, Nachbauer W, Sovak D, Nigg BM. Footprint parameters as a measure of arch height. Foot Ankle. 1992;13(1):22-6.
12. Welton EA. The Harris and Beath footprint: interpretation and clinical value. Foot Ankle. 1992;13(8):462-8.
13. Young CC, Niedfeldt MW, Morris GA, Eerkes KJ. Clinical examination of the foot and ankle. Prim Care. 2005;32(1):105-32.
14. Harris RI, Beath T. Hypermobile flat-foot with short tendo achillis. J Bone Joint Surg Am. 1948;30(1):116-40.
15. Biga N. Clinical examination of the foot and the ankle: data collection and interpretation of the pathogenic causal sequence of disorders. Orthop Traumatol Surg Res. 2009;95(4 Suppl 1):S41-8.
16. Murray MP, Drought AB, Kory RC. Walking patterns of normal men. J Bone Joint Surg Am. 1964;46(2):335-60.
17. Murray MP, Kory RC, Sepic SB. Walking patterns of normal women. Arch Phys Med Rehabil. 1970;51(11):637-50.
18. Silvino N, Evanski PM, Waugh TR. The Harris and Beath footprinting mat: diagnostic validity and clinical use. Clin Orthop Relat Res. 1980;(151):265-9.
19. Woodburn J, Helliwell PS. Relation between heel position and the distribution of forefoot plantar pressures and skin callosities in rheumatoid arthritis. Ann Rheum Dis. 1996;55(11):806-10.
20. Cavanagh PR, Morag E, Boulton AJ, Young MJ, Deffner KT, Pammer SE. The relationship of static foot structure to dynamic foot function. J Biomech. 1997;30(3):243-50.