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Population Differences in the Appearance of the Intermetatarsal Articular Facet of the First Metatarsal Bone

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Abstract Several studies have reported the incidence of the intermetatarsal articular facet, which is occasionally observed on the lateral side at the base of the first metatarsal bone, in some human populations. However, these reports did not provide the basic characteristics of the populations such as information on sex, age, laterality, and ethnicity. The purpose of this study is to investigate the incidence of this facet in several populations of different regions, eras, and ethnicity (European Americans, African Americans, modern Japanese, Kamakaura-period Japanese, Edo-period Japanese, and Jomon people) in order to determine the interpopulation, sexual, and left-right differences in this regard and to discuss the causative factors for its occurrence. The presence of this facet was confirmed in all the populations studied. Significant intergroup differences were observed among the European American, African American, and Japanese males and between the European American and Edo-period Japanese females. These results suggest that this facet can be regarded as an autapomorphic trait in humans and that it may be affected by ethnic differences among modern human populations.

Key words: Intermetatarsal articular facet, First metatarsal, Population difference, Laterality, Sexual dimorphism

Introduction

In humans, an intermetatarsal articular facet (IMTAF) is occasionally observed on the lateral side at the base of the first metatarsal bone (MT1) (Figure 1; Williams, 1995).

There are some different opinions with regard to what articulates with the base of MT1 on this articular facet. Fick (1904) inferred that a synovial bursa between the bases of MT1 and the second metatarsal bone (MT2) might be related to this facet. Grosshans and Meyer (1964) observed partial contact between the Lisfranc ligament (the tarsometatarsal ligament between the medial cuneiform and MT2) and the IMTAF of MT1 in embalmed feet. It is possible that the IMTAF of MT1 articulates with the os intermetatarseum, which is observed between the medial cuneiform and the bases of MT1 and MT2 in 0% to 14% of modern humans (Case *et al*., 1998). However, it appears reasonably probable that the base of MT1 directly articulates with that of MT2 due to the presence of articular cartilage on the intermetatarsal facets of both MT1 and MT2 in all cases of an IMTAF of MT1 (Grosshans and Meyer, 1964).

The presence of an IMTAF of MT1 is considered a derived or apomorphic trait, which appears to be unique to humans (Le Minor and Winter, 2003). This facet is observed in early hominids such as SKX5017 and OH8-H (Day and Napier, 1964; Susman and Brain, 1988). Trinkaus (1983) stated that it could frequently be observed in Neanderthals. According to the published reports (Pfitzner, 1896; Singh, 1960; Grosshans and Meyer, 1963; Le Minor and Winter, 2003), this articular facet can be observed in all samples, with an appearance rate ranging from 21.0% to 37.5%. In contrast, it is entirely absent in primates of 40 genera (Le Minor and

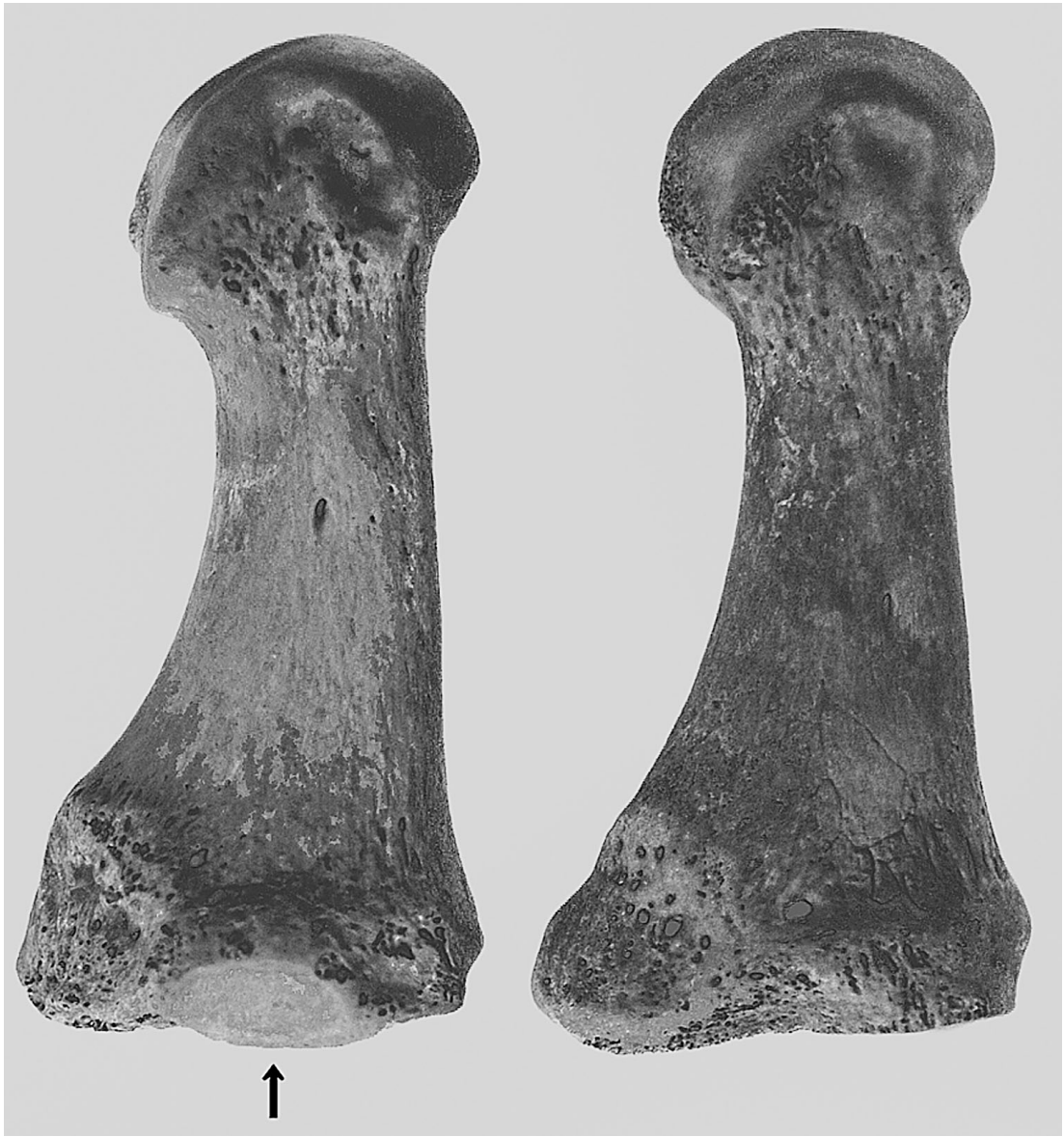

Fig. 1. Left first metatarsal bone.
The bone on the left has an intermetatarsal articular facet via which it is in contact with the second metatarsal bone; the right bone lacks this facet. The black arrow indicates the intermetatarsal articular facet.

Winter, 2003).

Fick (1904) considered the presence of the IMTAF of MT1 to be a pathological change induced by aging or by the use of hard and tight shoes. Le Minor and Winter (2003) concluded that phylogenetic and genetic factors appear to be predominant for the appearance of this facet because it was smooth and regular, exhibiting no pathological changes, and was observed in barefooted fossil hominids.

In previous studies, intra-/interpopulation variations have not been investigated in the appearance of the IMTAF of MT1 in modern humans. Further, no investigations on sexual and left-right

differences in its appearance have been published to date, except for the report by Le Minor and Winter (2003) that documented no significant left-right difference.

The purpose of this study is to examine the incidence of the IMTAF of MT1 in several human populations as European Americans, African Americans, modern Japanese, Edo-period Japanese, Kamakura-period Japanese, and Jomon people in order to compare this incidence among populations of different cultures, eras, and ethnicity; further, it aims to determine whether the IMTAF of MT1 can be stated as an autapomorphic trait that is predominantly affected by phylogenetic and genetic factors, as concluded by Le Minor and Winter (2003).

Materials and Methods

Table 1 describes the bone specimens analyzed in the present study. The incidence of the IMTAF of MT1 in European Americans and African Americans was examined using bone specimens housed at the Cleveland Museum of National History (Hamann-Todd collection) and the National Museum of Natural History, Smithsonian Institution (Terry collection). The incidence of the IMTAF in modern Japanese was examined using bone specimens of known age and sex collected from the 1880s to the 1950s; the specimens were stored at the University Museum at the University of Tokyo, the Kyoto University Museum, the Graduate School of Medicine at Chiba University, the Graduate School of Social and Cultural Studies at Kyushu University, and the Jikei University School of Medicine. All the Kamakura-period Japanese specimens used in this study were excavated at the Yuigahama site and were stored at St. Marianna University School of Medicine. The incidence of the IMTAF in the Edo-period Japanese was examined using skeletal remains stored at the National Museum of Nature and Science in Tokyo, while that in the Jomon people was examined using skeletal remains stored at the National Museum of Nature and Science as well as the University Museum, the University of Tokyo.

Table 1. Number of the specimens analyzed in the present study.

	male	female	total
Modern Japanese	50	43	93
Edo Japanese	88	46	134
Hatchoubori site	1	0	
Jitouin site	2	1	
Housenji site	2	2	
Higashikanda site	2	0	
Ennouji site	3	0	
Yushima3chyo-me site	7	1	
Syugyouji site	1	1	
Uwanokoukou site	1	1	
Haxtusyouji site	2	1	
Narihira site	1	0	
Ikenohata shichikencho site	59	35	
Hoxtushouji site	7	4	
Kamakura Japanese	29	13	42
Jomon	32	23	55
Ebishima site	6	6	
Hikozaki site	1	1	
Hobi site	3	3	
Ikawazu site	4	3	
Kasori site	1	0	
Ko site	2	1	
Mitsuzawa site	0	1	
Miyano site	1	0	
Nakazawahama site	3	1	
Numazu site	1	0	
Sanganji site	2	1	
Shijimizuka site	0	1	
Tsukumo site	1	1	
Ubayama site	6	3	
Yoyama site	1	1	
European American	50	50	100
African American	50	50	100
total	299	225	524

In all cases, the left and right first metatarsal bones were intact. Modern specimens of unknown age and sex were not included in this analysis. The upper age limit for the modern specimens was set at 50 years because a degenerative joint disease is observed to occur in 1–10% of US citizens under the age of 50 years and in 20–85% of those older than 50 years (Cotran *et al*., 1989). The age of the Kamakura, Edo, and Jomon specimens was estimated by evaluating the morphology of the pubic symphysis, costosternal ends of the ribs, and cranial sutures (Sakaue, 2006). Specimens whose age was estimated to be more than 50 years were excluded.

The sexes of these excavated specimens were determined based on the greater sciatic notch, angle of the inferior pubic ramus, and skull morphology. The present study analyzed a total of 524 specimens, comprising 299 males and 225 females.

According to Grosshans and Meyer (1963), the location and number of IMTAFs of MT1 are variable. In the present study, this facet was defined as an additional, smooth articular facet exhibiting a clear and continuous margin on the lateral side of the MT1 base.

A two-tailed Fisher's exact probability test was used to examine group-specific, sexual, and left-

Table 2. Number and incidence of the intermetatarsal articular facet in each group.

	Modern Japanese		Edo Japanese		Kamakura Japanese		Jomon		European American		African American	
	right	left	right	left	right	left	right	left	right	left	right	left
	% (N)	% (N)	% (N)	% (N)	% (N)	% (N)	% (N)	% (N)	% (N)	% (N)	% (N)	% (N)
male	2.0 (1)	4.0 (2)	5.7 (5)	10.2 (9)	3.4 (1)	3.4 (1)	6.3 (2)	15.6 (5)	36.0 (18)	46.0 (23)	20.0 (10)	26.0 (13)
female	9.3 (4)	16.3 (7)	2.2 (1)	6.5 (3)	7.7 (1)	7.7 (1)	8.7 (2)	13.0 (3)	16.0 (8)	32.0 (16)	10.0 (5)	20.0 (10)

"*" designates a significant difference between sexes at the 5% level. There is no significant difference between the incidences of the right and left side at the 5% level.

Table 3. The results of Fisher's exact probability test for intergroup differences.

male		Modern Japanese		Edo Japanese		Kamakura Japanese		Jomon		European American	
		r.	l.	r.	l.	r.	l.	r.	l.	r.	l.
Recent Japanese	r.										
	l.										
Edo Japanese	r.	0.417									
	l.		0.327								
Kamakura Japanese	r.	0.590		1.000							
	l.		1.000		0.502						
Jomon	r.	0.557		1.000		1.000					
	l.		0.104		0.520		0.228				
European American	r.	***0.000***		***0.000***		***0.000***		***0.003***			
	l.		***0.000***		***0.000***		***0.000***		***0.008***		
African American	r.	***0.004***		***0.020***		0.059		0.114		0.081	
	l.		***0.002***		***0.027***		***0.009***		0.412		***0.041***

female		Modern Japanese		Edo Japanese		Kamakura Japanese		Jomon		European American	
		r.	l.	r.	l.	r.	l.	r.	l.	r.	l.
Recent Japanese	r.										
	l.										
Edo Japanese	r.	0.193									
	l.		0.188								
Kamakura Japanese	r.	0.676		0.604							
	l.		0.156		1.000						
Jomon	r.	1.000		0.256		0.610					
	l.		1.000		0.393		0.337				
European American	r.	0.373		***0.032***		0.103		0.489			
	l.		0.095		***0.002***		***0.001***		0.150		
African American	r.	1.000		0.206		0.448		1.000		0.554	
	l.		0.789		0.074		0.059		0.734		0.182

Bold Italic: $p<0.05$

right differences, with the significance level set at the 5%. SYSTAT version 10.2 was used for all statistical analyses.

Results

The results are presented in Tables 2 and 3 and in Figure 2.

Table 2 and Figure 2 reveal that no significant right-left differences in incidence of the IMTAF of MT1, although the incidence was consistently higher on the left foot than on the right.

Table 2 also shows no significant sexual differences in the incidence of the IMTAF, except for the left side of the modern Japanese and the right side of the European Americans.

Table 3 shows the differences among the Japanese, European American, and African American males. The incidence of IMTAF of MT1 in both the right and left feet in European American males was significantly higher than the values in the other groups, except for the right in African American males ($p=0.081$). The incidence in African American males differed significantly from that in the modern and Edo Japanese males for both sides and from that in the Kamakura Japanese for the left side; however, it did not differ from the value in Jomon males at the 5% level. No significant inter-group difference was observed among the Japanese samples considered. The inter-group differences in females largely coincided with those in males, although statistically significant differences were observed only between the European Americans and the Edo and Kamakura Japanese.

Discussion

Le Minor and Winter (2003) investigated the incidence of the IMTAF of MT1 in primates and

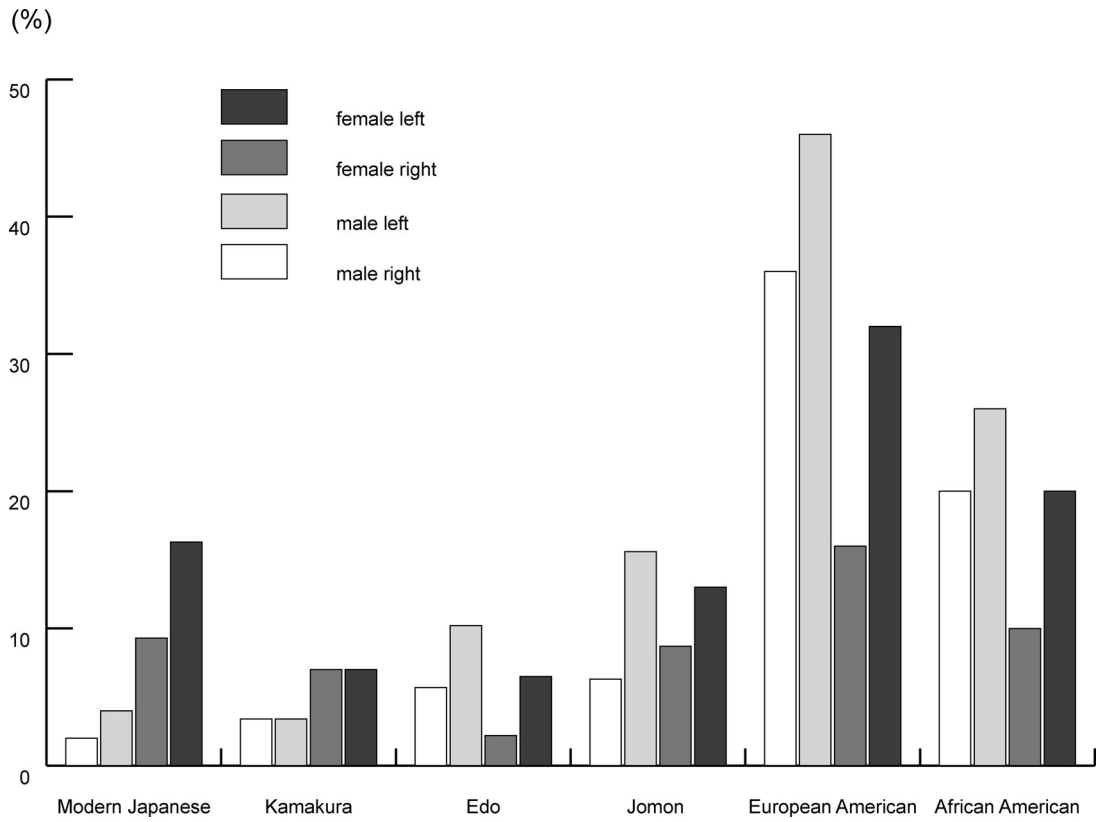

Fig. 2. Bar graph of the incidence of the intermetatarsal articular facet in each population.

humans; they found no cases of the IMTAF among nonhuman primates in contrast to 127 cases for 412 bones among humans. The results of the present study confirm the occurrence of the IMTAF in all groups used.

It has been recognized that the IMTAF of MT1 is associated with bipedalism in human evolution. This facet occurs in the cases where the MT1 lies close and parallel to the MT2 (Day and Napier, 1964). This structural position in the human foot indicates permanent adduction of the hallux, resulting in a lack of opposability (Trinkaus, 1983). However, if the IMTAF is predominantly associated with bipedalism, its incidence is expected to be relatively high and to show few interpopulation differences. Among early hominids, this facet was not observed in one australopithecine specimen (A.L.333-54) that was considered to exhibit permanent adduction of the first ray based on the morphology of the medial cuneiform and first metatarsal joint (Latimer *et al*., 1982; Latimer and Lovejoy, 1990). In Neanderthals, this facet was not observed in 4 of 7 cases (57.2%) (Trinkaus, 1983). In modern humans who have acquired bipedalism, the incidence of the IMTF observed in previous studies, ranging from 21.0% to 37.5%, and that observed in the present study, ranging from 2.0% to 46.0%, are not very high. Thus, the acquisition of bipedalism is probably a requirement but not the direct determining factor for the occurrence of this facet.

The level of physical activity on the feet probably dose not have significant influence on the appearance of the IMTAF of MT1. Some degree of dorsoplantar movement between MT1 and MT2 is probably possible at this articular facet (Le Minor and Winter, 2003). However, similar to the other IMTAFs, the movement at this facet would be limited to slight gliding because its articulating surface is flat and can be classified as a plane joint. The hallucal tarsometatarsal joint also exhibits slight motion of a few degrees in the transverse plane and slightly dorsomedial to the plantar-lateral direction in the sagittal plane, since the anterior articular surface of the medial cuneiform is slightly convex in the transverse plane and nearly flat in the vertical plane (Sarrafian, 1983). Thus, the magnitude of the movement at this facet is probably limited; this could explain its low incidence in the Jomon people, who must have been physically the most active of the groups considered in this study, since they were hunter-gatherers. Romash *et al*. (1990) researched the effectiveness of surgical treatment of hallux valgus and metatarsus primus varus, and they observed that the feet exhibiting the IMTAF of MT1 tend to be less mobile at the first tarsometatarsal joint than those lacking this facet. Thus, the IMTAF of MT1 appears to contribute to the stability of the first tarsometatarsal joint and to the rigidity of the metatarsal bone arrangement rather than to decrease the friction caused by slight gliding.

Funakoshi (1988) verified that the angle between the major axes of the MT1 and MT2 was significantly greater in the Jomon people than in the modern Japanese, and he considered this to be associated with lifestyle changes, such as the use of shoes, among the modern Japanese. Although this type of structural difference was observed in the foot skeleton, no significant difference in the incidence of the IMTAF was observed between the Japanese and the Jomon people in the present study. Thus, structural differences in the tarsometatarsal bone arrangement may not be a contributing factor to the appearance of this facet.

The present study suggests that the incidence of the IMTAF of MT1 may have been affected by ethnicity. Although European Americans and African Americans may have lived under similar conditions and adopted the western lifestyle, a significant difference was observed between these samples. There were distinctive differences among the Japanese samples in this study with regard to lifestyle: the modern Japanese had a partly westernized lifestyle; the Edo-period and Kamakura Japanese had a traditional Japanese lifestyle, and the Jomon people were hunter-gatherers. Nevertheless, the incidence of the IMTAF was lower in all the Japanese samples as com-

pared to both the American samples, and no significant difference was observed in this regard among the Japanese samples.

However, the intergroup differences in the incidence of the IMTAF at the base of MT1 were not as distinct among females as compared to males, and significant sexual differences were observed in its incidence between the Japanese and European Americans. The present study also revealed that the incidence of the IMTAF in the left MT1 tended to be higher than that in the right MT1 among all the samples studies, except the Kamakura Japanese, although this difference was not significant. Thus, the appearance of the IMTAF may be slightly influenced by sex and/or laterality.

Fick (1904) suggested that wearing tight shoes may be involved in the formation of the IMTAF of MT1. However, the effect of the type of shoes worn could not be ascertained for the samples examined in the present study. No information was available on whether the European Americans and African Americans in this study had habitually worn tight shoes. Further, there was no material evidence that the Jomon people in this study moved with barefoot. The modern Japanese individuals whose bone specimens were analyzed died between the latter half of the 19th century and the first half of the 20th century. It was not until the early part of the 20th century, i.e., until after the great Kanto earthquake in 1923, that the Japanese began to wear shoes regularly (Sato, 1971).

As suggested by Le Minor and Winter (2003), the IMTAF of MT1 can be regarded as an autapomorphic trait in humans. These researchers also concluded that phylogenetic and genetic factors may predominantly contribute to the appearance of this facet. The results of the present study suggest that the appearance of this facet may possibly be influenced by ethnic (including genetic, sexual, and cultural) differences among modern human populations. In order to confirm the influence of genetic factors on its appearance, it is necessary to investigate its frequency in many other human populations or its appearance in fetuses and infants.

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