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Bone mineral density of the metatarsal bones and the first ray in male sportsmen

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Abstract

Objectives: Measurement of bone mineral density (BMD) is used frequently for assessment of bone strength and prediction of fracture risk in clinical settings. Among the bones in feet, fractures are seen often in second and third metatarsal of active sportsmen. This study was carried out to evaluate the reasons of increased risk of stress fractures in feet of active sportsmen by determining the BMD in overused regions.

Methods: Two groups were examined in the present study. First group included males who were not sportsmen while the second and third groups were formed by professional male soccer and basketball players respectively. Areal bone density was measured by dual energy x-ray absorptiometry and the BMD values were calculated by using the rectangular region of interest in metatarsals.

Results: The first metatarsal had the highest BMD in all groups ($P<0.05$). The fifth metatarsal had the second highest BMD value. Similarly subchondral measurement of the BMD revealed that the first tarsometatarsal joint were significantly denser than the first metatarsophalangeal joint ($P<0.05$). BMDs of all metatarsals in non-sportsmen group were significantly lower than BMDs of sportsmen groups and there were no noticable differences of BMD between soccer and basketball players.

Conclusion: Because the degree of activity–induced enhancement of bone mineralization were similar in all metatarsals of active sportsmen, increased incidence of fractures in second and third metatarsals must be partly due to anatomical positioning of these bones. Hence appropriate shoe designs which have support for second and third metatarsals may decrease fracture incidence.

Key words: bone mineral density; metatarsal bones; sportsmen

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Introduction

Measurement of bone density is used frequently in the assessment of bone strength in both clinical and research settings.[1,2] Structural strength and stiffness depend upon the bone density and bone geometry and that bone density is also a good predictor of fracture risk as well as in load at failure in biomechanical testing. The dual energy x-ray absorptiometry (DXA), that typically gives information about bone mass on a projected area and the BMD, has been a useful technique for the evaluation of fracture risk via bone density and bone strength. Additionally, strong correlations between the BMD and bone strength can be found in several DXA studies.[3,4]

Potential causes of the stress fractures include a mechanical loading with excessive intensity or frequency, anthropometric factors like step length or foot type, muscle fatigue, bone health and exercise properties, such as duration or frequency of training.[5-8] Stress fractures of the metatarsal bones are frequently reported overload injuries in long distance runners and are considered to be a result of a multi-factorial process.[9] Most studies are focused on the second and the fifth metatarsal bones because they are prone to both fracture and stress fracture in active sportsmen.[10,11] Furthermore all these studies were performed either in dry bones or cadavers.[12-14]

The resistance of other metatarsal bones to fracture might be due to differences in BMDs of these bones. To the best of our knowledge, there is no study examining the changes in BMDs of the metatarsal bones in healthy subjects. Hence the goal of our study was to examine the changes in metatarsal bones of active sportsmen which may further clarify the reasons leading to fractures in second and third metatarsal bones in active sportsmen. We, here, specifically determined the BMDs of all metatarsal bones and the BMDs of first ray (the bone structures, I. tarsometatarsal [TMT] and I. metatarsophalangeal [MTP] joint of the medial part of the foot) due to their important biomechanical functions.

Materials and Methods

Subjects

Two groups were examined in this study. The control subjects were 18 male students who had not done any sports regularly. The sportsmen groups were consisted of 20 professional soccer and 17 basketball players (**Table 1**). All the subjects were meticulously examined by a physiatrist. None of them had joint problems and had undergone an orthopedic surgery, and they had not used any drugs affecting bone metabolism. The study was approved by the Ethical Committee of the Medical Faculty, University of Akdeniz. All the participants were volunteers (≥ 18 years old) and had given a written consent.

Table 1
Physical characteristics (mean ± SD)

	Active sports group		Non-sportsmen
Parameter	Soccer (n=20)	Basketball (n=17)	(n=18)
Age (years)	18.91 ± 0.70	19.12 ± 0.99	19 ± 0.49
Weight (kg)	70.95 ± 6.67	80.65 ± 9.51	67.33 ± 5.98
Height (cm)	178.3 ± 4.91	187.94 ± 7.40	177.22 ± 6.62
BMI (kg/m^2)	22.30 ± 1.78	22.77 ± 1.87	21.48 ± 2.13

BMI: body mass index.

DXA measurement

Areal bone density was measured using a DXA instrument (Norland XR36, Norland Medical Systems, Fort Atkinson, MI, USA). Imaging of both feet was acquired in research mode at sitting position. The total density of right and left feet was calculated by using whole foot area. The standardized regions of interest (ROI) method were used for the assessment of BMDs in metatarsal bones, the first TMT and the first MTP joints. A rectangular shaped ROI was chosen in the trabecular bone region of each metatarsal bone. Additionally, ROI was chosen in the subchondral bone layer of the distal part of the medial cuneiform (DP MC), first metatarsal base (MTB), first metatarsal head (MTH), and proximal phalanx base (PPB) (**Figure 1**). BMD values in these areas are used as g/cm^2 in statistical analysis. Data of both groups were analyzed and compared by the SPSS 13.0 production facility. BMDs of the right first, third, fourth metatarsal bones, left second metatarsal bones and left whole foot were compared with the One Way Anova of the Parametric tests.

BMDs of the right foot's second and fifth metatarsal bones, left foot's first, third, fourth and fifth metatarsal bones, and the BMDs of whole right foot were tested with Mann Whitney Nonparametric Test. The differences among the groups were determined by using Tukey's HSD from Post Hoc tests.

Subchondral BMDs of MTH were compared with the One Way Anova of the Parametric tests. Subchondral BMDs of DP MC, MTB, PPB were tested with Kruskal-Wallis of the nonparametric test. In addi-

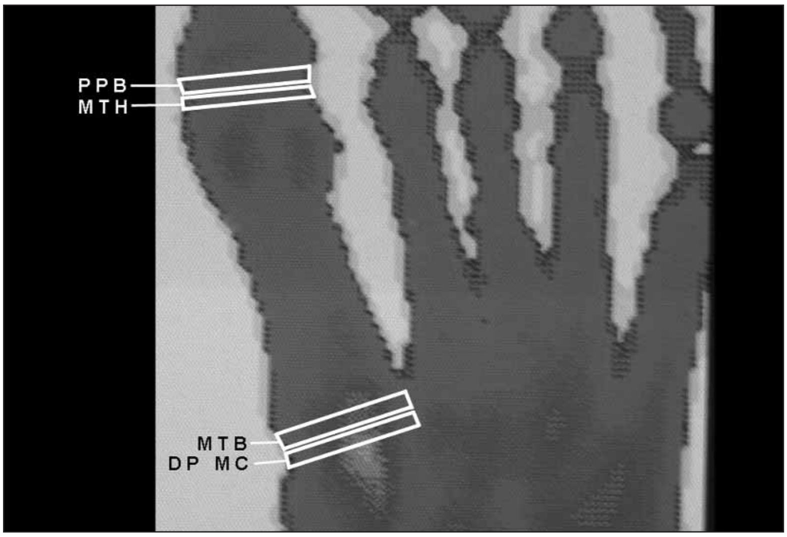

Figure 1. Subchondral bone mineral densities (BMDs) of the first tarsometatarsal (TMT) and metatarsophalangeal (MTP) joints (Soccer, right foot, 18-year-old male, height 178 cm, weight 73 kg). **DP MC:** distal part of the medial cuneiform; **MTB:** metatarsal base; **MTH:** metatarsal head; **PPB:** proximal phalanx base.

tion, we used the Mann-Whitney test to find out the group which causes the difference. P values less than 0.05 were considered as significant.

Results

Physical characteristics of groups were shown in **Table 1.** The body weights of basketball players were significantly higher than control group which may affect the BMD values. We specifically examined the possible correlation between the body weights and BMD values within the groups. We could not find a significant correlation between the body weight and BMD values in our study groups.

As seen in **Table 2**, the BMDs were significantly lower in the non-sportsmen group than the active sports group. However, there were no significant differences between the soccer and basketball players. The BMDs of the whole foot (of left & right) showed no significant dif-

Table 2
Bone mineral densities of the metatarsal bones and the feet
(R: right; L: left; BMD: bone mineral density) (mean ± SD and range-g/cm^2)

	Active sports group					
Variable	**Soccer (n=20)**		**Basketball (n=18)**		**Non-sportsmen (n=18)**	
BMD g/cm^2	**Mean ± SD**	**Extremes**	**Mean ± SD**	**Extremes**	**Mean ± SD**	**Extremes**
Right foot (Whole)	0.665±0.127	0.49-0.98	0.678±0.096	0.46-0.85	0.491±0.054	0.42-0.61
1st metatarsal bone (R)	0.606±0.081	0.50-0.76	0.653±0.075	0.46-0.78	0.480±0.068	0.39-0.59
2nd metatarsal bone (R)	0.478±0.103	0.32-0.71	0.522±0.109	0.40-0.90	0.363±0.042	0.29-0.43
3rd metatarsal bone (R)	0.490±0.109	0.33-0.73	0.507±0.041	0.41-0.58	0.383±0.049	0.30-0.44
4th metatarsal bone (R)	0.515±0.119	0.37-0.77	0.502±0.051	0.37-0.58	0.384±0.049	0.30-0.47
5th metatarsal bone (R)	0.541±0.093	0.41-0.70	0.525±0.067	0.38-0.64	0.396±0.059	0.31-0.47
Left foot (Whole)	**0.660±0.124**	**0.50-0.97**	**0.676±0.096**	**0.46-0.86**	**0.492±0.057**	**0.41-0.61**
1st metatarsal bone (L)	0.614±0.088	0.48-0.77	0.640±0.066	0.47-0.73	0.476±0.061	0.40-0.56
2nd metatarsal bone (L)	0.465±0.105	0.31-0.71	0.480±0.058	0.38-0.59	0.356±0.041	0.29-0.43
3rd metatarsal bone (L)	0.470±0.118	0.36-0.79	0.471±0.051	0.38-0.55	0.347±0.049	0.29-0.43
4th metatarsal bone (L)	0.497±0.128	0.33-0.89	0.491±0.063	0.36-0.60	0.375±0.052	0.30-0.47
5th metatarsal bone (L)	0.530±0.114	0.40-0.80	0.542±0.079	0.38-0.68	0.415±0.069	0.32-0.50

ferences. In sportsmen group, the densities of the first metatarsal bones were higher than the other metatarsal bones in both feet (P<0.05). In soccer players the fifth metatarsal bone was significantly denser than the second and the third metatarsal bones (P<0.05). On the other hand, in basketball players there were no significant differences among the BMDs of the second, third, fourth and fifth metatarsal bones (P>0.05). In the control group, the BMDs of the first metatarsal bones had the highest values and the second and the third metatarsal bones had the lowest BMDs values (P<0.05). The coefficient of variation (CV) value for BMD was estimated to be 6.9% for each metatarsal bone.

As seen in **Table 3**, the subchondral BMDs of the first TMT joint was significantly higher than the BMDs of the first MTP joint in all groups (P<0.05). The subchondral BMDs decreased from the proximal part towards to the distal part in all TMT and MTP joint surfaces. A dramatic decrease was observed in the BMDs of soccer group (P<0.05), however no significant differences between basketball and non-sportsmen groups were identified (P>0.05). Subchondral BMDs of the DP MC, the first MTB, the first MTH and the first PPB were compared in all groups. BMDs of the non-sportsmen groups were significantly lower than those of soccer and basketball players. DP MC was significantly higher in basketball players (P<0.05) and there were no significant differences in between the soccer and basketball players except the subchondral BMDs of the DP MC.

Discussion

In this study, we aimed to investigate the BMDs of all metatarsal bones and the effects of two types of physical activity (soccer and basketball) on the BMD values which may explain selective vulnerability of second and third metatarsal bones to fracture. We, here, specifically examined metatarsal bone density as well as first ray including joint area (TMT and MTP).

The subchondral density has been studied in various bones including joints such as hip, knee, elbow, wrist and ankle.[15-18] To our knowledge, there is no study examining the changes in metatarsal bones in healthy subjects as well as active sportsmen. There are few studies which measured the BMD values in dry bones or cadavers.[12-14]

The relationships among the bone density, mechanical properties of the bone and the fracture risk have been reported.[13] However, physical activity, nutrition, lifestyle and other environmental factors are also important determinants of the potential peak BMD.[4,12,19]

Table 3

Subchondral bone mineral densities (g/cm^2) of the first tarsometatarsal (TMT) and first metatarsophalangeal (MTP) joints in all groups (mean ± SD and range-g/cm^2)

Variable	Active sports group					
	Soccer (n=20)		Basketball (n=18)		Non-sportsmen (n=18)	
BMD g/cm^2	Mean ± SD	Extremes	Mean ± SD	Extremes	Mean ± SD	Extremes
Right first TMT joint						
DP MC (Distal part of the medial cuneiform)	0.873±0.080	0.74-0.99	0.910±0.139	0.43-0.99	0.708±0.109	0.58-0.87
MTB (metatarsal base)	0.856±0.088	0.71-0.99	0.891±0.132	0.46-0.99	0.644±0.109	0.54-0.81
Right first MTP joint						
MTH (metatarsal head)	0.586±0.107	0.42-0.79	0.575±0.102	0.34-0.79	0.463±0.048	0.37-0.54
PPB (proximal phalanx base)	0.516±0.091	0.35-0.69	0.545±0.093	0.35-0.69	0.431±0.079	0.35-0.59
Left first TMT joint						
DP MC (Distal part of the medial cuneiform)	0.872±0.098	0.70-0.99	0.930±0.097	0.62-0.99	0.684±0.084	0.60-0.87
MTB (metatarsal base)	0.842±0.095	0.67-0.99	0.928±0.092	0.63-0.99	0.668±0.094	0.52-0.81
Left first MTP joint						
MTH (metatarsal head)	0.586±0.089	0.45-0.78	0.553±0.072	0.37-0.69	0.462±0.056	0.40-0.58
PPB (proximal phalanx base)	0.512±0.099	0.34-0.72	0.507±0.082	0.36-0.65	0.435±0.059	0.35-0.55

BMDs of second and the fifth metatarsal bones were examined in previous studies performed in dry bones or cadavers, because they are prone to both fracture and stress fracture.[19] Courtney et al.[1] reported that the average load at failure for the second metatarsal bone was higher than the third, but the authors did not carry out a statistical comparison. The load at failure was significantly greater for the first metatarsal bone than the others.[2]

Increases of bone mass in the whole body, lumbar spine, hip, trochanter, leg and forearm have been observed in sportsmen.[20-26] A cumulative effect on the skeleton may have occurred in soccer and basketball players because of their sports history of school years.[20] Despite of it increased fractures in second and third metatarsal bones is observed in active sportsmen[27-29] which may be caused by insufficient mineralization of these bones compared to other metatarsal bones. This possibility was searched in this study. The BMDs of the first metatarsal bone in both feet were higher than that of the other metatarsal bones ($P<0.05$) in all groups. Similarly, in all three groups the subchondral BMDs decreased from the proximal towards the distal part (TMT and MTP joints) demonstrating normal structure of foot. We here also demonstrated that the BMD values of the metatarsal bones and the whole foot were significantly higher in male sportsmen compared with the controls. Between basketball and soccer players, there was no significant difference.

The BMD values for the fracture prone metatarsal bones e.g. second and third, were decreased significantly only in control group. Although the BMD values for second and third metatarsal bones were slightly lower than the rest in active sportsmen, similar degree of enhancement in BMD values were detected in these bones. Hence increased fracture incidence in second and third metatarsal bones may not be solely due to inefficient mineralization of these bones. Other possibilities must be considered.

These possibilities may include factors such as foot type, foot position, type of shoes, walking habits and sports activities which may have impacts on stability of metatarsal bones leading cracks.[20,30] Anatomically first ray of second and third bone do not contact the surface as strongly as the remaining metatarsals which may lead micro fractures during excessive exercise. Hence appropriate shoe design may prevent these fractures.

Conclusion

This study has demonstrated that the BMDs of all metatarsal bones, whole foot and the TMT and MTP joints of sportsmen were higher than the non-sportsmen. Because the degree of activity induced enhancement of bone mineralization were similar in all metatarsal bones of active sportsmen, increased incidence of fractures in second and third metatarsal bones must be partly due to anatomical positioning of these bones. Hence appropriate shoe designs which have support for second and third metatarsal bones may decrease fracture incidence in sportsmen.

Our results also documented weaker parts of the foot region, which may help to gain a better insight to improve different shoe types to support the lower regions.

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