

A three dimensional reconstructive study of tarsal bones of ballerinas and sedentary females using MDCT images

HaticeCatal Reis¹, Ozsen Corumluoglu²

¹Department of Geometrics, Faculty of CivilEngineering, Yildiz Technical University, DavutpasaCampus, 34220, Esenler, Istanbul, Turkey, Email: hatice.catal@yahoo.com.tr

²Department of Geometrics, Faculty of Engineering, University of KatipCelebi, Izmir, Turkey, Email: ocorumlu@hotmail.com

¹Corresponding Author

Abstract

*In this research, it has been studied peculiarities in feet **tarsal** bones of elite female ballet dancers if there has been any disorder and change developed in those **tarsal** bones during their ballet practice and their professional ballet life. To find out that, cuneiform 1, 2, 3, navicular, cuboid, calcaneus bones of tarsal joint were compared with those of sedentary females on the basis of biometric ratios of these bones in length, surface area and volume by means of three-dimensional (3D) reconstruction using 2D multidetector computed tomography (MDCT) images. For this purpose, the axial images of the right and left feet of 5 elite female ballerinas (their date of birth is 1992, their mean weight is 49.2 ± 1.2 kg, mean tall of the group is 166.8 ± 6.2 cm and mean shoes number of them is 37.2 ± 1.2) and 5 sedentary females (their date of birth is 1992, their mean weight is 50.4 ± 3.6 kg, mean tall of the group is 163 ± 10 cm and mean shoes number of them is 36.8 ± 1.2) were obtained by MDCT. Stack of these 2D images were then transferred to a personal computer to form 3D model of each **tarsal** bone in one layer specially arranged for that bone. Length, surface area and volumetric measurements were then done interactively and manually on those 3D models.*

*This study showed that the differences between biometric ratios of ballerinas and sedentary females' **tarsal** bones were significantly contrary to null hypothesis which was established as there is no difference between biometric ankle bone ratios of these females of both groups. Therefore null hypothesis was rejected. Authors suggest that intense whirling action on toe practiced in ballet dance can most probably lead to some **tarsal** bone proliferations in both feet especially in left foot of ballerinas. 3D reconstructed results belonging to the ballerinas and sedentary females help orthopedists to diagnose pathological formations and deteriorations related to tarsal bones of ballerinas and may be used for anatomical education in medicine faculties, respectively.*

We hope that the results from the biometric and reconstructive techniques carried out in this work will contribute to the present knowledge on ballet education given in ballet dance courses and shed light onto the future medical studies related to skeletal structure of foot under abnormal and long term pressure.

Key words: Three-DimensionalReconstruction, Ankle, Ballerina, Image Processing, Morphometry, Bone, MDCT.

1. INTRODUCTION

Ballet as one of the important theater art is a show including an academic dance technique combined with other art of dancing figures and performed in a theater [URL 1]. Human body is used as a machine in a ballet dance. Feet are the most important machine parts in this art group. Excellent balance and coordination are important for classical ballet dancers, and postural stability requires adequate proprioception from the tarsal joint. Ballerinas performing this extreme dance of art figures are generally suffered by unintentional feet accidents. In such injury and disability cases, diagnose and treatment become important issues for ballerinas' health and for the rest of their professional dance life (Howse and Hancock 1988). True diagnose and treatment decisions must therefore be given and necessary operations must be performed immediately and rapidly. Wrong diagnoses and treatments always carry risks that can end ballerinas dance life. It is predicted that the outcomes from this study as biometric ratios and statistical analyses will provide a good platform and reference by contributing and enlightening the existing knowledge on ballet art and related medical problems in the chain of diagnose and treatment.

There are few studies on ballerina's feet bone disorder in the literature. In the first case study, it is seen that for depicting a stress fracture of great toe sesamoid bone, film radiography, nuclear bone imaging, and CT were used. This was the first to report using MR imaging on that bone of ballerinas (Burton and Amaker 1994). In another research, several Turkish female ballet dancers and sedentary female of comparable age and body mass index were studied (Kilicarslan et al. 2007). The outcome measure from this study was the bone mass. Ballet dancers have got many problems, this study aim is injuries of the foot, ankle, knee, back, hip and their treatment (Anthony, et al. 1972). Anterior ankle impingement in a ballet dancer (Heim et al. 1998). In other research, it was stated that ballet dancers as athletes were susceptible to ligamentous and bony injury. They reviewed retrospectively the bone scans (technetium-99m methylene diphosphonate) of several ballet dancers with pain in the back and/or lower extremities to determine the usefulness of scintigraphy in the detection of stress lesions of bone. They found out that stress fractures were most prevalent in the feet, and stress reactions were most prevalent in the tibiae. The study confirmed that ballet dancers sustain significant bone stress in their legs and feet. Their results showed that scintigraphy can be used to detect stress fractures and stress reactions at both symptomatic and asymptomatic sites in their population (Nussbaum et al. 1988). This study was to compare ballet dancers' and non-dancers' joint coordination during standing (Tanabe et al. 2014). From these studies above, one can easily reach a conclusion such as that ballet dancers have a great risk of bone injury on their feet. But none of them indicate which part or parts of which foot have this risk more than others and in what extent. To find out that, first of all we constructed digital 3D models from 2D Multidetector Computerized Tomography (MDCT) images of several female ballet dancers and female controls. Following that, volume, surface area and length measurements were collected for each bone of ballerinas' ankle on these digital 3D models. This is going to be the first record putting forward the biometric measures on ballerinas' tarsal bones using digital 3D models constructed from 2D MDCT images, even if one study similar to this one is recorded so far. But it was about hand bones of elite male judo players (Kalayci 2008). In this study, statistical differences between feet ankle bones of ballerinas and sedentary females were computed and analyzed by using these 3D models.

2. METHODS

In this research, ankle bones (cuneiform 1, 2, 3, navicular, cuboids, and calcaneus) of female ballet dancers and sedentary females were studied. Anatomical structures of tarsal bones of ballerinas and sedentary females significantly differ, even though their ankle bones' surface area, volume and length differentiate from one group to another and also right foot to left foot of same person. Therefore, statistical and biometrical measurements were carefully conducted for both feet.

Before starting to the study here, for not putting the volunteers' health under risk and for given great care and consideration, all the regulations, procedures and standards were followed carefully regarding the Ethical Commission Agreement of Konya Clinical Researches' Ethical Commission of Health Ministry (with decision number of 004, and date of 01.08.2010) (Catal 2010).

Volunteers were chosen among ballerinas and healthy sedentary females with no orthopedic injury background. Part time dancers and sportswomen were excluded from this research. Thus, only full time professional female ballet dancers were picked up. Therefore it was not easy to find many female ballet dancers who can meet these criteria. Finally we found five ballerinas to build up our ballerina test group and then five female for sedentary group as well. 2D MDCT axial images of female ballet dancers' and controls' ankles in the test groups were then scanned. Following that, 3D models of each female's right and left tarsal bones in both groups were reconstructed by these MDCT axial images. Ballerinas who formed a special population were born in 1992, their average foot size was 37.2 ± 1.2 , their average tall was 166.8 ± 6.2 cm, and their average weight was 49.2 ± 1.2 kg. These features of ballerinas became directing criteria on the choose of sedentary control females. So that, sedentary females chosen were again born in 1992, their average foot size was 36.8 ± 1.2 , their average tall was 163 ± 10 cm, and their average weight was 50.4 ± 3.6 kg. Images were collected from two MDCT imaging centers. They are Ankara Ataturk Education and Research Hospital and Selcuk University's Selcuklu Medical Faculty. The procedure accepted at Helsinki Declaration (Goodyear et al. 2007) and Regulations of Computed Tomography Usage of Turkish Radiology Association (URL2) were followed in the scanning processes carried out in this research.

During the scanning process of the feet, scanning parameters were adjusted to $64 \times 0,5$ mm as physical detector collimation and $4 \times 0,5$ mm as resulting section collimation, scanning thickness of 0,5 mm, mA 100, kV 120, pixel sizes of 512×512 in radiometric resolution of 16 bits' gray levels. A great and prior consideration was given to the volunteers' health in this study under the professional radiologists' guidance while assigning scanning parameters and dosage. Furthermore, dosage lowering parameters were also applied as well. Images scanned axially were saved in a personal computer which 3D Doctor (3D modeling) software was installed, in DICOM format.

Feet belonging to both groups were scanned putting them side by side. Imaging and scanning parameters were chosen the same for all scanning processes. Volunteer feet were tied up to scanner's table to improve MDCT image accuracy during the scanning process (Catal 2010). A higher resolution MDCT device was used (Toshiba Aquillon, America Medical Systems).

Since tissues and other bones which are not subject to this study must be separated from the ankle bones to be studied, it is therefore required MDCT image pixels have to be classified. Once the classification is performed, classified region is separated from others. Gray layers are then assigned to each region (Dogan and Altan 2003). During interactive segmentation process, gray pixel values which describe ankle bones can

be chosen by assigning pixels with higher and lower gray values appearing in the ankle region of each MDCT image by a sliding bar in the software. Since the same machine was used and the same technical features were adjusted in the scanning process for every volunteers, higher and lower sliding bar values were kept the same for all volunteers. After segmentation, errors seen in each slides were corrected manually by mouse. By that, a boundary polygon was drawn around the edges of ankle bone appearing in each slide (Figure 1).

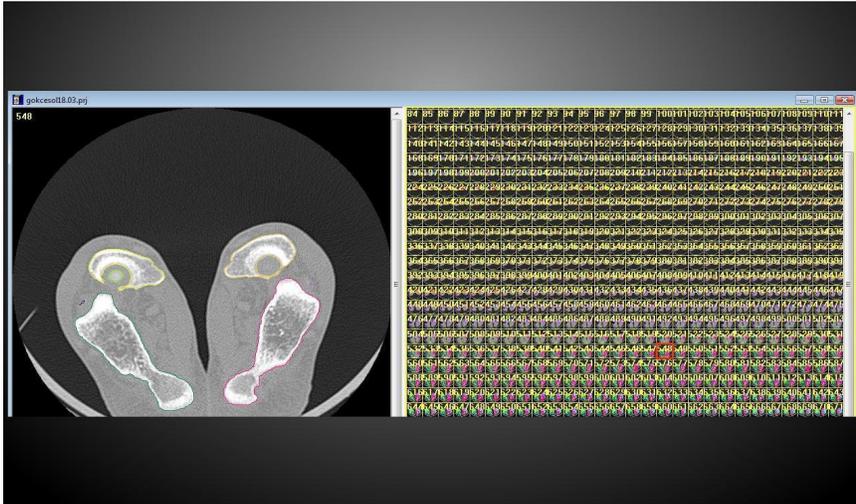


Figure 1. Two-dimensional outlines drawn on MDCT image slides.

Since it is used manual and interactive segmentation processes, it is called as semi-automatic segmentation (Kalayci 2008). Segmentation for each slide was averagely finished in 3-4 minutes. Figure 1 shows the semi-automatic segmentation process on one slide in the left window and all other slides used in one project (here it is ankle project) in the right window. After all, all corrected boundaries of ankle bones in each slide were stacked and overlaid to reconstruct a 3D model of bones by 3D rendering component of the software (Figure 2).

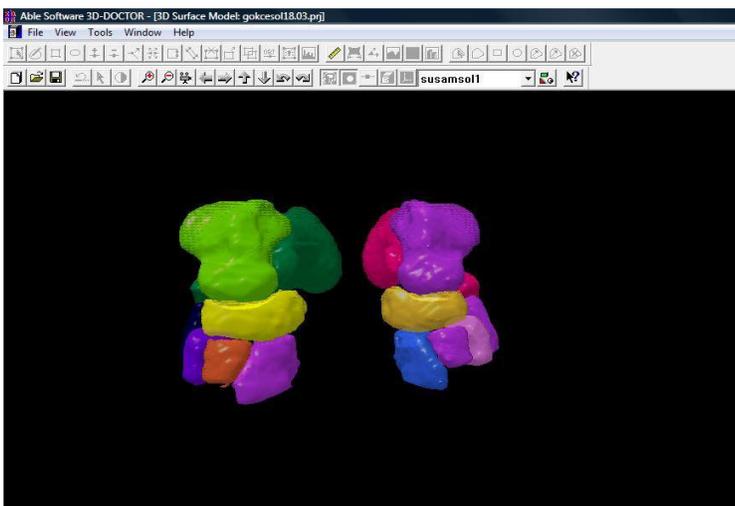


Figure 2. 3D reconstructed images of tarsal bones in both feet of a ballerina.

After constructing 3D models of tarsal bones, volume, length and surface area values of each ankle bone for every volunteer were obtained on those 3D models. Bone ratios for all those values were then individually computed with respect to each ankle bone against to others in left and right feet of each volunteer. For statistical analyze, statistical values were obtained using Microsoft Office Excell 2007 and a web based Statistic textbook (StatSoft 2010) were utilized. Significance value of $P < 0,05$ was tested for each bone values by applying t test. Percentage rate (MV) and standard error (SEM) values were given for volumes, surface areas and lengths in the tables below. The cells including values within $p < 0,05$ confidence were not signed by a symbol (*). B.V-Ratio, B.A-Ratio and B.L-Ratios indicate volume, surface area and length ratios for ballerinas respectively. S.V-Ratio, S.A-Ratio and S.L-Ratios indicate volume, surface area and length ratios for sedentary control females respectively.

3. RESULTS AND CONCLUSIONS

Table 1. Parameters of tarsal bones belonging to right foot of ballerinas and sedentary females. Data expressed as the mean (\pm SEM). (MV stands for mean value).

Right tarsal bones	B.V-Ratio (%)		S-V. Ratio (%)		B.A- Ratio (%)		S-A Ratio (%)		B.L- Ratio (%)		S.L- Ratio (%)	
	MV	SEM	MV	SEM	MV	SEM	MV	SEM	MV	SEM	MV	SEM
Cuneiform-1	7,36	0,81	7,32	0,12	8,79*	0,48	7,16*	0,46	12,6	0,22	13,38	1,14
Navicular	7,63	0,63	7,56	0,42	9,20	0,87	9,99	0,96	8,29*	0,21	9,594*	0,62
Talus	24,73	0,64	26,5	1,37	20,89	1,45	19,21	2,31	14,2	1,49	13,99	0,15
Cuneiform-2	2,75	0,16	2,74	0,24	4,41	0,36	4,13	0,38	9,52	0,6	9,01	0,42
Cuneiform-3	3,63	0,2	3,24	0,21	5,93	0,55	5,49	0,43	12,12	0,84	11,53	0,57
Cuboid	7,83	0,27	7,02	0,99	13,33	2,28	11,64	1,18	15,65	0,82	15,4	0,67
Calcaneus	46,08	1,53	45,61	1,55	37,44	2,3	42,38	5,33	27,61	1,04	27,09	0,45

* means that differences among the means of different groups in the same row are statistically significant in value of $p < 0.05$. Ratios were analyzed by t test.

Table 1. Parameters of tarsal bones belonging to left foot of ballerinas and sedentary females. Data expressed as the mean (\pm SEM). (MV stands for mean value).

Left tarsal bones	B.V- Ratio (%)		S-V. Ratio (%)		B.A- Ratio (%)		S-A Ratio (%)		B.L- Ratio (%)		S.L- Ratio (%)	
	MV	SEM	MV	SEM	MV	SEM	MV	SEM	MV	SEM	MV	SEM
Cuneiform-1	7,26	0,8	7,41	0,31	8,88*	0,91	6,66*	0,73	12,6	0,52	13,72	1,31
Navicular	7,37	0,78	7,36	0,24	10,49*	0,33	8,38*	1,04	8,3	0,08	9,48	0,72
Talus	24,91*	0,9	27,31*	0,79	21,13*	1	17,08*	0,87	14,3	1,48	13,47	0,73
Cuneiform-2	2,75	0,11	2,84	0,16	4,52	0,45	3,74	0,27	9,63	0,69	9,16	0,57
Cuneiform-3	3,57*	0,13	3,07*	0,15	6,1	0,63	4,95	0,22	12,18	0,92	11,87	0,38
Cuboid	8,52*	0,21	6,32*	0,72	11,62	1,54	11,73	1,09	15,54	0,73	14,54	0,83
Calcaneus	45,35	1,51	45,67	1,12	36,75*	1,46	47,47*	2,97	27,43	0,76	27,76	0,41

* means that differences among the means of different groups in the same row are statistically significant in value of $p < 0.05$. Ratios were analyzed by t test.

Since each bone shows different volume, surface area and length from one individual's body to another, mean values for the bones were not computed and recorded. Instead of mean values for ankle bones, bone ratios with respect to one bone to another one in the same foot were calculated. Therefore all bones in an ankle area such as cuneiform 1, 2, 3, navicular, talus, cuboids, calcaneus bones were given in ratio comparison form. Moreover, statistically important differences established at $p < 0.05$ were interpreted in terms of ratios between the ankle bones of each foot in both groups (refer to Tables 1 and 2).

Based on the data obtained from 3D reconstructed images, all the ratios of volume, surface area and length values of the right and left ankle bones of ballerinas and control females were shown in the tables 1 and 2 in detail. Values in some cells of above tables marked by * indicate that statistically significant deviations appeared at the relevant bones as outcomes from t test done.

Results in these tables represent statistical differences in the bones; cuneiform 1 in terms of surface area ratio and navicular in terms of length ratio for right foot ankle of female ballet dancer. On the other hand, some other values in the same tables also represent statistically significant differences in the bones; cuneiform 1, navicular and calcaneus in terms of surface area ratio, talus in terms of volume and surface area ratios and cuneiform 3 and cuboids in terms of only volume ratio for left foot ankle of ballerinas.

In terms of the volume, surface area and length, disparities in many biometric ratio values of some ankle bones in especially left foot of professional female ballet dancers have been found statistically significant when compared with those of healthy control females. Therefore this case should be taken into consideration in orthopaedic procedures of female ballet dancer.

Our main purpose with this study has already been to provide basic morphometric information regarding the ankle bones of female ballet dancers by comparing those of control females and by means of 3D reconstruction of MDCT images, and also to reveal if ballet dance have negative effects on ankle bones in both feet of female ballet dancers.

Regarding the volume, surface area and length, most of the female ballet dancer biometric ratio values, which were found higher than those of control females, were statistically important as compared with those of sedentary females. Therefore outcomes from this research suggest that ballerinas possibly have ankle bones injury and proliferation, especially on tarsal bones of left foot. However, as the validation of the data is necessary before being broadly applied on a clinical basis, further reconstructive, pathological and biomechanical studies are required to reveal definitely the exact reason of some ankle bone injuries in female ballet dancers. We are also planning a further similar study on different bones in both feet of ballerinas.

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