Asian Biomedicine Vol. 10 No. 5 October 2016; 455 - 459 DOI: 10.5372/1905-7415.1005.508

Brief communication (Original article)

A semiautomatic segmentation approach to biometric measurement of the talus bone of sedentary women and ballerinas using CT images

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Background: Ballet produces much stress on bones in the feet of ballerinas. Monitoring and detecting talus bone deformation is important for their quality of health and profession.
Objectives: To determine differences in the talus bone between ballerinas and sedentary women.
Methods: We evaluated biometric differences in the talus bone of 5 ballerinas referenced to 5 similar sedentary women recruited into the present study. We acquired 20 multidetector computed tomographic images including right and left feet. Semiautomatic region-based image processing using 3D-Doctor (Able Software Corp) was used to create three-dimensional (3D) virtual models of the talus bones. Biometric measurements were made on the 3D models and statistical analysis conducted.
Results: The mean talus bone length of ballerinas was 3.37 cm (SD 0.12; range 3.11 to 3.52). The talus bone length of sedentary women was 3.29 cm (SD 0.16; range 3.04 to 3.65), and tended to be shorter than that of the ballerinas ($P = 0.08$, t test). However, the test was insufficiently powered. The mean volume of the talus bones from the ballerinas was 24.8 cm^3 (SD 0.83) and smaller than that from the sedentary women, 26.9 cm^3 (SD 1.25) at $P < 0.001$ (t = 4.38, 18 degrees of freedom. Difference 2.1. Two-tailed 95% confidence interval for difference of means: 1.08 to 3.08). We found less variation in the feet of ballerinas than sedentary women.
Conclusions: Volumetric measurements show that feet of ballerinas are smaller and retain similar shape and size than the irregular feet of sedentary women.

Keywords: Image processing, MDCT, segmentation, talus, 3D Model

Photogrammetric methods find application to solve biomedical image processing problems. Photogrammetry collects information regarding objects such as shape, localization, dimension, and volume. Although early studies concentrated on the face and body [1], photogrammetry has become an opinion for diagnosis and treatment for orthopedic and plastic surgery, anatomy, radiology, and forensics [1, 2]. Biometric measurements of the talus bone have been made [3, 4]. These measurements have usually focused on the diagnosis and treatment of talus bone fractures [5]. Multidetector computed tomographic (MDCT) imaging is a widely used diagnostic technology [6, 7] and can be used to analyze talus bone fractures. Determining the fracture location and type of displacement (undisplaced or partially displaced) is crucial for planning management of this critical ankle injury. The epidemiology of primary bone tumors of the talus has been studied [8]. Fracture of the lateral process of the talus has been studied by CT [4]. An unusual fracture pattern of a talus and calcaneus was found in a 17-year-old boy [9]. The talus may develop avascular necrosis [10]. There are three joints: the ankle, the subtalar joint, and the talonavicular joint, which control the flexibility and the arch of the foot [11]. The talus is located within the ankle “mortise” or hinge, which is made up of the two leg bones, the tibia and fibula. The talus bone consists of three main parts: the head, neck, and posterior process. Approximately 60%-70% of its surface is covered with joint cartilage. It is connected to distal tibia, distal fibula, calcaneus and navicular bone. Together, the talus and calcaneus form the hind foot. The talus bone is the second largest of the tarsal

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bones. The neck inclines downwards medially at approximately 24° and its anterior articular or navicular surface is large, oval, and convex [12].

Ballet produces much stress on bones in the feet of ballerinas. Ballerinas are threatened by unusual injuries, bone deformation, and fractures [13-16]. Talus bone deformation can cause loss of ankle mobility for ballerinas. Therefore, monitoring and detecting talus bone deformation is important for their quality of health and profession [17]. The presented study sought to determine differences in talus bones between ballerinas and sedentary women using a three-dimensional (3D) talus bone model constructed from MDCT. Biometric measurements taking into account photogrammetric techniques were made using 3D bone models.

Material and methods

A Toshiba Aquilion CT system (Toshiba Medical Systems, Tochigi, Japan) was used to acquire talus bone data. Parameters for scanning were detector collimation 65 × 0.5–4 × 0.5 mm; slice thickness 0.5 mm, 100 mA, 120 kV, spatial resolution 512 × 512, and radiometric resolution 16 bit. In the scanning process, we minimized radiation exposure and optimized resolution [16]. After approval by the institutional ethics committee of Konya Clinical Research Institution (document No. 004; January 08, 2010), we selected 5 volunteer semiprofessional ballerinas and 5 sedentary women volunteers without a sports history. We obtained written informed consent for their participation. Ten feet (5 left and 5 right) of ballerinas and 10 feet of sedentary women (5 left and 5 right) were scanned. We obtained 20 images in all. The imaging procedures were conducted according to the Declaration of Helsinki [18] and to the standards of the Turkish Ministry of Health. We processed 1050 slices. We identified the health status of the volunteer ballerinas and sedentary women according to standards of Turkish Ministry of Health. All had normal health status. The general flow chart of the present study is shown in **Figure 1**.

Each of the 5 ballerinas was 18 years old and average (SD) shoe size, height, and weight were 37.2 (1.2), 166.8 cm (6.2), 49.2 kg (1.2) respectively. We attempted to match the selection of sedentary women with the ballerinas so that they had similar height, shoe size, and weight (18 years, 36.8 (1.2), 163 cm (10), and 50.4 kg (3.6) respectively). MDCT images were obtained from the Ankara Ataturk Training and Research Hospital and Selcuk University, Faculty of Medicine. Digital Imaging and Communications in Medicine was the standard for the management of medical imaging information. The medical images were stored "DICOM" format.

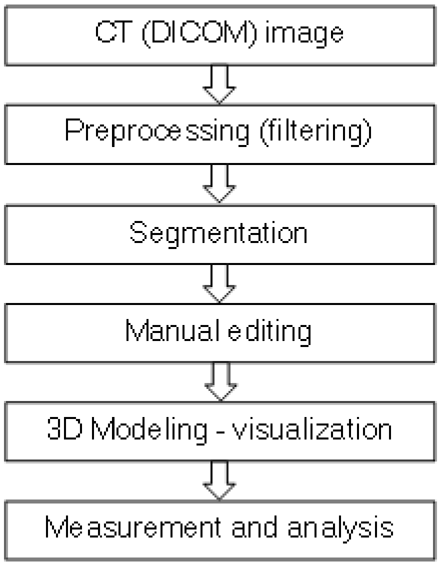

Figure 1. Flowchart of the study

To avoid motion artefacts, feet were immobilized during scanning. Preprocessing consisted of median and mean filtering steps for noise removal. Following this step, segmentation was used to split bone tissue from other tissues. A region growing method [19] was applied and the required seed point was defined interactively by using Hounsfield units in the range of 32900-40000. Obtaining some noisy data after segmentation is unavoidable. Therefore, results achieved in the present study consisted of some noisy data, but this noise was reduced by filtering, and 3D talus models were created using 3D-Doctor (Able Software Corp, Lexington, MA, USA).

We made biometric measurements of 3D talus bone models in the present study. The measurement method is shown in **Figure 2** showing head and posterior process measurements of the talus. The distances between head and posterior process were measured manually on the 3D talus bone models. We analyzed measurements using SPSS Statistics for Windows, version 21 (IBM Corp, Armonk, NY, USA) and calculated descriptive variables including mean, standard deviation, and variance. A two-tailed *t* test was used to examine differences.

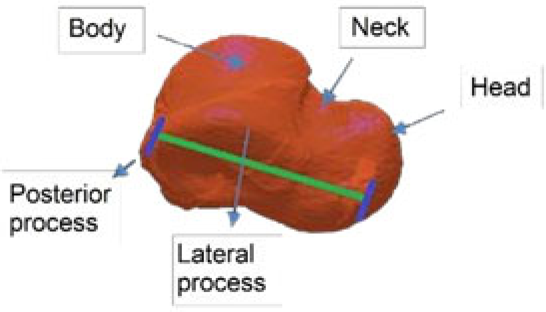

Figure 2. Measurements of the talus bone using a 3D image (3D-Doctor; Able Software Corp, Lexington, MA, USA)

Results

A 3D-Reconstruction of a ballerina's foot skeleton is shown in **Figure 3**, showing the location of the talus bone.

Talus bone measurements are shown in **Table 1**. Descriptive statistics are shown in **Table 2**. The mean talus bone length of ballerinas was 3.37 cm (SD 0.12; range 3.11 to 3.52). The talus bone length of sedentary women was 3.29 cm (SD 0.16; range 3.04 to 3.65), and tended to be shorter than that of ballerinas, although the difference was not significant ($P = 0.08$, t test). The power of the two-tailed test with α 0.050 was just 0.22 and therefore below the desired power of 0.80. We found less variation in the feet of ballerinas than in sedentary women.

The volumetric calculations for ballerinas and sedentary women are shown in **Table 3**. The mean volume of the talus bones from the ballerinas was 24.8 cm^3 (SD 0.83) and significantly smaller than the mean volume of talus bones from the sedentary women, which was 26.9 cm^3 (SD 1.25) ($P < 0.001$; $t = 4.38$, 18 degrees of freedom. Difference 2.082. Two-tailed confidence interval (95%) for difference of means: 1.084 to 3.080). We found less variation in the feet of ballerinas than in sedentary women. Deviations outside the normal range may be used to determine deformation of talus bone.

Figure 3. 3D-Reconstruction of a ballerina's right foot skeleton using 3D-Doctor (Able Software Corp, Lexington, MA, USA). Talus bone shown in blue.

Table 1. Talus bone measurements of ballerinas and sedentary women

	Ballerina		Sedentary	
No.	Right foot (cm)	Left foot (cm)	Right foot (cm)	Left foot (cm)
1	3.43	3.39	3.20	3.34
2	3.46	3.11	3.31	3.04
3	3.48	3.29	3.65	3.17
4	3.52	3.33	3.29	3.29
5	3.31	3.35	3.25	3.36

Table 2. Descriptive statistics for the talus bones of ballerinas and sedentary women

	n	Mean (cm)	Standard Deviation	Variance
Ballerina	10	3.37	0.12	0.01
Sedentary women	10	3.29	0.16	0.03

Table 3. Talus bone volumes

No	Sedentary volume (cm^3)		Ballerina volume (cm^3)	
	right foot	left foot	right foot	left foot
1	24.8	26.6	25.9	26.3
2	27.5	27.4	24.3	23.7
3	24.8	26.6	24.9	25.0
4	27.5	27.3	24.3	25.2
5	27.8	28.7	24.2	24.3
mean	**26.5**	**27.3**	**24.7**	**24.9**

Discussion

The measurements between the head and posterior process found that ballerinas and sedentary women and have a slightly different talus bone size, that tended to be longer in ballerinas. While the variation between right and left talus bones was small for ballerinas, it was higher for sedentary women. Our study was insufficiently powered to determine whether a difference actually exists. Therefore, the lack of a significant difference should be interpreted cautiously.

While the talus bone length of ballerinas was tended to be longer, the volumetric size was significantly smaller than it was in sedentary women. The feet of the ballerinas retained a similar shape and size. Whereas feet of sedentary women have been shaped according to their daily activities and use, and their feet are therefore irregular [20].

The talus bone length of female and male Egyptian volunteers were different [20] and could be used to determine sex for forensic purposes. Female and male talus bone lengths of north Italian volunteers between 19 and 70 years old were measured and showed that talus bone length is a reliable measurement for determining sex [21].

Early recognition of foot deformation could increase the professional life of ballerinas through protective measures. Talus bone length measurement has been used to observe deformities [16, 22]. The talus bone lengths of 49 Malaysian women were measured using CT images. Biological and environmental factors were found to determine the shape and size of talus bone [22]. We chose ballerinas and sedentary women in the present study to determine whether study of the talus bone might be a useful for anticipating occupational injuries in ballerinas. Deviations outside of the similar normal range of talus bone size in ballerinas might indicate deformation. A limitation of this study was the small number of participants, which lead to it being underpowered for length and other measurements.

Conclusions

In constructed 3D models, talus bone volume was found to be significantly smaller in ballerinas than in sedentary women. The feet of ballerinas retain similar shape and size, whereas the feet of the sedentary women appear more irregular than those of ballerinas, and are probably shaped according to their various activities of daily use. Deviation outside of the similar normal range of talus bone size in ballerinas may be used to determine deformation of talus bone. We recommend the ankles of ballerinas be examined periodically. Data from the biometric and MDCT 3D reconstructive methods used in this study may contribute to knowledge in orthopedics and digital image processing.

Acknowledgments

The authors are grateful to Selcuk University, Scientific Research Project Coordination for their technical help (Project No: 10101011).

Conflict of interest statement

The authors declare that there is no conflict of interest in this research.

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