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Evaluation of trabecular structure of hamate using micro-computed tomography

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Abstract

Objectives: In this study, we intended to reveal the trabecular structure of hamate by using micro-computed tomography.

Methods: This study was carried out on 55 human dry hamates. The bones were scanned with a micro-CT device. Volume, surface, and trabecular parameters (trabecular number, trabecular thickness, trabecular separation) of the scanned bones were analyzed.

Results: The mean percentage of the bone volume was 44.930±5.859%, trabecular number was 1.31±0.150 mm^{-1}, trabecular thickness was 0.35±0.056 mm, trabecular separation was 0.57±0.087 mm.

Conclusion: Hamate has sufficient strength for screw implantation in terms of trabecular thickness and number, but weaker in terms of trabecular separation when compared with other carpal bones. Hamate has the greatest trabecular thickness among the other carpal bones, while it is ranked as the second in terms of trabecular number.

Keywords: carpal bones; hamate; micro-computed tomography; microstructure; trabeculae

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Introduction

Hamate is a cuneiform bone with its special unciform process called as hook of hamate projecting from distal part of the palmar surface.[1] Hamate articulates with triquetrum, 4th and 5th metacarpal bones, and also with the ulnar side of the capitate. The hook of hamate projects from the volar side 1–2 cm distally and radially to the pisiform bone. It forms the ulnar side of the carpal tunnel and the radial side of Guyon's canal. Its ossification is not completed until the age of 15.[2] Several structures attach to the hook of hamate such as pisohamate ligament and transverse carpal ligament. Hamate is prone to subluxation and fractures because of its weak blood supply. Biomechanical factors, such as ligaments and muscles attaching to the bone can lead to fractures and subluxations. Blood supply may affect fracture healing (union-non-union procedure) and occurring avascular necrosis after trauma.[3]

Micro-computed tomography (Micro-CT) is a valuable method for the investigation of bone morphometry and microarchitecture. This method uses data sets obtained by X-ray attenuation for the 3-dimensional representation of material density. In this era resolution of micro-CT devices has increased up to several micrometers.[4]

The literature reveals some pathological cases such as fractures,[5–8] avascular necrosis,[9–11] osteoblastoma,[12,13] osteochondroma,[14,15] and osteomyelitis[16] related to hamate. Hamate fractures occur in the body and hamulus parts of the bone. Both types of fractures are characterized by pain felt on the ulnar side of the wrist, which may be associated with ulnar paresthesia. Delayed diagnosis of the fracture may cause ulnar neuritis, ulnar artery thrombosis, and rupture of the flexor digitorum profundus tendons of 4th and 5th fingers.[17]

Clinical CT and micro-CT can be used to determine the bone microstructure. Studies have shown that all the values that can be measured with clinical CT can be measured more precisely with micro-CT. However, despite of the high resolution of micro-CT, its ability to scan only small parts that can be placed in its chamber makes it impossible to use it in a clinical setting.[18] This study

aimed to explore the trabecular microstructure of human dry hamates using micro-CT scanning method.

Materials and Methods

Fifty-five human dry hamates without any external deformity were included in the study. The bones were obtained from collections of Anatomy Departments of Hacettepe and Ankara Universities in Turkey. Scanning and analysis were executed via micro-CT device (SkyScan 1174, SkyScan, Aartselaar, Belgium) at Hacettepe University. The scanning parameters were set as follows: degree of rotation=180º, exposure time=2700 milliseconds, currency= 800 mA, voltage= 50 kVp, projection= 33 µm and scanning time= 90 minutes.

After the scanning procedure, the raw data in TFT format were reconstructed with Nrecon software (Micro Photonics Inc., Allentown, PA, USA) and axial images were generated in BMP format with 33 µm of projection. Then these reconstructed data were transferred to CTAn software and 2D–3D analysis was performed with this software. In this study we studied 2 groups of parameters; (i) volume-surface and (ii) trabecular properties. In the volume-surface group, we examined the following parameters: tissue volume, bone volume, percent bone volume (bone volume/tissue volume), bone surface, bone surface/volume ratio; while in the trabecular group we examined trabecular number, trabecular thickness, trabecular separation, structure model index and degree of anisotropy.

Statistical analysis was performed with IBM SPSS Statistics Version 23.0 (Armonk, NY, USA) with 95 % confidence interval. The distribution of variables (whether normally distributed or not) was tested via the Kolmogorov-Smirnov test.

Results

The measurements were performed on 3D reconstruction images of the hamates (**Figures 1** and **2**). The average percentage of bone volume was 44.930±5.859%. There was high range in the average percentage of bone volume ranging between 29.65–60.78%. While the mean trabecular thickness was 0.350±0.056 mm, the average number of trabeculae for each mm was 1.31±0.15. The average value for the trabecular separation, which indicates the mean space between trabeculae, was 0.570±0.087 mm. For trabecular number, trabecular thickness, and trabecular separation values, there was an up to two-fold difference between the minimum and maximum values (**Table 1**). While the samples showed a wide scatter in terms of structure-model index, the samples were much more homogeneous in terms of degree of anisotropy.

Discussion

Bone strength is an important factor for implant treatment. This factor is related to bone integration. In some studies, a relationship is observed between bone quality and the success of implant treatment.[19,20] Bone mass, bone mineral density, macro and microarchitecture, and matrix properties are some of the factors which determine bone quality. Cortical bone is the primary determinant of bone robustness while the spongy bone is part of bone-implant integration. Information of trabecular bone structure has some importance for the success of implant treatment and further evaluation of implant surface architecture. Bone/implant integration is dependent upon the bone quality and bone/implant interphase.[21] Trabecular bone is the determinant of bone integration and forms the bone/implant interphase. For this reason, the trabecular bone structure should be researched to obtain objective and detailed scientific information. Lee et al.[22] scanned bones that had 4 different quality levels with the micro-CT device and revealed a statistically important relationship between bone quality and bone volume density, bone surface/volume ratio. Also, statistically significant correlations were observed between all the parameters. For this reason, in addition to trabecular parameters (trabecular thickness, number, and separation, structure-model index, degree of anisotropy) some other parameters (tissue volume, bone surface, bone volume, bone surface/volume ratio, percentage bone volume) which are affected by trabecular structure were also examined in the present study.

Tissue volume represents both volumes of bone tissue and spaces between these bone tissues while bone volume includes the only volume of bony structure but not spaces between these structures. Tissue volume and bone volume were observed as 2526.120±604.615 mm^3 and 1137.100±318.973 mm^3 subsequently in this study.

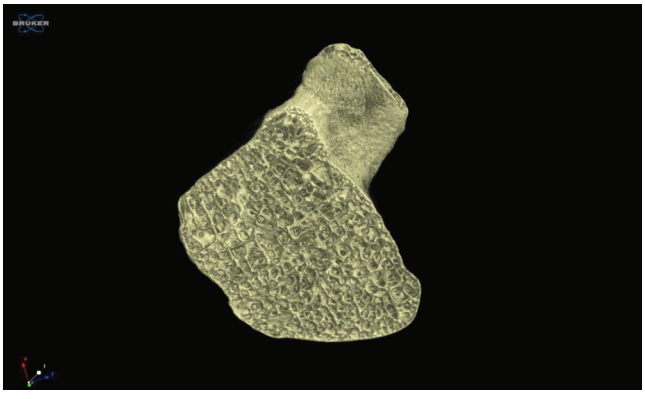

Figure 1. Trabecular structure of hamate.

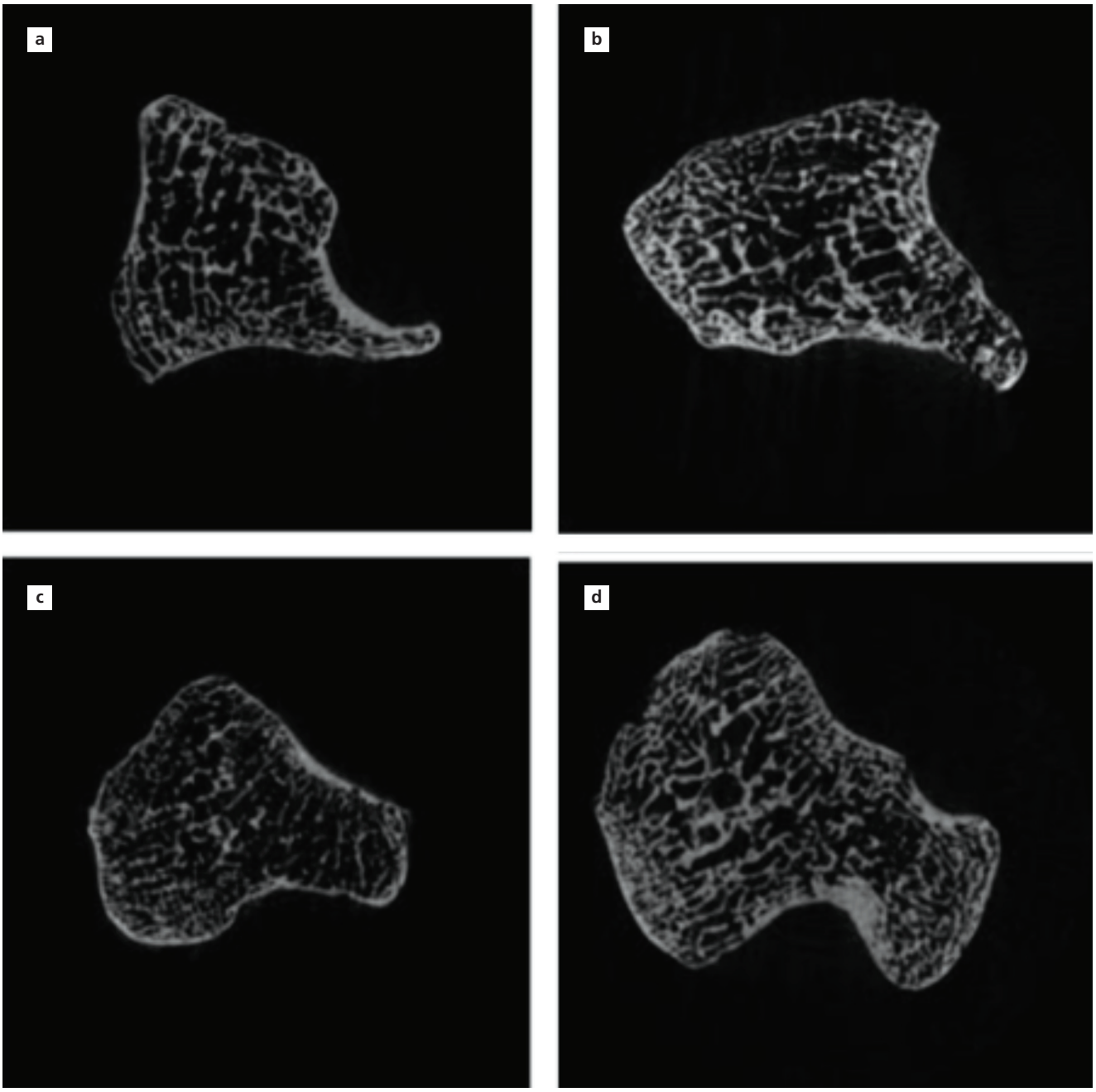

Figure 2. Trabecular number, trabecular thickness, and trabecular separation of different hamates (**a-d**).

Percentage bone volume is the ratio of bone volume to tissue volume and was observed as 44.930±5.859% in our study. Previous studies have revealed data belonging to other carpal bones regarding bone and tissue volumes but since each carpal bone has a different dimension, it is quite an expected result that these bones will have different volume. So, it is not logical to compare these bones with each other in terms of volumes.

The bone surface represents the surface of trabeculae in inspected area. In our study the mean bone surface was measured as 12149.250±3738.144 mm^2. Trabecular number and thickness are parameters that change proportionately with the bone surface. Wurnig et al.[23] measured trabecular number and thickness as 2.24±0.46 mm^{-1} and 0.229±0.032 mm for cadaveric hamates. In our study, these values were 1.31±0.150 mm^{-1} and 0.35±0.056 mm for dry

Table 1
Results of the measurements (n=55).

	Mean±SD	Min.–Max.
Tissue volume (mm^3)	2526.12±604.615	1432.99–4358.62
Bone volume (mm^3)	1137.10±318.973	540.46–1987.47
Percentage bone volume (%)	44.93±5.859	29.65–60.78
Bone surface (mm^2)	12149.25±3738.144	6266.40–20443.43
Bone surface/volume ratio (mm^{-1})	10.78±2.006	7.78–17.38
Trabecular number (mm^{-1})	1.31±0.150	0.90–1.61
Trabecular thickness (mm)	0.35±0.056	0.23–0.49
Trabecular seperation (mm)	0.57±0.087	0.38–0.83
Structure-model index	-0.12±0.638	-1.40–1.05
Degree of anisotropy	1.30±0.093	1.13–1.49

hamates subsequently. The bone surface/volume ratio represents the proportion of bone surface in the bone volume of the region of interest. Bone surface is also affected by trabecular number and thickness. In the aforementioned study[23] bone surface and bone surface/volume ratio parameters were not measured. Although it is not possible to judge the difference of the bone surface and bone surface/volume ratio with our study precisely, it is clear that none of these values (trabecular thickness and number) shows difference when compared with our study.

The trabecular number is the number of trabeculae that are observed in each mm of the sample. The higher number of trabeculae contributes positively to bone strength. We observed this value as 1.310±0.150 mm^{-1} while Wurnig et al.[23] as 2.24±0.46 mm^{-1}. In different studies, researchers compared normal carpal bones in various pathological conditions. Han et al.[24] compared normal lunates with those lunates which had Kienböck's disease, and they measured trabecular number as 1.57±0.41 mm^{-1} for normal lunates. Nufer et al.[25] studied normal trapezium and trapezium bones with osteoarthritis. The trabecular number was revealed as 1.26±0.18 mm^{-1} for non-pathological trapezium bones. Qu et al.[26] evaluated normal scaphoids and non-union scaphoids. They measured trabecular numbers for proximal and distal parts as 0.08±0.04 mm^{-1} and 0.07±0.05 mm^{-1} for normal specimens. It is known that bone strength changes proportionately with the trabecular number. Accordingly, it is possible to order the strength of the bones as lunate, hamate, trapezium, and scaphoid in terms of decreasing bone strength.

Trabecular thickness is the mean thickness of trabeculae in inspected area. Bone strength increases with higher trabecular thickness values. The trabecular thickness was revealed as 0.35±0.056 mm in our study. Wurnig et al.[23] found this value as 229±32 μm (0.229±0.032 mm) and Han et al.[24] as 0.160±0.024 mm for normal lunates. Nufer et al.[25] measured the trabecular thickness as 0.17±0.02 mm for normal trapezia; while Wurnig et al.[23] measured 0.220±0.036 mm for normal scaphoids. Increasing trabecular thickness is a factor that contributes to bone strength positively. When the bone strength is compared in terms of trabecular thickness the strength order will be in decreasing order as hamate, scaphoid, trapezium, and lunate.

Trabecular separation is a measure of the mean distance between trabeculae.[23] When trabecular number and thickness increase trabecular separation decreases and the behavior of these 3 parameters in this manner would increase the bone strength. In conclusion, the higher value of trabecular separation means the lower strength of the bone. In our study, the trabecular separation value was measured as 0.57±0.087 mm. Han et al.[24] revealed this value as 0.52±0.21 mm for lunates, Nufer et al.[25] 0.74±0.18 mm for trapezia, Qu et al.[26] as 0.33±0.04 mm (for proximal part) and 0.33±0.05 mm (for distal part) for scaphoids. In terms of trabecular separation, the bones can be ordered as the scaphoid, lunate, hamate, and trapezium in decreasing order of bone strength.

By the results of our study and other studies, it may be quite possible to judge differently when only one parameter is considered for determination of strength of the bone. For the diagnosis of some metabolic diseases such as osteoporosis and design of implant treatment for bone fractures, it is vital to consider multiple parameters to choose the correct treatment. And it is necessary to compare the results between samples whether they are statistically important or not.

Structure-model index is a trabeculae related factor. This factor may have -4, -3, 0, 3 and 4 values. "-4" and "-3" values correspond to spherical and cylindrical cavities while 0, 3 and 4 values represent smooth plate, cylindrical and spherical trabeculae. In our study, we measured the mean structure-model index as -0.12±0.638. These results indicate that our hamates had smooth plate-like trabeculae. Wurnig et al.[23] didn't study this parameter in their study. Han et al.[24] showed this value as 1.99±0.31 for normal lunates, Nufer et. al.[25] 1.35±0.44 for normal trapezia and Qu et al.[26] 0.63±0.74 and 0.63±1.00 for proximal and distal parts of normal scaphoids. These results indicate that all the mentioned carpal bones together with hamate have smooth trabeculae. Change of structure-model index shows the changing pattern of trabeculae. For instance, Qu et al.[26] compared normal scaphoids with non-union scaphoids and observed that the latter has a higher value of structure-model index at its distal part. They also observed that the trabecular shape of the distal part resembled a cylinder in contrast to the proximal part's trabeculae. However, proximal part has a lower SMI showing its plate-like appearance, which is also an indicator of dense trabecular structure and stronger bone. The plate-like trabecular structure is a result of higher mechanical stress while the cylindrical shape is a result of lower mechanical stress. In conclusion, it can be said that hamates may be exposed to high mechanical stress.

Degree of anisotropy is a representation of trabecular distribution in the region of interest. If it is equal to 1 it means an isotropic trabecular distribution (alignment along the same axes) exists but values greater than 1 show anisotropic distribution. In this study, this value is measured as 1.30±0.093. This result shows us that our hamate samples have an anisotropic trabeculae distribution. Wurnig et al.[23] measured this value as 1.56±0.08. In previous studies, degree of anisotropy was revealed as 0.44±0.86 for lunates[24] and 1.28 ±0.04 for trapezia.[25] Accordingly, we can conclude that hamates and trapezia have an anisotropic trabeculae distribution in contrast to lunates which have an isotropic distribution. The degree of anisotropy is a measure of bone adaptation to the changing conditions of the structure-model index. For instance, Han et al.[24] observed that in the case of progressing bone necrosis, nonnecrotic bony tissue changes its trabecular distribution towards anisotropic in response to compressive stress. So, it is important to be aware of changing pattern of trabecular distribution due to different conditions.

Bone quality is so important for screw implantation and lower bone quality affects screw stability in a negative manner.[27] For this reason, it is vital to evaluate the trabecular structure that has important effects on bone quality and strength. It is stated that the bone reorganizes its trabecular structure as a response to increasing force load in the affected region.[28] Accordingly, a carpal bone with an inner position, attached structures (muscles, ligaments, etc.), and microarchitecture would respond to different physiological and pathological conditions in a special manner. So, each bone should be evaluated by considering its position relative to other bones. For instance Mc Lean et al.[29] observed 2 types of distinct joints between triquetrum and hamate which were named as TqH-1 and TqH-2 respectively depending on articular surfaces of triquetrum and hamate. In another study, it was revealed that depending on the joint surfaces of triquetrum and hamate, a rotational motion occurs instead of helicoidal movement that refers to a saddle joint.[30] So in addition to anatomical properties, functional properties should be considered for any medical intervention on carpal bones. In addition to relative positions of the carpal bones, the intrinsic structural dynamics of individual bones should also be evaluated for a proper localization of screws. For instance, in a study documenting the differences of bone volume-surface and trabecular properties between different quadrants of scaphoid bone, no differences in terms of bone quality and density between these 4 quadrants was noted.[31] The vascular supply of the carpal bones is another factor affecting the healing process. Hamate is noted to have two regions of vascular entry and without intraosseus anastomoses. This type of vascular supply pattern puts hamate in a low risk group for developing avascular necrosis.[32] Another factor that might have a role in healing process could be the bone age. The analysis of images obtained by CT of the carpal bones is a valid method in the evaluation of bone maturity in children. Choi et al.[33] stated that capitohamate (CH) planimetry could be a reliable method for determining bone age. Determining the normal anatomy of the carpal bones will also help to determine the most appropriate parameters in the clinic for treating wrist pathologies.[33–35]

Our aim in this study was to define the trabecular structure of hamate, which is one of the parameters affecting the bone strength. Trabecular number, thickness, separation, structure-model index, and degree of anisotropy can be regarded among other factors. Examining only the dry bones and inability to identify the age and genders of the samples are two big limitations of our study. Therefore, we suggest carrying out new studies comparing dry bones with cadaveric specimens and trabecular structure changes in different pathological conditions together with the vasculature of hamate.

Conclusion

It is obvious that hamate bone has sufficient strength for screw implantation in terms of trabecular thickness and number, but weaker in terms of trabecular separation when compared with other carpal bones. Hamate has the greatest trabecular thickness among the other carpal bones, while it is ranked as the second in terms of trabecular number. In terms of trabecular separation, the carpal bones can be ordered as the scaphoid, lunate, hamate, and trapezium in decreasing order of bone strength.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

HO: protocol/project development, data collection, data analysis, manuscript writing/editing; HHC: supervision; MO: data collection, data analysis; FG: data collection, data analysis.

Ethics Approval

The study was approved by Ethical Committee of Hacettepe University (No: GO 18/131-12) and performed in accordance with the Helsinki declaration of principles.

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