Research Article / Araştırma Makalesi

Investigation of the Human Maxilla and Mandible Trabecular Microstructure with Micro-Computed Tomography

İnsan Maksilla ve Mandibula Trabeküler Mikro Yapısının Mikro Bilgisayarlı Tomografi ile İncelenmesi

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Abstract

Background: Mechanical properties of the maxilla and mandible are important factors for determining implant stability. Clinical studies indicate an association between poor bone quality and the rate of implant failure. Various methods suitable for long-term monitoring of implant stability have been developed. Micro computed tomography (Micro-CT) technique has been a common method to study 3D trabecular bone microstructures. In this study, it was aimed to describe the trabecular microarchitecture of the maxilla and mandible. Understanding the mechanical capacity of trabecular bone will offer further insight into the prognosis and progression of implant treatment and surgical techniques.
Materials and Methods: Twenty cadaver maxilla and mandible specimens were scanned using micro CT. Samples were scanned with the following parameters. Scan data were transferred to Ctan software and analyzed. Morphometric parameters; tissue volume (BC), bone volume (HR), bone volume percentage (HR/DC), tissue surface (BC), bone surface (BC), intersection surface (KSR), bone surface/volume ratio (BC/HR), bone surface density (BS/TV), trabecular pattern factor (Tb.Pf), structure pattern index (YMI), trabecular thickness (Tb. Th), trabecular separation (Tb. Sp), trabecular number (Tb.N), and anisotropy degree (DA) was studied with the CTAnalyzer software.
Results: Tissue volume (TV) and mean bone volume (BV) of the mandible were higher than those of the maxilla (p = 0.007). The mean HF mean in the mandible was 159.415 ± 91.523 mm3 for maxilla and 278.816 ± 122.853 for the mandible, and this difference was significant (p = 0.007). The mean HF was found to be significantly lower in the mandible (p = 0.007). HF and CSR parameters of the mandible were significantly higher than the maxilla (p = 0.007).
Conclusions: Our study showed that there is a measurable difference in bone density between the maxilla and mandible. We believe that it will provide information that guides the physician and contributes to the healing process of the patient in all dental surgical applications, especially implants. The prevalence of supratrochlear foramen and the supracondylar process was higher on the left side; however, both are detected on the right side. We believe that the data obtained would be helpful for an orthopaedic surgeon during intramedullary nailing, and for differential diagnosis of some osteolytic lessons for a radiologist . In addition, these variations can be an important indicator in the differentiation of different races.

Key Words: Micro-computed tomography, Trabecular bone microstructure, Maxillae, Mandible

Öz

Amaç: Maxilla ve mandibulanın mekanik özellikleri implant stabilitesini belirleyen önemli bir faktördür. Klinik çalışmalar düşük kemik kalitesi ile implant başarısızlığı oranı arasında bir ilişki olduğunu belirtilmektedir. İmplant stabilitesinin uzun süreli izlenmesi için uygun çeşitli yöntemler geliştirilmiştir. Mikro bilgisayarlı tomografi (Micro-BT) tekniği, 3D trabeküler kemik mikro yapılarını incelemek için için yaygın bir yöntem olmuştur. Bu çalışmada maksilla ve mandibulanın trabeküler mikromimarisinin tanımlanması amaçlanmıştır. Trabeküler kemiğin mekanik kapasitesinin anlaşılmasının, implant tedavisinin prognozunda, ilerlemesinde ve cerrahi tekniklere daha fazla bilgi sunacağını ortaya koyacaktır.
Materyal ve Metod: Yirmi adet kadavra maksilla ve mandibula örneği, mikro BT kullanılarak tarandı. Numuneler aşağıdaki parametrelerle tarandı. Tarama verileri CTAnalyzer yazılımına aktarıldı ve analiz edildi. Morfometrik parametreler; doku hacmi (DH), kemik hacmi (KH), kemik hacmi yüzdesi (KH/DH), doku yüzeyi (DY), kemik yüzeyi (KY), kesişme yüzeyi (KSY), kemik yüzeyi/hacim oranı (KY/KH), kemik yüzey yoğunluğu (BS/TV), trabeküler patern faktörü (Tb.Pf), yapı modeli indeksi (YMI), trabeküler kalınlık (Tb. Th), trabeküler ayrılma (Tb. Sp), trabeküler sayı (Tb.N) ve anizotropi derecesi (DA), CTAnalyzer yazılımıyla çalışıldı.
Bulgular: Mandibulanın doku hacmi (DH) ve ortalama kemik hacmi (KH), maksillanınkinden istatistiksel olarak anlamlı derecede yüksekti (p = 0.007). KY ortalaması mandibulada 159.415 ± 91.523 mm3, maxillada 278.816 ± 122.853 idi. Bu fark anlamlıydı (p = 0.007). KY ortalaması mandibulada olarak düşüktü (p = 0.007). Mandibula KY ve KSY parametreleri, maxilla'dan istatistiksel anlamlı derecede yüksekti.
Sonuç: Çalışmamız, maksilla ve mandibula arasında kemik yoğunluğu açısından ölçülebilir bir fark olduğunu gösterdi. Özellikle implant başta olmak üzere tüm diş hekimliği cerrahi uygulamalarında hekime yol gösterici ve hastanın iyileşme sürecine katkıda bulunan bilgiler sunacağı kanaatindeyiz.

Anahtar Kelimeler: Mikro bilgisayarlı tomografi, trabeküler kemik mikro yapısı, Maxilla, Mandibula

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Introduction

The maxilla and mandible consist of an outer cortical and an inner trabecular substance. Inside, there is a very stable braided structure consisting of thin bone trabeculae (1). Bone structure and cortical bone thickness have been that there are variables that are valued for the primary stability and technical success rate of endosseous implants (2, 3).
Bone is a tissue that optimizes itself depending on the loading limitations on it. The biomechanics of a dental implant are important to its longevity within the bone. Biomechanics of a dental implant can have a harmful effect on the bone surrounding the implant due to physiological and mechanical factors (4).
The use of osseointegrated implants in dentistry has greatly contributed to clinical dentistry. A few practical studies have demonstrate an association among insufficient volume, weakness, or poor bone quality and implant failure (5).
In osseointegration micro properties of bone are important factors that determine primary implant stability (6). Adequate bone volume and density is an important binder behind longer-lasting and more robust implants. Primary implant stability is essential for successful dental implantation. Therefore, trabecular bone density and cortical bone thickness are very important for primary implant stability Insufficient primary stability in a dental implant is one of the main reasons of unsuccessful (7, 8).
Other relevant treasons of implant unstable include inflammation, bone loss and overload, age, systemic chronic diseases and lifestyle, surgical procedures. Early detection of each problem is very vital. Exertion should be made to solve the problem while the damage is taken under control (5, 9).
Trabecular bone and implant stability are closely related in dental implants. While bone trabecula is very important in implant healing, it is less important in primary fixation of the implant (10, 11, 12).
Quantitative analysis of bone is a method employ to investigate the trabecular structure of bone. The morphology of the bone trabecula can be easily observed using 3D analysis.
In general, local bone density and trabecular quantification at implant can be measured using CT. The relationship between primary implant stability and trabecular bone density and cortical bone thickness has been extensively studied in the literature. However, studies examining the relationship between implant stability and trabecular bone microstructure are quite limited (13).
Micro-CT technique provides a holistic view for imaging small samples in three dimensions and quantifying trabeculae. It is a increasingly sensitive, non-dangerous method that capables the production of a true 3D image from a set of 2D datasets. Analysis can be done immediately from the scanned data. Micro-computed tomography has been common method to measure bone trabecula microstructures with its speed of analysis, non-invasiveness, and high spatiality compared to histology (13, 14).
This technic is not employ for clinical imaging in vivo due to its high radiation content. It is restricted to examining inanimate specimens. This technic is also applied in the mea surements of the microstructure of the bone internal structure (15-18). Morphometric paremeters bone volume, total volume, bone volume ratio, trabecular thickness, trabecular number and trabecular separation can be calculated with Micro-CT data (16, 19).
Experimental studies (13, 14, 20, 21, 22, 23) have shown that important the mechanical adequacy of trabecular bone microarchitecture and implant treatment. He pointed out that it may reveal important information about its effect on prognosis. A future in vivo study will greatly assist clinicians in providing and preparing optimal dental treatment options for patients in determining the true role of these clinical factors described above in long-term implant success. To understand the microstructural differences between jawbones and their effect on "bone quality" patterns, a larger and homogeneous sample is needed. In this study is to define the microarchitecture of maxilla and mandible trabecular bone.

Materials and Methods

Bone specimens

Ethical agreement was acquired from Ankara Yıldırım Beyazıt University Ethics Committee (Project number: D-KA16 / 10). In this study, a total of 20 bone tissues, including 10 maxilla and 10 mandibles, were obtained from fresh cadavers used in student education in the Laboratory of the Department of Anatomy of Erciyes University Faculty of Medicine. A total of 20 bone samples were prepared from cadaver maxillary and mandibular anterior regions. Each specimen was then prepared in a 3x3 cm size. To standardize the process of evaluating the trabecular structure of the samples, each bone specimen was drilled here with a 1 mm diameter fissure at two points 3 mm apart and 10 mm long. Then, the samples were scanned Micro-CT.

Examination of Bone Trabecula

The specimens were scanned with using Skyscan 1275® micro-CT system (SkyScan, Kontich, Belgium) with the following parameters: 80 kV, 125 µA, 26 µm pixel size, 49 ms exposure time, 0,2° rotation step, 360° rotation. Scan time was 35 minutes for each sample. The reconstruction of images was using NRecon software (NRecon version 1.7.4.2; Bruker microCT, Skyscan) (Fig.1A-B). Scanning data was then transferred into CTan software (CTan version 1.7.4.2; Bruker microCT, Skyscan) and analyzed with this program. We analyzed the samples were for tissue volume, bone volume, percent bone volume, tissue surface, bone surface, intersection surface, bone surface/volume ratio, bone surface density, trabecular pattern factor, structure model index, trabecular thickness, trabecular number, trabecular separation and degree of anisotropy. For 2 dimensional view was used the CTAn software and for the 3-dimensional view the CTvol (CTvol version 1.7.4.2; Bruker microCT, Skyscan) software (Fig.2).

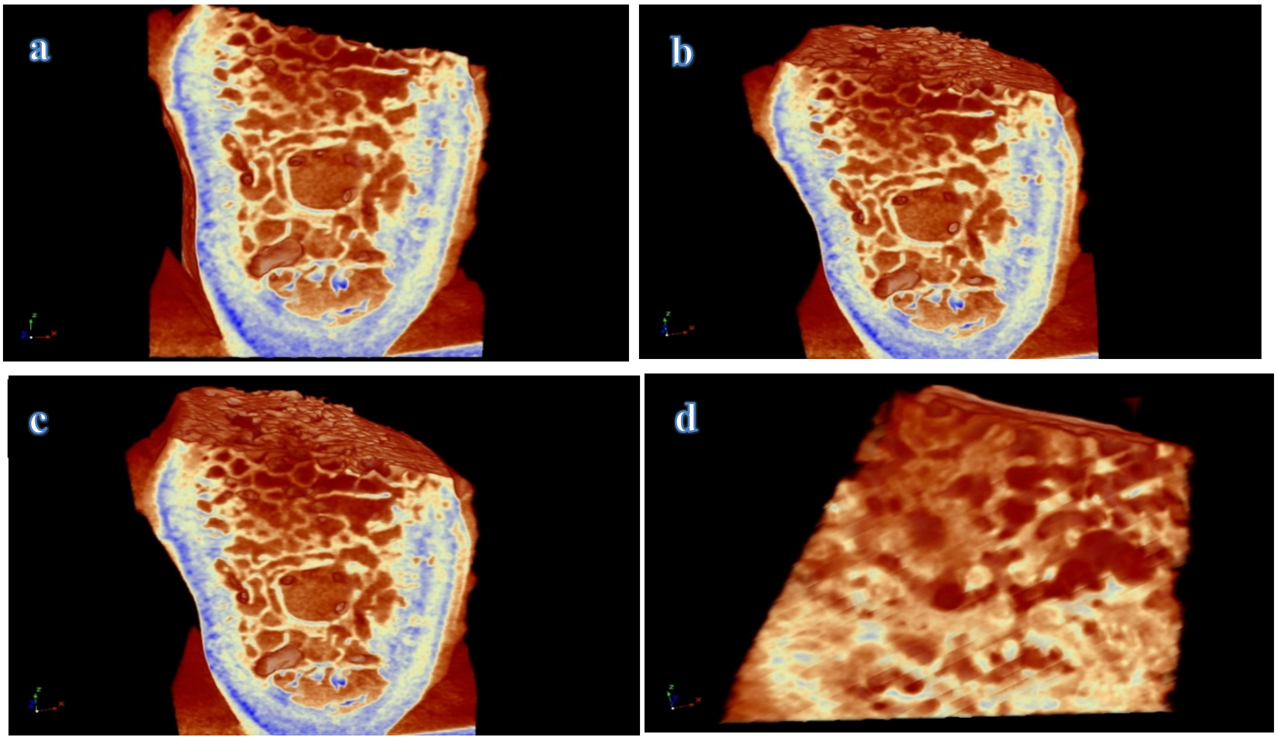

Figure. 1A. Images reconstructed with NRecon software: Mandible sagittal (a, b, c) and transverse (d) section

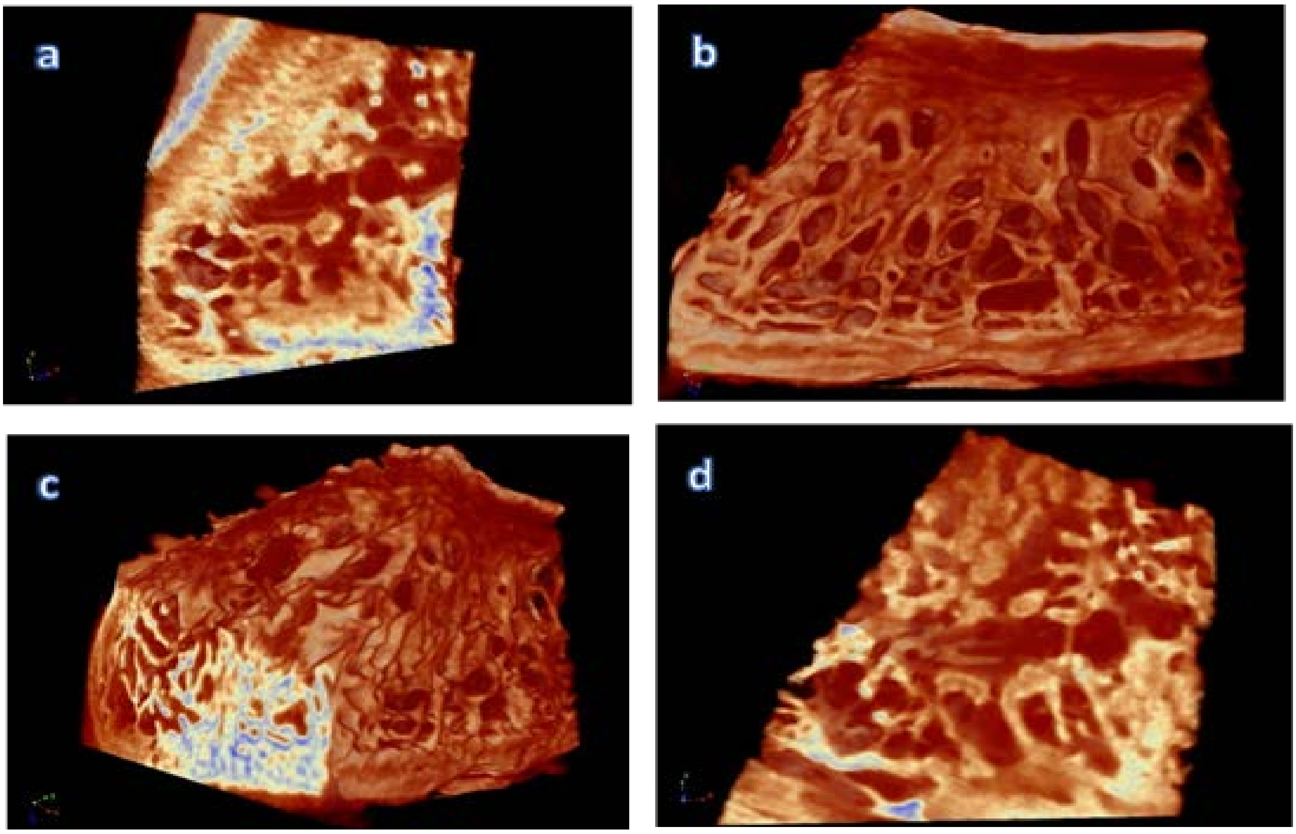

Figure 1B. Images reconstructed with NRecon software: Maxillae coronal (a), sagittal (c, d) and transverse (b) section

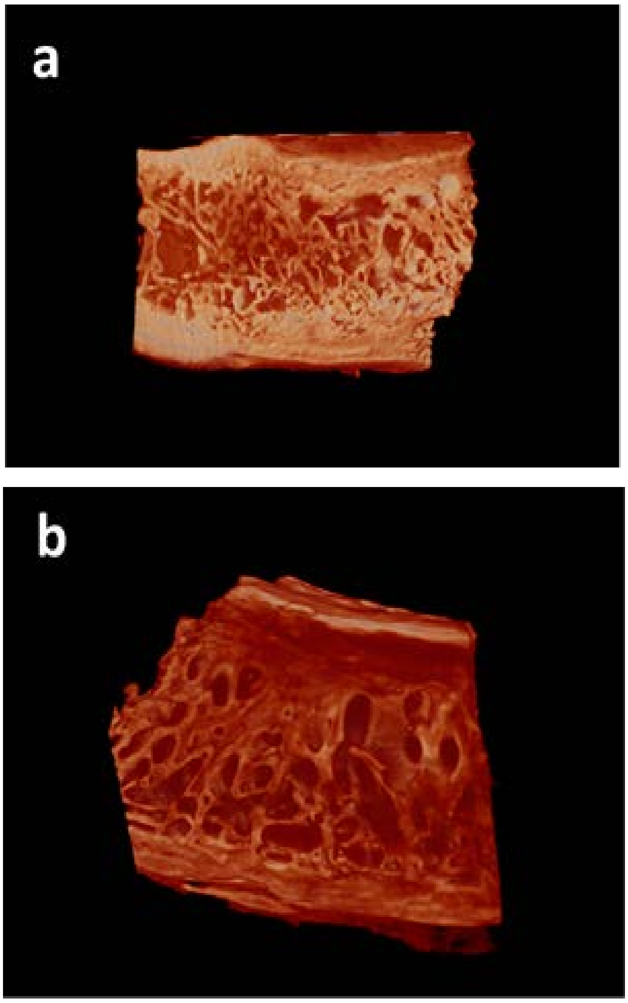

Figure 2. 3D trabecular view prepared using CTvol software:
(a) mandible,
(b) Maxillae

Statistical analysis

The distributions of the measurements in the study were examined with the Shapiro-Wilk test. Normally distributed measurements were shown with mean ± standard deviation (mean ± ss), other measurements were shown as median (min-max). The measurements of the mandible and maxilla were compared with the paired-t-test and the Wilcoxon test, depending on the distribution. P<0.05 was considered statistically significant. IBM SPSS Statistics 21.0 (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.) program was used for statistical calculations.

Results

Mean and standart deviation for maxillae and mandible assessed were presented in Table 1. The tissue volume (TV) of the mandible was significantly higher than that of the maxilla (p = 0.009). The average bone volume (BV) was 82.374 ± 64.823 mm3 in the maxilla, 166.792 ± 94.99 mm3 in the mandible, and was significantly higher than the maxilla (p = 0.003). Tissue surface (TS) mean was 159.415 ± 91.523 mm3 for maxilla and 278.816 ± 122.853 for the mandible, and this difference was significant (p = 0.007). Similarly, in the average values of the Bone surface (BS) and Intersection surface (IS) parameters, the BS and IS values of the Mandible were significantly higher than Maxilla. (maxilla BS 286.344 mm3, IS 92.447 mm3; mandible BS 447.975 mm3, IS 188.024 mm3) (BS p-value = 0.009, IS p-value = 0.001).

A difference was observed between maxilla and mandible for BV / TV, BS / BV, BS / TV, Tb. Pf, SMI, Tb.Th, Tb. N, Tb. Sp, DA parameters, but this difference was not important (p> 0.05) (Table 2).

Table 1. Mean and standart deviation for maxillae and mandible

	Maxilla	**Mandibular**	**Test**	
Measurements	**Mean±SD Median (min-max)**	**Mean±SD Median (min-max)**	**Statistics**	**p-value**
Tissue volume mm^3	103.148 (10.737-221.840)	150.271 (63.708-464.910)	Z=2.599	0.009
Bone volume mm^3	82.374±64.823	166.792±94.99	3.928	0.003
Percent bone volume *(BV/TV),*	75.584±13.526	79.384±10.945	0.757	0.468
Tissue surface mm^2	159.415±91.523	278.816±122.853	3.449	0.007
Bone surface	286.344 (59.346-507.305)	447.975 (150.060-1349.921)	Z=2.599	0.009
Intersection surface	92.447±44.352	188.024±75.685	4.932	0.001
Bone surface / volume ratio	4.615±2.390	3.945±1.772	0.781	0.455
Bone surface density	3.394±1.573	3.025±1.129	0.652	0.531
Trabecular pattern factor	-2.650±1.387	-4.924±3.353	1.789	0.107
Structure model index	-1.384±1.778	-2.008±2.934	0.702	0.500
Trabecular thickness	1.026±0.557	1.109±0.491	0.453	0.661
Trabecular number	0.945±0.444	0.822±0.308	0.797	0.446
Trabecular separation	0.388 (0.195-1.502)	0.386 (0.177-2.333)	Z=0.153	0.878
Degree of anisotropy	0.515±0.167	0.562±0.221	0.478	0.644

Statistically significant correlations are highlighted in gray. nCorrelation is significant at P<0.05

Tissue volüme (TV); Bone volume (BV), Percent bone volume (BV/TV), Tissue surface (TS), Bone surface (BS), Intersection surface (İS), Bone surface / volume ratio (BS/BV), Bone surface density BS/TV, Trabecular pattern factor (Tb.Pf), Structure model index (SMI), Trabecular thickness (Tb.Th), Trabecular number (Tb.N), Trabecular separation (Tb.Sp), Degree of anisotropy (DA).

Table 2. Comparison between the Maxillae and Mandible

	Maxillae	Mandible	Ratio
TV (mm^3)	103.148	150.271	47.123
BV (mm^3)	82.374	166.792	84.418
BV/TV	75.584	79.384	3.800
TS (mm^2)	159.415	278.816	119.401
BS Bone surface (mm^2)	286.344	447.975	161.631
İS (mm^2)	92.447	188.024	95.577
BS/BV	4.615	3.945	-670
BS/TV	3.394	3.025	-369
Tb.Pf	-2.650	-4.924	-2.274
SMI	-1.384	-2.008	-624
Tb.Th (mm)	1.026	1.109	0,083
Tb.N	0.945	0.822	
Tb.Sp	0.388	0.386	0,002
DA	0.515	0.562	

Tissue volüme (TV); Bone volume (BV), Percent bone volume (BV/TV), Tissue surface (TS), Bone surface (BS), Intersection surface (İS), Bone surface / volume ratio (BS/BV), Bone surface density BS/TV, Trabecular pattern factor (Tb.Pf), Structure model index (SMI), Trabecular thickness (Tb.Th), Trabecular number (Tb.N), Trabecular separation (Tb.Sp), Degree of anisotropy (DA).

Discussion

Micro-CT is useful for examining geometric three-dimensional parameters such as the orientation, shape and connection of trabeculae. It provides reliable findings in examining bone changes in pathophysiological conditions and evaluating changes in microarchitecture after treatment with antiosteoporosis agents (20, 24, 25).

The outcome of this study show the alveolar bone density and microarchitecture of the human maxilla and mandible, and the quantitative difference in microstructure between the mandible and maxilla. In line with this result, clinicians may have the knowledge to apply more appropriate and more accurate options in dental treatments.

Trabecular number, trabecular thickness, Trabecular separation, junction density, and SMI represent bone quality.Tb. N determines the number of trabeculae at a given distance. Tb. Th measures the thickness of trabecular structures.Tb. Sp measures the spaces between non-bone structures. SMI is a plate-like indicator as opposed to rod-like trabecular structure. The lower the ratio, the more osteoporosis (26-28).

In the results obtained from this study, significant differences were observed in the parameters between Maxilla and mandible. Bone volume in the mandible (BV) was found to be quite high in comparison with the maxilla. Results for the mandible were higher than Maxilla for all parameters used for bone quality assessment. Bone volume (BV), Percent bone volume (BV / TV), Tissue surface (TS), Bone surface (BS), Intersection surface (İS) have been seen in the average values of the parameters. The most prominent parameter is 161,631 the belong to the Bone surface rates (BS).

In our study, the mean of Tissue volume, Bone volume, Tissue surface bone surface, and Intersection surface of the Mandible was found to be statistically significantly higher than the maxilla. As a result of the researches in the literature, there is no study comparing the Tissue volume (TV), Bone volume (BV), Tissue surface (TS), bone surface (BS), and Intersection surface (IS) parameters, which are statistically different in our study by comparing the maxilla with the mandible.

Percent bone volume (BV / TV), Bone surface/volume ratio (BS / BV), Bone surface density BS / TV, Trabecular pattern factor (Tb. Pf), Structure model index (SMI), Trabecular thickness between Maxilla and mandible in our study. A difference was observed in (Tb. Th), Trabecular number (Tb. N), Trabecular separation (Tb. Sp), Degree of anisotropy (DA) parameters, and this difference was not statistically significant ($p > 0.05$). A comparison of these parameters has been made in the studies conducted and different findings were found from our study.

In our study, Trabecular thickness (Tb. Th) was found to be 1.026 mm in the maxilla and 1.109 mm in the mandible, and this difference was not statistically significant. Similarly, in the study conducted by Fanuscu and Chang (20), Trabecular thickness (Tb. Th) varied between the mandible and the maxilla between 0.09 mm and 0.13 mm. In yet another study, Kim JY and Henkin J. (23) reported that the average trabecular thickness between the maxilla and the mandible was 0.10 mm and 0.09 mm on average, Ding and Hvid (29) reported that Three-dimensional trabecular thickness changes in trabecular thickness between different age groups, but statistically only from 70 years of age. After that, Kim JY and Henkin J. (23) Tb. Th value is statistically insignificant, but the mandibular region has a higher value than the maxillary regions, However, unlike these studies, Block et al. (22) Trabecular thickness Tb. were significantly higher in the mandible than in the maxilla.

In this study, Trabecular separation, (Tb. Sp) was 0.388 in the maxilla and 0.386 in the mandible.

There was no significant difference. In some studies, it was reported to be high, although there was no statistical significance. Blok et al. (22) Trabecular separation (Tb. Sp) was 0.69 in the maxilla and 0.71 mm in the mandible in his study. Similarly, Kim JY and Henkin J. (23) reported that this measurement was higher in the maxilla compared to the mandible and ranged from 0.44 mm to 1.77 mm, but no significant what is not the same was observed between the groups.

In our study, the Trabecular number (Tb. N) was 0.945 in the maxilla and 0.822 in the mandible. Y. Blok et al. Similar to our study, the Trabecular number (Tb. N) was found to be 1.57 in the maxilla and 1.50 in the mandible, but Kim JY and Henkin J. (23) and Fanuscu and Chang (20) compared to Maxilla, the Trabecular number (Tb. N) in the mandible is approximately reported that twice as many were found. Kim JY and Henkin J. (23) reported no significant difference in Tb. N or SMI.

Fanuscu and Chang (20) found nearly twice as many in BV / TV, and BMD in the mandible when compared to Maxilla. The connectivity density and structure model index (SMI) was 2.5 times and 3.3 times higher in the mandible, respectively. Blok et al (22) Compared to the maxilla the anterior mandible had a significantly higher BFV (p <0.001) and DA (p = 0.042). Akça et al (14). Percent bone volume (BV/TV) between the maxilla and mandible in 2006 was statistically significant at 95% confidence level (P <0.05). In a study Kim JY and Henkin J. (23) BV / TV stated that although the difference was not statistically significant, the amount of bone in the anterior mandible was the highest. On the other hand, BS / BV, which is a parameter characterizing the complexity of the structure, showed an inverse relationship with BV / TV. Kim JY and Henkin J. (23) reported about twice as many BV / TV and BMD in the mandible compared to Maxilla.

Conclusion

The outcomes demonstrate that there is a measurable quantitative difference in bone density between maxilla and mandible. In this study, using micro-CT, Tissue volume; Bone density with Bone volume (BV), Tissue surface (TS), Bone surface (BS), Intersection surface (OS) parameters were investigated. These parameters are highly correlated with the three-dimensional microarchitecture parameters that represent the quality of the trabecular bone.

This preliminary study reveals that understanding the mechanical capability of the trabecular bone, the prognosis of implant therapy, advances in implant design, and surgical techniques can be found in more information.

Abbreviations

TV, Tissue volume
BV, Bone volume
BV/TV, Percent bone volume
TS, Tissue surface
BS, Bone surface
IS, Intersection surface
BS/BV, Bone surface / volume ratio,
BS/TV Bone surface density
Tb.Pf Trabecular pattern factor
SMI, Structure model index
Tb.Th, Trabecular thickness
Tb.N, Trabecular number
Tb.Sp, Trabecular separation
DA, Trabecular separation

Ethical Approval: *Ethical agreement was acquired from Ankara Yıldırım Beyazıt University Ethics Committee (Date: 19/04/2019 Project number: D-KA16 / 10).*

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Writing manuscript: H.S., F.G., M.O.
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