

Alveolar bone density and its clinical implication in the placement of dental implants and orthodontic mini-implants

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ABSTRACT

هدف هذا البحث الي قياس كثافته عظام الفكين من خلال دراسة وتحليل الأشعة المقطعية لعدد 100 مريض (50 من الذكور و50 من الإناث) مما تم معالجتهم خلال عام واحد بكلية طب الأسنان بجامعة الدمام. وقد تم تحليل الأشعة المقطعية باستخدام برنامج سمبلانت وبرنامج إيكات. لخصت الدراسة إلى أن كثافة العظام بالعينة التي تم اعتمادها كانت أقل عموماً من كثافة العظام في الدراسات المماثلة على الشعوب المختلفة مما يشير إلى ضرورة قياس كثافة العظام وتحليلها لكل مريض قبل البدء بعمل غرسات الأسنان أو براغي تقويم الأسنان.

Objectives: To assess the bone density in maxilla and mandible in dentate and edentulous patients in Saudi population.

Methods: This study involved a retrospective analysis of cone beam CT images of 100 patients (50 male and 50 female) who have come to College of Dentistry, University of Dammam, Dammam, Kingdom of Saudi Arabia between January 2014 and 2015. Using the bone density option in the Simplant software, the Hounsfield unit (HU) was calculated at the edentulous sites. While for dentate sites, a region of interest was selected coronally at 3-5 mm to the root apex using I-CAT vision software. The densities of the buccal bone and cancellous bone were measured at interradicular areas of a specific teeth.

Results: The highest bone density at the edentulous sites was at the mandibular anterior region (776.5 ± 65.7 HU), followed by the mandibular posterior region (502.2 ± 224.2 HU). Regarding the dentate sites, the highest bone density was at the buccal cortical plate of the lower incisor teeth (937.56 ± 176.92 HU) and the lowest bone density was at the cancellous bone around the posterior maxillary teeth (247.12 ± 46.75 HU).

Conclusion: The alveolar bone density at dentate and edentulous sites in our population is generally lower than the norm reference density of other populations, which

dictates the need for quantitative assessment of bone density before implants and mini-implants placement.

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The success of dental implants and orthodontic mini-implants in the upper and lower jaw requires an adequate quantity and quality of bone. Although the mechanism of connecting bone and mini-implants is different than with dental implants, bone quality still dictates the primary stability of both dental implants¹ and mini-implants. Therefore, it affects the overall treatment plan.^{2,3} A treatment plan could involve some modifications, either during the surgical procedure, or in selecting an implant and mini-implant design, size, and surface texture.^{4,5} Bone quality is a term that dictates multiple factors that contribute to bone strength.⁶ However, clinicians use bone mineral density (BMD) as an objective indicator to differentiate the different qualities of bone.⁷⁻⁹ A patients' BMD is reported as a T-score, which is the number of standard deviations (SD) above or below the mean BMD for normal young adults. It has been documented that patients with osteopenia have a T score of -1 to -2.5 SD and osteoporosis were less than -2.5.¹⁰ Low bone quality problems differ in different populations.¹¹ In Saudi Arabia, osteoporosis is more severe than in the rest of the world, with a reported prevalence ranging from

30-48%.¹¹⁻¹³ Therefore, Saudi clinicians recommended the early screening of bone quality in Saudi females.¹⁴ Moreover, osteoporosis societies in the Middle East and North Africa recommended that each country should establish its local BMD reference data.¹⁵ Although dual energy x-ray absorptiometry (DXA) has been used as a valid tool for measuring BMD at different skeletal sites, such as the spine and femur,^{12,13} it does not offer cross-sectional imaging. Consequently, it is not applicable for implant placement. Therefore, other tools, such as computerized axial tomography (CT) and cone beam CT (CBCT) have been used to measure BMD in the oral cavity.¹⁶ Many studies have validated CBCT by comparing its results with histological findings,¹⁷ CT and micro CT results.¹⁸⁻²¹ Cone beam CT is currently the most commonly used tool to assess the quantity of bone in the upper and lower jaw during dental implant planning and mini-screw placement.²²⁻²⁴ With low radiation exposure, new CBCT machines can generate high quality Digital Imaging and Communications in Medicine (DICOM) images, which can be easily reformatted by computer programs, such as Simplant and DentaCT, to yield an accurate measurement of BMD.^{25,26} Bone mineral density that was expressed in Hounsfield units (HU) was originally classified into D1: with HU >1250, D2: with HU ranging from 850-1250, D3: with HU ranging from 350-850, and D4: with HU <350.³ Such classification has been updated by combining D2 and D3 into one group that has a HU range from 500-850.⁸ Furthermore, it was found that D1 is mainly present at the anterior mandible, D2 and D3 at the posterior mandible and anterior maxilla, and D4 at posterior maxilla. A Hounsfield calculation depends on the density values for air (-1,000), water (0), and dense bones (+1,000), which are arbitrary.⁸ This study was designed to fulfill the need for an objective quantitative alveolar bone density reference in Saudi population. We aimed to investigate the bone density at different areas of the upper and lower jaws using CBCT.

Methods. *Study parameters.* This study was approved by the Ethical Committee of the University and followed the principles of Declaration of Helsinki. The study involved a retrospective analysis of 100 consecutive CBCT images for 100 different patients

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(50 male and 50 female) who presented to the College of Dentistry, University of Dammam, Dammam, Kingdom of Saudi Arabia between January 2014 and 2015. The CBCT scans (I-CATTM, 3-D imaging system, Imaging Sciences International Inc., Hatfield, PA, USA) were taken from the Dental College at 0.4 voxels and 8.9s. The CBCT scans were originally taken from patients as a part of screening prior to dental implant placement, or wisdom tooth surgery. The identified and retrieved images were from patients who were Saudi, adult (>18 years), medically fit, partially dentate with no pathological bone conditions in the upper or lower jaw, and no history of orthodontic treatment. Moreover, the inclusion criteria involved cigarette smokers' patients, who smoke up to a pack per day. The patients' characteristics were identified from the data reported in the retrieved patients' files. The sample size calculation was based on an estimated number of 300 valid CBCT images (according to the inclusion criteria), on 95% confidence level and 8% confidence interval.

Assessment of BMD at the dental implant site (edentulous areas). All scans were viewed using I-CAT vision (Q version 1.8.1.10, Imaging Science International, Hatfield, PA, USA) and were then exported to SIMPLANT software (Simplant 17 Pro, Dentsply Implants, Belgium) for implant planning. Using the interactive setting of Simplant, a simulated implant was placed on panoramic images according to a simulated future prosthetic plan. The implant location was adjusted by manipulating the simulated implant on the cross-sectional images. The simulated implant size was selected to allow for 2 mm of bone from the floor of the maxillary sinus, inferior alveolar canal, and nasal floor. Using the bone density option in the Simplant software, the HU was calculated at the implant site and at 1 mm around the implant (Figure 1).

An oral and maxillofacial surgeon calculated HU at different edentulous sites in the upper and lower jaw after inter-examiner calibration and discussion of 5 cases that were randomly chosen. The bone density at each implant site was measured twice on each image. In the case of multiple edentulous sites, a mean value was taken so that quadrant had a mean value for the upper anterior area, upper posterior area (distal to canine root), lower anterior area, and lower posterior area (distal to canine root).

Assessment of BMD at the mini-implant sites (dentate areas). All scans were viewed using I-CAT vision software (Q version 1.8.1.10, Imaging Science International, Hatfield, PA, USA). A region of interest

(ROI) was selected coronally at 3-5 mm to the root apex. Each ROI was viewed in axial sections. The densities of the buccal bone and cancellous bone were measured by selecting points at interradiolar areas between the central incisors, central and lateral incisors, lateral incisors and canine, canine and first premolar, first and second premolars, second premolar and first molar, and first and second molars. When measuring the density of the cortical bone, its center point was chosen. The density of the cancellous bone was measured halfway bucco-lingually between the buccal and palatal or lingual cortical plates. Hounsfield units were calculated using the bone density option in the I-CAT vision software. An oral and maxillofacial surgeon calculated the HU at the different dentate sites in the upper and lower jaw after inter-examiner calibration and discussion of 5 cases that were randomly chosen. The BMD of each area was measured twice on each image for both the right and left sides.

Statistical analysis. All data were collected from the retrospective analysis of CBCT images and entered into MS Excel sheets and then, the Statistical Package for Social Sciences software version 22 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. All data were presented as mean and SD. One-way analysis of variance (ANOVA) was used. A Tukey range test was performed for multiple comparisons of the 4 dentate sites in the maxilla and mandible. An independent t-test was used to compare similar edentulous and dentate sites.

Results. The sample included 100 patients with a 1:1 male to female ratio. The mean age was 36.1 ± 11.3 . The study investigated a total of 220 edentulous sites (38 maxillary anterior and 36 maxillary posterior, and 22 mandibular anterior and 124 mandibular posterior) and a total of 800 dentate sites around the incisors, canines, premolars, and molars (buccal, cancellous, and lingual or palatal cortical bone).

There was no significant difference in the bone density in the dentate and edentulous sites between the male and female patients, between smokers ($n=25$) and non-smokers ($n=75$), or between either sides of the maxilla and mandible, while assessing the bone density using SIMPLANT software. Therefore, we mix-matched the measurements of maxilla and mandible on either sides and between male and female patients. The highest bone density at the edentulous sites was at the mandibular anterior region (776.5 ± 65.7 HU), followed by the mandibular posterior region (502.2 ± 224.2 HU), the maxillary posterior (320.05 ± 193.6 HU) region, and the maxillary anterior (313.84 ± 190.7 HU) region. There was no significant difference in bone densities between the maxillary anterior and posterior regions. However, there was a significant difference in the bone densities between the mandibular anterior region and all of the other sites. Furthermore, there was no significant difference between the edentulous and dentate sites in different regions, except for the upper anterior region (Table 1).

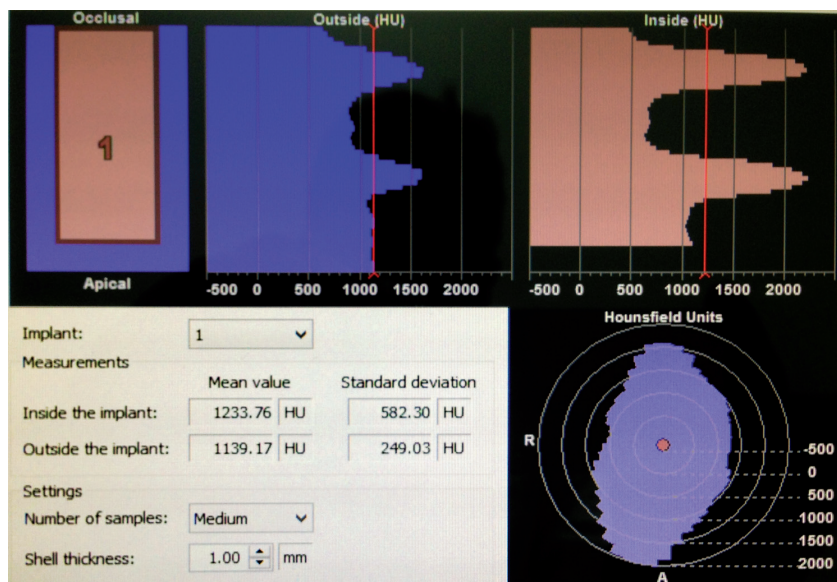


Figure 1 - Bone density in Hounsfield units (HU) at the simulated implant site.

Table 1 - Average bone density at edentulous and dentate sites in Hounsfield units.

Site	Edentulous sites	Dentate sites	P-value
Max anterior	313.84 ± 190.7 (n=38)	718.84 ± 27.59 (n=200)	0.005
Max posterior	320.05 ± 193.6 (n=36)	562.36 ± 127.15 (n=200)	0.091
Mad anterior	776.5 ± 65.7 (n=22)	823.96 ± 54.28 (n=200)	0.51
Mad posterior	502.2 ± 224.2 (n=124)	745.84 ± 19.40 (n=200)	0.12

Data were presented as mean ± SD and numbers in bracket.

Table 2 - Bone density measured at each dentate site of the maxilla and mandible in Hounsfield units.

Jaw	Site	Incisor	Canine	Premolar	Molar	P-value
Maxilla	Buccal	756.85 ± 139.27 ^b	756.59 ± 158.48 ^b	725.05 ± 138.37 ^b	623.44 ± 170.05 ^a	0.000
	Cancellous	618.57 ± 144.83 ^c	621.80 ± 154.98 ^c	509.08 ± 159.65 ^b	247.12 ± 46.75 ^a	0.000
	Palatal	839.66 ± 173.82 ^c	719.62 ± 185.35 ^b	722.72 ± 153.76 ^b	546.80 ± 176.33 ^a	0.000
Mandible	Buccal	937.56 ± 176.92 ^c	901.16 ± 185.36 ^{ab}	845.09 ± 172.22 ^a	903.14 ± 151.32 ^{ab}	0.002
	Cancellous	776.54 ± 173.52 ^c	599.20 ± 231.15 ^b	600.04 ± 198.24 ^b	476.34 ± 269.47 ^a	0.000
	Lingual	872.96 ± 190.12	856.37 ± 148.33	833.14 ± 154.24	816.86 ± 159.94	0.079

Data were presented as mean±SD. same letters (^{a, b, c, ab}) are not significant at $p=0.05$ by Tukey test.

Regarding the dentate sites, the highest bone density was at the buccal cortical plate of the lower incisor teeth and the lowest bone density was at the cancellous bone around the posterior maxillary teeth. There was a significance difference in the bone density between the bones (labial and cancellous) at the lower anterior regions and the bones (labial and cancellous) at the lower posterior regions (Table 2). In the same vein, all of the maxillary bones had a bone quality that is ranged from 350-850 HU, except the cancellous bone around the maxillary posterior teeth, which was less than 350 HU.

Discussion. This study measured bone densities at multiple sites using a protocol that has been used in previous studies.²⁴ Therefore, we objectively compare our results with different populations.

In our study, we used DentaCT to measure the bone densities at dentate sites. DentaCT is a recognized application for reformatting CBCT images of the maxilla and mandible²⁵ to measure the density at edentulous sites. It was necessary to use virtual implant planning software to simulate implant placement. Simplant is one of the most common software programs that are currently used to fabricate a surgical guide for computer-guided implant insertion.²⁷ There is a strong correlation between the bone density value generated by Simplant and the subjective quality score.⁸

Our study reported the measurement of bone density using CBCT in HU. Although Lekholm and Zarb's²⁸ classification and Misch's classification were based

on the HU generated from CT, still it was recorded that there is a positive high correlation between the HU generated from CBCT and CT. Moreover, it was concluded that the HU generated from CBCT is usually higher in number than the corresponding CT for the same bone area.¹⁸ Moreover, density values of CBCT and CT have been revealed to be correlated to the bone density values based on the Lekholm and Zarb classification.²⁸ The correlation coefficient has been reported to be 0.59-0.61.²⁹ This study showed that the bone densities across all of the edentulous sites were D3-D4. Although this result differs from both Lekholm and Zarb's classification²⁸ and Misch's classification,³ which indicate that the anterior mandibular region is usually D1 (>1250 HU) and that the mandibular posterior region is D2 (850-1250 HU), it is consistent with the general trend of the Saudi population, which shows high percentages of osteoporosis and osteopenia. The same conclusion can be confirmed by evaluating the bone density in the maxilla because there was no significant difference in the bone densities between the maxillary anterior and posterior regions. Furthermore, the mean BMD at the maxillary anterior (313.84 ± 190.7 HU) and posterior regions (320.05 ± 193.6 HU) was lower than the BMD findings in other studies from the USA³⁰ (517 ± 177 and 333 ± 199 HU), UK⁸ (696.1 ± 244 and 417.3 ± 227.3), and Italy³¹ (708 ± 277 and 505 ± 274 HU). Such comparison revealed that BMD in our population is far less than compared with other population especially if we considered that HU values that are generated based on CBCT images in our study

is by default higher than the corresponding HU values that are generated from CT images. Comparing the BMD of edentulous sites with dentate sites showed no significant differences at the anterior mandible, posterior mandible, and posterior maxilla. The anterior maxilla dentate sites showed higher bone densities than the edentulous sites. Such findings could be explained based on the age of the patients included in the study. Older patients have the anterior sites edentulous compared with the age at which dentate sites occur.

For the dentate sites, the highest bone density was at the buccal cortical plates of the lower incisors and the lower molars. These results are similar to findings from other studies and could be due to the increase in cortical plate thickness from the anterior to posterior regions and the reinforcement of the buccal cortical plate at the posterior region by the external oblique ridge.³²

For the maxillary dentate sites, the density of the buccal cortical plate at the anterior and posterior regions was lower than that found in a sample Korean population.³² These results could be due to the high prevalence of osteoporosis in the Saudi population.

These data could be relevant when choosing the type of mini-implants that should be used in our population. Because orthodontic mini-implants depend on mechanical interlocking for their attachment with bone, it may be more appropriate because of the general trend of low bone density to use self-drilling screws rather than predrilled screws. Furthermore, teeth movement would be expected to be faster in our patients, which could be seen as important factor when considering the amount of required force and the future degree of relapse. It is necessary for an orthodontist to quantify bone density using CBCT to choose the best location for insertion of mini-implants, especially if high forces are anticipated. In regard to dental implants, multiple studies^{1,3,4} confirmed that one of the factors that dictate the primary stability of dental implants and a high implant stability quotient (ISQ) during insertion is the density of the available bone. Our findings may be informative to implant surgeons working in our population who may need to modify their drilling protocol or implant selection. Furthermore, immediate loading protocols that have been designed using research on different populations have to be cautiously applied by prosthodontics working in our population. A routine assessment of bone quality that is parallel to the regular evaluation of bone quantity for every case should be used, especially with the current availability of CBCT technology.

Although our study has provided an initial step in the direction of bone density assessment and its clinical relevant to surgeons, prosthodontics, and orthodontics working in our population, still it was limited to 100 patients who belong to the Eastern Provenance of Saudi Arabia. Multiple studies covering different areas in Saudi Arabia using CBCT are recommended to establish a norm reference value for the whole population.

In conclusion, the alveolar bone density at dentate and edentulous sites in our population is generally lower than the norm reference density of other populations, which dictates the need for quantitative assessment of bone density before implants and mini-implants placement.

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