Assessment of Radiodensity at Mandibular Periapical Bone Sites using Three-Dimensional Cone-Beam Computed Tomography

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ABSTRACT

Objectives: The aims of this retrospective study were to objectively assess bone density values obtained by cone-beam computed tomography and to map the periapical and inter-radicular regions of the mandibular bone.
Material and Methods: In total, periapical bone regions of 6898 roots scanned by cone-beam computed tomography were evaluated retrospectively, and the results were recorded using Hounsfield units (HU).
Results: The correlation between periapical HU values of adjacent mandibular teeth were strongly positive ($P < 0.01$). The anterior region of the mandible yielded highest mean HU value (633.55). The mean periapical HU value of the premolar region (470.58) was higher than that was measured for molar region (374.58). The difference between furcation HU values of the first and second molars was unnoticeable.
Conclusions: The results of this study have tried to evaluate the periapical regions of all mandibular teeth, which could ease to predict the bone radiodensity before implant surgery. Even though the Hounsfield units provide the average radio-bone density, a site-specific bone tissue evaluation of each case is essential for appropriate cone-beam computed tomography preoperative planning.

Keywords: cone-beam computed tomography; bone density; dental implants.

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INTRODUCTION

Improved implant surface technology has made it reasonable to insert dental implants into fresh extraction sockets. Immediate implantation is an enhanced protocol for osseointegration determined by Brånemark [1] and it was termed 'Type 1' installation at a consensus conference [2]. Immediate insertion not only minimizes post extraction bone resorption but also improves the aesthetic results by maintaining the periodontal apparatus of the extracted tooth [3]. One of the most important indications for immediate implant placement is to attain primary stability of the placed implant. Primary implant stability is the essential parameter for the long-term success of an implant treatment by enhancement of the osseointegration process [4]. This stability mostly defined as the biomechanical engagement with cortical bone [5]. Periapical region of the alveolar bone is essential to achieve adequate implant stability. Therefore, if surrounding anatomy of the bone is available, prepared implant socket should exceed 3 to 5 mm beyond the apex [6].

Bone quality compose of the various aspects of bone structure, including bone turnover, mineralization level, and compound of mineral and bone matrix [7]. Bone mineral density and microstructure of the alveolar bone are the strongest features for bone strength [8]. Therefore, alveolar bone density needs to be simultaneously evaluated to provide a more accurate estimation of bone strength [9,10]. Several radiographic methods can be used to evaluate the alveolar bone density, including dual-energy X-ray absorptiometry, ultrasound, medical computer tomography (CT), cone-beam computed tomography (CBCT) [11-15]. Although micro-computed tomography (micro-CT) is considered as a gold standard for the bone assessment, this method is limited to *ex vivo* bone samples and cannot be applied clinically in daily practice [16,17]. In recent years, CT has been a common imaging technique for the evaluation of the bone structure and density [18-21]. Even more recently, due to the need for more affordable imaging techniques with lower radiation dose, CBCT has been widely employed for implant surgery [22]. CBCT was introduced into dental radiography in 1997 for more accurate linear measurements. Afterward, the use of CBCT for qualitative assessments before implant surgeries has continued to grow [23,24]. Other clear advantages of CBCT over CT scanners are its good spatial resolution, as well as a good pixel/noise ratio [25].

Three-dimension of CBCT data using SimPlant® Pro version 17.01 software (Dentsply Implants NV; Research Campus 10, Hasselt 3500, Belgium) facilitates mapping the bone around dental roots within a defined area [26,27]. Although some CBCT studies have been conducted to analyse bone thickness around teeth, the information regarding radio-density in the periapical region has been under-represented [26,28]. Therefore, the aims of this retrospective study were to evaluate periapical and inter-radicular bone densities of all mandibular teeth and to provide a bonemap of lower jaw using a cone-beam computed tomography system.

MATERIAL AND METHODS

The CBCT scan images in the archives of the College of Dentistry at the University of Illinois at Chicago between January 2004 and April 2016 were used for this retrospective study. The study protocol was approved by the Institutional Review Board of University of Illinois at Chicago (No. 2016-0448). Eight hundred patients were included in the study in terms of the inclusion and exclusion criteria.

The inclusion criteria were:

- Scan images with high resolution.
- No developmental anomalies.
- No periapical lesions.

Supernumerary, third molar and impacted teeth were excluded from the evaluations. In total, 6164 teeth were included in the study, resulting in a convenience sample of 6898 roots. Patient privacy and confidentiality were respected and no personal data were unveiled.

The CBCT scans were acquired by i-CAT® Model 17-19 CBCT device (Imaging Sciences International; Hatfield, Pennsylvania, USA). with the following exposure protocol: 110 mm FOV, 26.9 seconds exposure cycle, 1.4 mA and 120 kV, with a resolution of 0.2 voxels, the thickness of 0.1 mm. Digital Imaging and Communications in Medicine (DICOM) standard (https://www.dicomstandard.org/) was used to save the images of the scans. Hounsfield unit (HU) measurements in CBCT images were performed on a Dell monitor with a resolution of 1366 x 768 pixels (Dell Inc.; Round Rock, Texas, USA) using Simplant® Pro 17.01 (Dentsply Implants NV).

Practicing due to the use of the SimPlant® software (Dentsply Implants NV) and interpreting the density measurements in CBCT images were provided over numerous periods. All subsequent radio-density measurements of the bone were carried out by one experienced examiner (S.G.).

The following radio-density measurements were performed through HU option of the Simplant® software (Dentsply Implants NV) around each included root by choosing targeted square in the image (Figure 1) (2 × 2 mm square targeted field size; with a modification) [29]:

1. Periapical bone density: CBCT-HU value was measured on the line of the radiological apices of the roots.
2. Retromolar bone density: CBCT-HU value of the retromolar region.
3. Furcation bone density: CBCT-HU value of the mandibular teeth.

Intra-observer reliability of the measurements was examined by using interclass correlation coefficients. The Pearson value r^2 for intra-observer variability was 0.97.

Statistical analysis

All recorded data were sent for statistical evaluation to a data editor of Number Cruncher Statistical System (NCSS) version 24.0 (NCSS LLC Inc.; Kaysville, Utah, USA) (https://www.ncss.com/). Besides the descriptive statistical analysis (mean, standard deviation, minimum and maximum values), the Shapiro-Wilk test was applied for the normality of the data. Mann-Whitney U-Test was used for the comparison of nonparametric data; whereas the Spearmen test was applied for the calculation of the correlation coefficient between quantitative values. We defined a strong linear association between variables as $r \geq 0.7$ ($P < 0.01$), a moderate association as $0.6 < r < 0.7$ ($P < 0.01$), and a weak association as $r < 0.6$ ($P < 0.05$). A P-value below 0.05 was considered as statistically significant. Parametric data were expressed as mean and standard deviation (M [SD]).

RESULTS

Differences between the left and right sides were small and statistically insignificant ($P > 0.05$). All mean CBCT-HU values were established in Table 1. Different colours were used to describe various CBCT-HU values of different teeth and regions in mandibular bonemap (Figure 2). The correlation between periapical CBCT-HU values of almost all adjacent teeth were strongly positive ($P < 0.01$). We found a weak correlation between the furcation areas of the first and second molar teeth ($P < 0.05$). The correlation coefficients and P-values were shown for all groups in Table 2.

Figure 1. The scheme of measured regions of the peri-radicular bone of mandible.

Table 1. Descriptive statistics of CBCT-HU values of mandibular bone

Region	Number (sample size)	Mean (SD)
Retromolar	255	252.38 (254.13)
Second molar - distal root	291	338.5 (234.92)
Second molar - furcation	91	383.71 (236.82)
Second molar - mesial root	252	347.31 (279.53)
First molar - distal root	640	377 (277.05)
First molar - furcation	515	379.64 (237.44)
First molar - mesial root	569	330.68 (280.22)
Second premolar	877	409.8 (252.92)
First premolar	1008	510.3 (254.21)
Canine	1094	562.76 (241.8)
Lateral incisor	1081	626.18 (309.41)
Central incisor	1086	669.26 (379.62)

CBCT = cone-beam computed tomography; HU = Hounsfield unit; SD = standard deviation.

The CBCT-HU values were summarized as four different mandibular regions (Table 3):

- Molar region (M): periapical regions of the mandibular first and second molar teeth.
- Furcation region (F): furcations of the mandibular first and second molar teeth.
- Premolar region (PM): periapical regions of the first and second mandibular premolar teeth.
- Lower anterior region (A): periapical regions of the mandibular anterior teeth.
- Retromolar region: between the last molar tooth and anterior edge of the ramus.

Correlation coefficients (r-value) between CBCT-HU values and age of the included patients were established in Table 4.

Table 2. Correlation coefficients between periapical bone radio-densities of adjacent mandibular teeth

Regions	Coefficient value	Second molar - distal root	Second molar - furcation	Second molar - mesial root	First molar - distal root	First molar - furcation	First molar - mesial root	Second premolar	First premolar	Canine	Lateral incisor
Second molar - furcation	r	0.559	1	-	-	-	-	-	-	-	-
	P	0.001[b]	-	-	-	-	-	-	-	-	-
Second molar - mesial root	r	0.761	0.757	1	-	-	-	-	-	-	-
	P	0.001[b]	0.001[b]	-	-	-	-	-	-	-	-
First molar - distal root	r	0.646	0.42	0.688	1	-	-	-	-	-	-
	P	0.001[b]	0.001[b]	0.001[b]	-	-	-	-	-	-	-
First molar - furcation	r	0.509	0.433	0.604	0.664	1	-	-	-	-	-
	P	0.001[b]	0.001[b]	0.001[b]	0.001[b]	-	-	-	-	-	-
First molar - mesial root	r	0.667	0.455	0.707	0.816	0.655	1	-	-	-	-
	P	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	-	-	-	-	-
Second premolar	r	0.586	0.462	0.593	0.682	0.578	0.667	1	-	-	-
	P	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	-	-	-	-
First premolar	r	0.431	0.289	0.502	0.547	0.524	0.546	0.68	1	-	-
	P	0.001[b]	0.016[a]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	-	-	-
Canine	r	0.356	0.369	0.455	0.459	0.446	0.431	0.529	0.702	1	-
	P	0.001[b]	0.002[a]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	-	-
Lateral incisor	r	0.331	0.231	0.378	0.386	0.375	0.336	0.4	0.586	0.73	1
	P	0.001[b]	0.058	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	-
Central incisor	r	0.32	0.291	0.333	0.404	0.367	0.309	0.398	0.54	0.676	0.838
	P	0.001[b]	0.017[a]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]	0.001[b]

[a]Statistically significant at level $P < 0.05$ (Spearmen's correlation test).
[b]Statistically significant at level $P < 0.01$ (Spearmen's correlation test).
r-value and P-value - Spearmen's rho.

Table 3. Descriptive statistics of CBCT-HU values determined at different regions of the mandible

Region	Mean (SD)
Mandibular molar region	374.58 (270.63)
Furcation of the mandibular first and second molars	377.37 (231.5)
Mandibular premolar region	470.58 (245.73)
Mandibular anterior region	653.55 (328.14)

CBCT = cone-beam computed tomography; HU = Hounsfield unit; SD = standard deviation.

Table 4. Correlation of CBCT-HU values with age

	Mandibular molar region	Mandibular premolar region	Mandibular anterior region
P-value	0.001[a]	0.001[a]	0.056
Correlation coefficient	0.3	0.24	0.08

[a]Significant correlation at the 0.01 level (Pearson correlation test).
CBCT = cone-beam computed tomography; HU = Hounsfield unit.

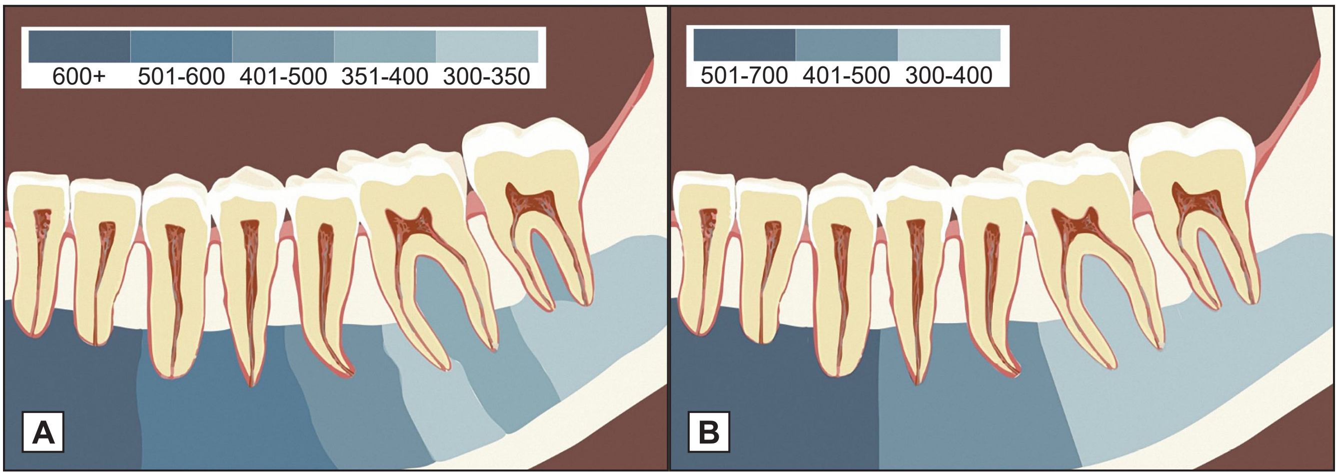

Figure 2. The bonemap of different regions of the mandible. A = bonemap in 50 HU sensitivity; B = bonemap in 100 HU sensitivity.

DISCUSSION

The evaluation of the bone quality before the implant surgery is essential for the clinicians. In particular for the immediate implantation protocol, accurate information about periapical bone radio-density will help the dentists categorize the bone quality, and more easily to determine the implant system. According to Romanos et al. [30] and Turkyilmaz et al. [31] primary implant stability after immediate placement seems to be enhanced due to the considerable increase of the peri-implant bone density. Therefore, we have currently focused on periapical bone radio-density, which facilitates to predict the quality of the bone before the immediate implant surgery.

In recent years, CBCT scanners are considered sufficiently compact and affordable to be installed in clinics. Regarding HU evaluations in CBCT images, the majority of authors have found it controversial because of the enhanced scattered beam and noise [32-35]. These researchers suggest that scatter and artifacts have undesirable impacts on the reliability of HU values in CBCT images. The HU value is routinely applied to determine the bone density in CT images [16-18]. However, there are also several studies reported that HU values could be used to evaluate the bone density in CBCT images [14,36]. Indeed, CBCT has outstanding advantages over CT, such as high resolution, potentially lower radiation dose, and reduced costs [37-40].

This retrospective study evaluates the periapical and inter-radicular bone densities around every single root and distributes the bonemap of the three regions in the mandible. In comparison with the previous studies, premolar region was evaluated as a separate region. The mean periapical CBCT-HU value of the premolar region (470.58) was higher than that was measured for molar region (374.58), but less than that was determined for anterior region (653.55) (Figure 2B). Moreover, the bone densities of the furcation and retromolar regions were assessed separately as well. The difference between furcation CBCT-HU values of the first and second molars was unnoticeable.

As far as the authors are aware, there are no studies published in English evaluating periapical bone density of each root. The previous studies have evaluated proper implant recipient sites in edentulous regions by the sagittal images [26,28]. A bonemap of the periapical regions, which may play critical role in immediate implant placement, has not been established yet. Therefore, this study might help the clinicians predict the periapical bone radio-density before the immediate implantation. We evaluated the periapical bone densities in a targeted square around the roots. The CBCT-HU value for each root was calculated and presented separately because the apical portion of the extraction sockets plays a crucial role in the primary stabilization of the immediately placed implants. The anterior region yielded highest mean CBCT-HU value (653.55), followed by the premolar region of the mandible (470.58). The results of this study were compatible with those reported by by Hao et al. [26] and others [16,23,26].

In this retrospective study, the mean CBCT-HU values of the periapical regions in elder patients were higher than in younger patients (Table 4). These results are in accordance with some three-dimensional CT studies [16]. The conventional studies have shown that the mineral density and bone volume fraction are significantly reduced in aged patients [41,42]. These dissimilar outcomes might be originated from applied assessment techniques and radiological technologies. Further studies using micro-CT may provide even more accurate information about periapical bone change with aging, even though the larger sample size of the present study showing a significant advantage in terms of obtaining precise mean values.

The periapical bone of the molar area was the lowest (374.58 CBCT-HU), and there was a decrease in periapical bone radio-density from the anterior to the retromolar region. The CBCT-HU value of the anterior area was the highest (653.55). These differences were supported by different CT and CBCT studies [16,23,26].

While this retrospective study is among very few such studies, there are some limitations to it. The results of the present study should be evaluated in osteoporotic patients to clarify the bone density differences with systemically healthy patients. Some studies showed statistically significant difference in densities of the osteoporotic patients' jaws [43-45].

The suspicion of the reliability of intensity values between different CBCT machines is another limitation [33]. Therefore, our established HU values are more appropriate with mentioned CBCT machine and three-dimensional evaluation software. In addition to the CBCT-HU uniformity, evaluated size and shape of the bone may result in difference in outcomes from other radiologic studies. Further clinical studies are needed to determine whether it will be possible to derive detailed bone radio-density information from HU in CBCT images. Nevertheless, authors also recommend some future clinical studies with micro-CT evaluations of bone biopsies so as to explore the correlation with HU values in CBCT.

CONCLUSIONS

This retrospective study demonstrated that the clinical application of cone-beam computed tomography to evaluate the radio-density of periapical bone sites before the immediate implant surgery could be beneficial to its lower radiation dose and lower cost. Within the above-mentioned limitations, the results of this study have tried to demonstrate the periapical regions of all mandibular teeth. The presented bonemap of different regions of the mandible will be helpful to provide a guideline for planning implant surgery. Even though our results provide the average radio-bone density in the periapical bone areas, individual evaluation of each case is essential for appropriate preoperative planning.

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