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Research Article

Studying the Correlation between CBCT Linear Measurement and Actual Measurement during Surgery in Implant Candidates

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Abstract

Background: One of the main uses of CBCT is the design of implant therapies, and linear calculations in these therapies are important in quantifying bone (height and width). However, previous researches have all been conducted on dry skulls and no research has been performed in patients' clinical conditions.

Aim of the Study: The aim of this research was to determine the correlation between CBCT linear measurements and actual measurements during surgery in patients undergoing implant surgery.

Materials and Methods: In diagnostic research, 54 patients were selected for implant treatment in the premolars and the distance of the mental foramen to the apex of the ridge was measured using a caliper during surgery. The same calculations were repeated in CBCT images with Romex is software by two observers at two 2-week intervals. The difference in bone height calculations in CBCT images and actual measurements during surgery were analyzed by repeated values and ANOVA.

Results: The difference in absolute value of bone height in CBCT images (second observer) and its actual values was 0.811 ± 0.54, 0.894 ± 0.67 between the first observer and its actual values,0.871 ± 0.63 between the first observer in the next 2 weeks later and the actual values,0.804 ± 0.57 between second observer in 2 weeks later and its actual values. The mean difference of bone height observations by 2 observers in 2 weeks from its actual values was equal to 0.0 ± 828.89 mm. No significant differences were observed between the absolute magnitude values of bone height measurements in CBCT images and their actual values at the time of surgery after exposure.

Conclusion: Given the limited bone height difference in CBCT images from its actual values, this imaging modality appears to be a useful and accurate tool for estimating bone height in implant surgery in clinical settings.

Keywords: *Cone-Beam Computed Tomography; Bone Height; Linear Computations*

Introduction

Evaluation of bone quality and quantity, alveolar bone height, and precise location of the anatomical structures adjacent to the implant site are crucial and important. The accuracy of linear measurements in implant and other surgeries performed in close proximity to anatomical structures such as the inferior alveolar canal and the mental foramen is very important. Intraoral and panoramic radiographs have been recommended to evaluate bone height at the implant site, but these images cannot provide 3D imaging information to achieve the best preoperative treatment plan at the implant site [1].

CBCT (cone beam computed tomography) is a new technology that provides cross-sectional images without superimposition or fading [2] and greatly reduces radiation dose. On the other hand, the CBCT method produces 3D images of the maxillofacial region with the lowest radiation dose and cost [3].

Recent researches results have shown that linear measurements in CBCT images are accurate, but part of this increase in accuracy may be due to an increased contrast followed by air replacement with soft tissue and reduced scattering radiation caused by the absence of soft tissue [4,5]. Therefore, it is necessary to evaluate the accuracy of linear measurements in the presence of soft tissue like that encountered by the surgeon in the clinic.

Some research has also been done to measure the geometric accuracy of different CBCT devices, in which linear measurements occurred between anatomical points on dry skulls in CBCT images compared to results with caliper or conventional CT measurements between the same points [5,6]. On the other hand - in some cases - the accuracy of linear CBCT measurements was obtained between the external points identified on the skulls and the measurements obtained from these studies may not be sufficiently accurate due to the absence of soft tissue around the dry skull. Therefore, other studies have determined the accuracy of linear measurements between points within the skull bone with external soft tissue surrounding the skull to specify the effects of X-ray attenuation in both the external soft tissue and the soft tissue within the bone [1,7]. There is no doubt that the contrast of the image when the bone is in contrast to the air, like that in the dry skull, is greater than when the image of the bone is against the soft tissue as it is in the living patient. The soft tissue surrounding the bone not only reduces the contrast of the image but also acts as an additional source of scattered radiation and can subsequently alter the image contrast and measurement accuracy of the points on the image. In addition to soft tissue, metallic artefacts and artefacts resulting from patient movement can also influence the accuracy of CBCT images. Differences in scanning protocols such as voxel size and the number of projection images per unit time are also some factors affecting the dimensional accuracy of linear calculations in implant treatments. Although CBCT images cannot differentiate different types of soft tissue, the soft tissue surrounding the bone as well as internal soft tissue can reduce image quality [7].

Purpose of the Study

The purpose of this research was to determine the correlation between CBCT linear measurements and actual measurements during surgery in implant candidates.

Materials and Methods

The research was a diagnostic one done by studying tests. For this purpose, 54 patients undergoing implant surgery in the premolars were evaluated and the distance of the mental foramen to the apex of the ridge was measured using a caliper of 0.1 mm during surgery. Next, in CBCT images of the same patients, the same distances were measured using the Romex is Viewer software (version 2.9.9). The caliper used in the research had an accuracy of 0.1 mm. Observations of CBCT images were performed by 2 different observers and the observers examined CBCT images and reported bone height measurements. On the other hand, two observers measured the same intervals to determine and measure the reliability of their calculations over a 2-week interval and calculated the internal and external reliability of the observers.

On the choice of CBCT images location and position of the mental foramen in the axial sections, the curvature of the panoramic images was drawn in more buccal mode and the panoramic thickness was reduced as far as possible so that the mental foramen aperture was well visible in the patient's panoramic radiographs. Those cross-sections of the mental foramen were selected to be most consistent with the location of the measurements during surgery. Also, in the measurement during surgery and in the measurement on CBCT images, if the patient had tooth decay, one of the adjacent teeth of the mental foramen hole was considered as the upper index of the measurements. If the patient was completely toothless - the shortest distance from the hole roof to the apex of the ridge, which was the most vertical distance at the same time, was selected as the measurement path. The roof of the mental foramen hole was also considered as high as possible.

Mean and standard deviation of bone height values in CBCT images were calculated and reported based on direct measurement during surgery with a caliper. The mean and standard deviation of the differences in bone height computations with its actual values were determined and reported too. Bone height measurements were compared with its actual values and the difference between the two values was analyzed statistically by Repeated Measurement ANOVA and paired comparisons were performed by the Pair wise Comparisons test. Differences in the calculations of bone height measurement based on qualitative criteria (less than 2 and 1 mm, 2 and 1 mm and more) were also analyzed by McNemar test in different groups with real height values. On the other hand, the linear regression test was used to investigate the effects of different calculations on CBCT images in predicting actual bone height values. Observers' intrinsic and extrinsic reliability in measuring bone height at baseline and 2 weeks later was assessed by Cronbach's alpha coefficient and intraclass correlation coefficient (ICC).

Results

According to the results of the research, in evaluating the repeatability of measuring radiographic bone height, Cronbach's alpha coefficient values in the first and second observers were 0.997 and their intraclass correlation coefficient (ICC) was 0.997. These values were 0.996 and 0.996, respectively, when measuring radiographic height in the first and second observers in 2 weeks later; they were 0.997 and 0.997 in measuring the radiographic height in the first observer and in the first observer after 2 weeks, 0.997 and 0.996 in Radiographic bone height measurement in the second observer and same observer after 2 weeks, 0.986 and 0.969 in Radiographic bone height measurement in the first observer and as the actual bone height results, 0.983 and 0.960 in Bone height measurement by second observer and as the actual bone height results, 0.983 and 0.963 in Measurement of radiographic bone height by the first observer in 2 weeks later and as the actual bone height results,0.987 and 0.968 in Measurement of bone height by second observer in 2 weeks later and as the actual bone height results, and 0.986 and 0.966 in the mean results of radiographic bone height measurement by two observers in the next 2 weeks and as the actual bone height results.

Radiographic bone height from the mental foramen to the apex of the ridge in the first observer was 8.67 ± 2.81 mm; in the second observer was 8.8 ± 2.83 mm; in the first observer after 2 weeks it was 8.74 ± 2.82 mm; in the second observer after 2 weeks it was 8.7 ± 2.74 mm. Mean observation after 2 weeks was equal to 8.72 ± 2.77 mm and the actual bone height was7.93 ± 2.71 mm. Results of repeated measures ANOVA showed that there were significant differences in bone height in different measurements ($p < 0.0001$).

The difference between bone height calculations in the first and second observers ($p < 0.02$), between the first observer and the actual values ($p < 0.0001$), between the second observer and its actual values ($p < 0.0001$), between the observations 2 weeks later of the first observer and actual bone height values ($p < 0.0001$), between observations 2 weeks later of the second observer and actual bone height values ($p < 0.0001$) and also between observers' mean observations at 2 weeks later and actual bone height values ($p < 0.0001$) was statistically significant but in other binary comparisons, no significant differences were observed (Table 1).

The first variable	Second variable	Mean of differences	P-value
Bone height in the first observer	Bone height in the second observer	0.134	02.0
	Bone height in the first observer after two weeks	07.0	74.0
	Bone height in the second observer after two weeks	032.0	0.1
	Average bone height after two weeks	051.0	91.0
	Actual bone height	735.0	0001.0
Bone height in the second observer	Bone height in the first observer after two weeks	064.0	97.0
	Bone height in the second observer after two weeks	102.0	29.0
	Average bone height after two weeks	083.0	45.0
	Actual bone height	869.0	0001.0
Bone height in the first observer after two weeks	Bone height in the second observer after two weeks	038.0	0.1
	Average bone height after two weeks	019.0	0.1
	Actual bone height	805.0	0001.0
Bone height in the second observer after two weeks	Average bone height after two weeks	019.0	0.1
	Actual bone height	767.0	0001.0
Average bone height after two weeks	Actual bone height	786.0	0001.0

Table 1: Comparisons of radiographic bone height by different observers and its actual height values.

According to the results of variance analysis with duplicate values, there were significant differences in values of different observation differences with gold standard observations ($p < 0.02$). According to the results of the binary comparisons test, only differences in bone height values based on second observer estimation showed a significant difference from the factual values and bone height difference by the first observer and actual values ($p < 0.01$); no significant differences were observed in other comparisons (Table 2).

The difference of radiographic measurements with actual values	Mean	Standard deviation
Bone height in the second observer	735.0	64.0
Bone height in the first observer	869.0	71.0
Bone height in the first observer after two weeks	805.0	72.0
Bone height in the second observer after two weeks	767.0	62.0
Average bone height in observers after two weeks	786.0	64.0

Table 2: Difference of radiographic bone height measurements in different observations with actual values.

According to the results of variance analysis for duplicate values, no significant difference was observed between the absolute difference values of observations of bone height measurements by the observers and its actual values ($p = 0.07$). Given the absence of significant differences in overall comparisons, no pairwise comparisons were made between the different groups in this respect (Table 3).

The absolute difference between radiographic measurements and actual values	Mean	Standard deviation
Bone height based on the second observer estimate	811.0	54.0
Bone height based on first observer estimate	894.0	67.0
Bone height in the first observer after two weeks	871.0	63.0
Bone height in the second observer after two weeks	804.0	57.0
Average bone height in observers after two weeks	828.0	59.0

Table 3: The difference of absolute values of radiographic bone height observations in different observations with actual values.

According to the results of a linear regression test, only the average results of the radiographic measurement of bone height by the two observers in the 2 weeks later had significant effects (Std Error = 0.03, $p < 0.0001$ and $B = 0.951$) in predicting actual bone height values.

The frequency of differences between the results of radiographic bone height measurements by the first and second observers and the actual bone height values with two different divisions have been presented in table 4 and 5.

Variable	Differences from actual values	Number	Percentage
Second observer	Less than 2 mm 2 mm or more Total	53 1 54	1/98% 9/1% 100%
First observer	Less than 2 mm 2mm or more Total	49 5 54	7/90% 3/9% 100%
First observer two weeks later	Less than 2 mm 2mm or more Total	49 5 54	7/90% 3/9% 100%
Second observer two weeks later	Less than 2 mm 2mm or more Total	52 2 54	3/96% 7/3% 100%
Average observations in 2 weeks later	Less than 2 mm 2mm or more Total	53 1 54	1/98% /1% 100%

Table 4: Frequency of differences between bone height measurement by the observers and its actual values with division less than 2 mm, 2 mm and more.

McNemar test showed no significant difference between the results of first and second observers ($p = 0.13$), first and second observers in 2 weeks later ($p = 0.38$), first observer at baseline and 2 weeks later ($P = 1.0$) and second observer at baseline and 2 weeks later ($p = 0.1$) and the actual bone height values.

McNemar test showed significant differences between the results of the first and second observers' evaluations and the actual bone height measurements ($p < 0.0001$). The difference of the results of the bone height by the first observer (2 weeks later) and its actual values from the results of the bone height by the second observer (2 weeks later) and actual values ($p = 0.1$), the difference of the results of the bone height by the first observer and its actual values from the results of the bone height estimate by the second observer (2 weeks later) and its actual values ($p = 0.13$) and the

Variable	Differences from actual values	Number	Percentage
Second observer	Less than 1 mm	36	7/66%
	1mm or more	18	3/33%
	Total	54	100%
First observer	Less than 1 mm	24	4/44%
	1mm or more	30	6/55%
	Total	54	100%
First observer two weeks later	Less than 1 mm	29	7/53%
	1mm or more	25	3/46%
	Total	54	100%
Second observer two weeks later	Less than 1 mm	30	6/55%
	1mm or more	24	4/44%
	Total	54	100%
Average observer observations in 2 weeks later	Less than 1 mm	31	4/57%
	1mm or more	23	6/42%
	Total	54	100%

Table 5: Frequency of differences between bone height measurement by the observers and its actual values with division less than 1 mm, 1 mm and more.

difference of the results of the bone height estimate by the second observer and its actual values from the results of the bone height estimate by the second observer (2 weeks later) and the actual values ($p = 0.7$) was not significant.

Table 6 presents the percentage of observers' measurement errors with their confidence intervals in groups of less and more than 1m.

Discussion

One of the key applications of CBCT imaging technique is the design of implant treatments prior to surgery. Intervals linear calculations in these treatments are usually performed during treatment planning and before surgery to determine the exact amount of alveolar bone (height and width) and consequently the size of implants. Linear calculations are also used in orthodontic treatments to determine the size of jaw tumors. The purpose of this research was to determine the correlation between CBCT linear calculations and actual measurements during surgery in implant-candidates.

Observer and error rate	Time	Error	95% confidence interval
First observer less than 1 mm	First week	44%	62/57%-32%
First observer less than 1 mm	2 weeks later	7/53%	31/66%-61/40%
First observer greater than 1 mm	First Week	6/55%	68%-38/42%
First observer greater than 1 mm	2 weeks later	3/46%	39/59%-69/33%
Second observer less than 1 mm	First week	7/66%	76/77%-36/53%
Second observer less than 1 mm	2 weeks later	6/55%	68%-38/42%
Second observer greater than 1 mm	First week	3/33%	64/46%-24/22%
Second observer greater than 1 mm	2 weeks later	4/44%	62/57%-32%

Table 6: Percentage of observers' measurement errors with their confidence intervals.

According to the results of the present research, the radiographic height of bone in the first observer was 8.2 ± 67.81 mm; in the second observer it was 8.8 ± 2.83 mm; in the first observer after 2 weeks it was 8.2 ± 74.82 mm; in the second observer after 2 weeks it was 8.7 ± 2.74 mm. The mean observation of observers after 2 weeks was equal to 8.72 ± 2.77 mm and the actual bone height was 7.93 ± 2.71 Millimeter (with significant differences).

On the other hand, the absolute magnitude difference of the radiographic observations of bone height between the second observer and its actual values was 0.811 ± 0.54 mm; it was 0.894 ± 0.67 mm between the first observer and its actual values; 0.871 ± 0.63 mm between the first observer in the 2 weeks later and its real values; 0.804 ± 0.57 mm between the second observer in the 2 weeks later and its real values. The difference in bone height observed by the two observers in the 2 weeks later from its real values was 0.828 ± 0.89 mm. There were no significant differences between the absolute magnitude values of bone height measurement in CBCT images and its true values when surgery after exposure to the area.

Despite significant differences from its actual values in bone height values based on estimates of different observers at first and second times, in all cases, the error was less than 1 mm. The error of determining bone height less than 1 mm by radiography was acceptable; based on the results of the present research, CBCT observations had the necessary accuracy for linear calculations of bone height in implant treatments [8]. However, in some cases, bone marrow or bone marrow artifacts may be mistaken for canal cross-section in radiographic images, resulting in an overestimation of bone height [9], as in all cases in this research, the observers over estimated slightly the bone height. In the research of Mehdizadeh., *et al*. (2011), the mean spiral tomography error in estimating maxillary alveolar bone was 0.74 mm [10] and in that of Bou Serhal., *et al*. (2000), the mean spiral tomography error was 26 mm in the posterior region of the maxilla [11]. In another study, the error of bone height measurement by spiral tomography was 0.66 mm [12]. Also, in research conducted by Shahab., *et al*. (2009), the difference in bone height measured in spiral tomography was 0.71 mm compared to actual value [13]. Amin Tavakoli., *et al*. (2009) also investigated the accuracy of Cranex Tome Spiral and Promax Linear tomography when evaluating the amount of maxillary posterior bone for use in implant treatment plan; they reported a less than 0.3 mm difference in mean height measurements compared to actual size and in relation to width a less than 0.5 mm difference [14].

Lascala., *et al.* (2002), in examining the accuracy of linear measurements CBCT showed that the dimensions obtained from dry skulls were all larger than the results of CBCT measurements and the mean difference between actual and radiographic measurements was in the range of 1.64 - 6.59 mm [15]. The numbers obtained in the recent research were more than the observations of the present one. Berco., *et al*. (2008) also reported a measurement error in each spatial plan in the range of 0.19 - 0.21 mm in a dry human skull [16].

Periago., *et al*. (2008) also examined the accuracy of linear measurements of CBCT volumetric images compared to direct measurements on 23 human dry skulls. They showed that although in most linear measurements, there was a statistically significant difference between actual and radiographic measurements, in most of these measurements, this difference was not clinically significant [17]. These observations were also documented in the present research. On the other hand, Al-Ekrish and Ekram (2011) examined the accuracy and reproducibility of linear computations on the anodized ridge and showed that both MDCT and CBCT had statistically and clinically significant computational errors [18]. These observations were not seen in the present research.

Timock., *et al*. (2011) investigated the reliability and reproducibility of buccal bone height and thickness calculations in the CBCT technique. They reported the mean difference of absolute values in buccal height to be 0.3 mm and in the buccal bone to be 0.13 mm. it was less compared to the results of the present research [19].

In another research, Sharifi., *et al*. (2013) evaluated the accuracy of linear measurements of CBCT on dry human skulls and found no significant difference between actual and radiographic measurements [20]. According to the results of the present research and regarding the qualitative evaluation of the results, there was no significant difference between the results of the calculations of the first and second observers in the first and second stages and the actual bone height values, although different quantitative results were recorded in this regard.

In the research of Fatemitabar., *et al*. (2010), the accuracy of CBCT (Planmeca) was reported to be 0.0 - 37.58 mm; it was lower than the present research [4].

Recent researches have all been done on dry skulls *in vitro*. Undoubtedly, the contrast of radiographic images when the bone is in contrast to the air, like that in the dry skull, is greater than when the bone image is against the soft tissue, such as the living patient. The soft tissue surrounding the bone not only reduces the contrast of the image but also acts as an additional source of scattered radiation and changes the image contrast and accuracy of the computations on the image. In addition to soft tissue, metal artefacts and artefacts resulting from patient motion can also affect the accuracy of CBCT images. Differences in scanning protocols such as voxel size and the number of projection images per unit of time are also some factors that affect the dimensional accuracy of linear computations. Although CBCT images may not differentiate the different types of soft tissue, the soft tissue surrounding the bone as well as the internal soft tissue can reduce image quality, all of which should be taken into account when comparing different research results [1,7].

On the other hand, 100% CBCT inaccuracy in linear measurements is related to its software problems. Manual measurement calipers obtain the distance between different points from the specified points in the mesial or distal, but about CBCT, measuring instruments on voxels perform this calculation and since the voxel is a volume quantity, measuring instruments measure the midpoints of the voxel. As a result, half of the voxel does not fall within the measurement range. Therefore, the measurements will be different from reality; however, these differences are not significant in large structures but are considered significant in small measurements [21]. Another problem is the partial volume effect, which is an important artifact of CBCT images. The presence of metal artifacts in patients with high metal repairs is also important. At the same time, in clinical conditions, there are problems such as patient movement during imaging and the presence of soft tissue in the image, which can affect the quality of the measurements.

The higher bone height values in the CBCT images may be due to the fact that Crest Ridge is not covered by dense bone in all cases and therefore it is difficult to determine the position of bone margins in some cases. The presence of an inferior dental canal and a grooved inferior border in the mandibular or maxillary sinus floor may lead also to more computational errors [18].

Given that the actual dimensions of the ridge in each of these studies are different, it is possible that the bone height values reported in these researches be not consistent with each other. Considering the results of the research, estimating bone height by approximately 1 mm should be taken into account when measuring bone dimensions in CBCT images and the necessary correction be done. On the other hand, the operator must record and measure the ridge dimensions of the implant site along with implant placement. The researchers also have suggested these measures: designing additional standard studies to evaluate the results of implant treatments designed by different imaging modalities and the use of implant simulation software to evaluate the dimensions of the ridge when determining the implant position with the aim of minimizing the effects of curved bone surfaces and preventing computational errors.

Some researchers put the biological risks of irradiation at the forefront. They believe that conventional radiographic techniques such as panoramic and intraoral radiography are sufficient for accuracy, although they may be less accurate than techniques such as CBCT or CT; they should be used for bone height and thickness calculations in implant treatments to avoid imposing a high dose of radiation as well as expensive costs on patients. However, the importance of using techniques such as CBCT or CT in specific cases of implant treatments has always been emphasized [22]. Basically, in evaluating a patient's radiographic examinations prior to implant surgery, two important factors are the accuracy and efficacy of the method used to accurately estimate the quantity and quality of the jaw bone and the dose received following the use of this particular imaging technique and the disadvantages and benefits for the patient should be measured. On the other hand, some have argued that tomographic images such as CBCT or other types of tomography are very effective in the spatial visualization of the jaw by the surgeon through creating a third dimension in radiographic images. Due to the possibility of examining the thickness of the jaws, their use in conjunction with conventional intraoral techniques is a necessity [23].

Since we used direct measurements during surgery by compass and Caliper with 0.10 mm precision as gold standard values, we can have very high confidence in this method in bone height calculations in implant treatments.

Aimed to determine the accuracy of linear calculations of anatomical intervals in CBCT, previous researches have used dry mandibles and have argued that using dry skulls can directly measure, anthropometric measurements, some distances as standard for comparison with CBCT measurements [15,16]. However, the accuracy of measuring distances in images obtained from patients can be affected by decreased image quality due to patient motion, metal-induced artifacts, and radiation attenuated by soft tissue; so it seems that the accuracy of the measurements in patients' measurements is lower compared to calculations on dry skulls [17].

The growing demand for implant treatments in dentistry has emphasized the need to use an imaging technique that can perform accurate calculations to prevent damage to living body structures. In previous years, these computations were performed by conventional CT techniques; with the development of the CBCT method, the accuracy of calculations related to implant treatments increased and the radiation dose of patients decreased. These benefits increased the use of CBCT over CT [24]. In addition, using newer software to provide some surgical reconstruction guidelines has reduced the risk of structural damage to the anatomical areas [25]. Some have shown that CBCT can be used to measure the quality [26] and quantity of bone [27] and ultimately, to reduce the risk of implant failure, because having accurate information through the CBCT can increase the accuracy of the patient selection stage.

Conclusion

Given the limited observational differences in bone height measurements in CBCT images with their actual values during surgery and lack of significant differences between the absolute value of measurements, this imaging modality seems to be an appropriate and accurate tool for estimating bone height in implant surgery in clinical settings.

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