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Is there any predictive bone parameter for implant stability in 2-dimensional and 3-dimensional radiologic images?

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Objectives. This ex vivo study aimed to compare radiomorphometric parameters between 2-dimensional (2-D) and 3-dimensional (3-D) radiographs and evaluate the influence of preoperative radiologic bone parameters on the clinical outcomes of implant stability.

Study Design. Implant recipient sites in fresh bovine blocks were evaluated on panoramic radiographs for gray value (GV), fractal dimension (FD), number of connected trabeculae (Co), and density of connected trabeculae (CoD). Cone beam computed tomography (CBCT) scans were evaluated for trabecular thickness (TbTh), cortical thickness (CTh), degree of anisotropy (DA), FD, and Co. Insertion torque (IT) and implant stability quotient (ISQ) were measured.

Results. GV was significantly correlated with all parameters in 2-D and 3-D images except FD in 2-D and Co in 3-D, and with all surgical parameters ($P \leq .029$). Co and CoD values on panoramic radiographs had significant correlation with TbTh, CTh, and DA values on CBCT images ($P < .001$). All 2-D parameters and TbTh and CTh in the CBCT data were significantly correlated with IT only ($P \leq .047$). Only GV was correlated with ISQ measurements ($P \leq .029$).

Conclusions. GV, Co, and CoD values on panoramic radiographs reflect the architecture of trabecular bone and the thickness of cortical bone, and might help predict implant stability in clinical situations. (Oral Surg Oral Med Oral Pathol Oral Radiol 2021;131:371−379)

Currently, the most promising way to restore missing dental structures with high success and survival rates is to place dental implants.[1] Because dental implant surgery is a routine operation in many clinics, understanding the factors affecting implant success and survival is critical to achieving excellence in clinical practice. Esposito et al. stated that the long-term success of implants depends primarily on good bone quality and quantity at the prospective surgical site and avoidance of overload.[2] Clinical studies have also shown that bone quality and bone quantity are major factors influencing implant survival.[3-5] The importance of these parameters in the success of implant therapy has created a need to understand the character of the bony structures in the oral and maxillofacial region.

Bone quality is determined by the amount of and topographic relationship between cortical and cancellous bone.[6] Lekholm and Zarb's classification of the macrostructure of bone, which could be simplified as the ratio of cortical and trabecular bone thicknesses, is widely used for the assessment of bone quality (Figure 1).[7-10] Several approaches have been used for the assessment of the implant recipient site, each having advantages and disadvantages over others. Histomorphometry and the clinical measurements of insertion torque (IT) and implant stability quotient (ISQ) values are 3 such proposed techniques. Unlike histomorphometry, which is invasive, IT and ISQ are noninvasive methods to predict local bone quality during and after implant insertion. It has been proposed that IT scores could be correlated with bone density and volume.[11] IT can be measured during implant insertion with a torquemeter or physiodispenser. Resonance frequency (RF) analysis is another noninvasive method that yields an electromagnetically expressed value, the implant stability quotient (ISQ). The ISQ value, an integer that is derived from RF analysis, can be measured at any time during the osseointegration process with a great degree of objectivity.[12] All of these methods initially require surgery, but it is crucial to assess bone tissue before surgery for dental implant placement to evaluate diagnostic, prognostic, and optional factors.[13,14] The only noninvasive preoperative approach is through radiologic analysis of bone.

Statement of Clinical Relevance

Implant success depends on the quality and quantity of alveolar bone. Bone quality may be related to parameters on 2-dimensional and 3-dimensional radiographs. The correlation of these parameters with surgical parameters may enable prediction of successful implant placement.

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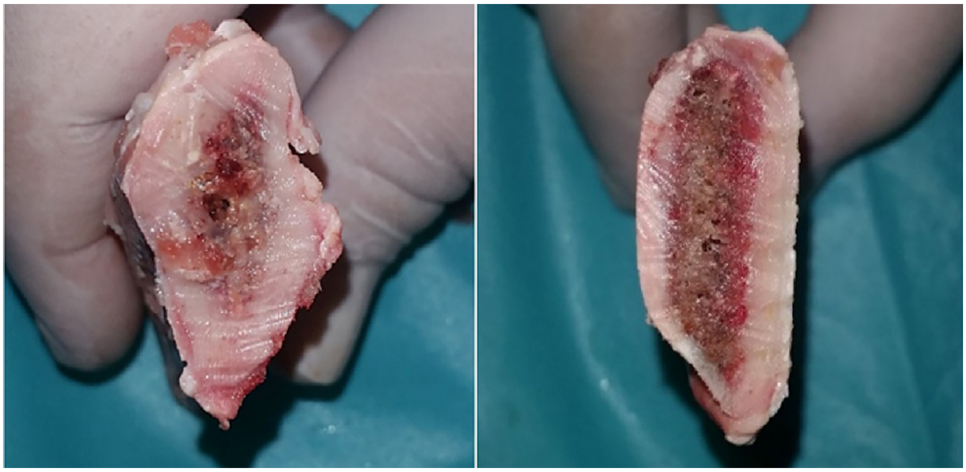

Fig. 1. The specimen represented on the left has thick cortical bone with a relatively thin trabecular part. The specimen on the right has rather thin cortical bone with thicker trabecular bone.

Computed tomography (CT), with its calculation of Hounsfield units (HU) based on the attenuation of x-rays in tissues, is a time-tested standard method of bone quality measurement. The greater exposure dose and lower spatial resolution of CT compared with cone beam computed tomography (CBCT) limits its use in the dental implantology field. However, CBCT does not have a standardized system for numerically evaluating bone quality.[15-17]

The position paper of the American Academy of Oral and Maxillofacial Radiology on the use of radiology in implant treatment recommends panoramic radiography for initial overall evaluation of patients receiving implants.[18] The guidelines also suggest that the choice of imaging technique must be decided according to the internationally recognized principle of radiation protection: keeping radiation exposure to the patient "as low as reasonably achievable" (ALARA)—that is, using the minimum radiation exposure that results in optimal diagnostic quality. Referral for CBCT is recommended when clinical examination indicates a need for bone augmentation or site development, and it has been affirmed that cross-sectional images provide the greatest diagnostic yield.[18]

Research indicates that there is likely to be an interconnection between 2-D histomorphometry and 3-D data as detected by the analysis of conventional radiographs. With newly developing image analysis software, the predictive power of both 2-D and 3-D radiographs has increased.[19-23] Many radiomorphometric parameters can aid in the assessment of the strength and architecture of cortical and trabecular bone, which may correlate with clinical measurements and, therefore, allow better prediction of the prognosis of implants. In previous studies, a gray value (GV) scale ranging from 0 to 255 in an 8-bit digital image has been defined as pixel intensity, which has been shown to provide limited but effective information in discriminating osteoporotic versus healthy bone.[19,21] Moreover, the mechanical strength of the bone also depends on its adapted distribution, morphology, and orientation of trabeculae—that is, the microarchitecture of trabecular bone.[19,24] The components of microarchitecture include the fractal dimension (FD), connectivity (Co), connectivity density (CoD), trabecular thickness (TbTh), cortical thickness (CTh), and the degree of anisotropy (DA).[25-27]

The objective of this investigation was to evaluate the correlation of radiomorphometric indices as measured on panoramic radiographs and CBCT scans, along with clinical measurements of bone quality. The null hypothesis stated that there would be no statistically significant correlations between the indices and bone quality.

MATERIALS AND METHODS

Standardized 7-cm bone blocks were prepared from fresh bovine ribs after dissecting the overlying soft tissue. The bone blocks contained different proportions of cortical and cancellous bone, depending on the sites on the rib. The blocks were randomly assigned for implant placement. Implant sites were created at 10-mm intervals and labeled with molten gutta percha as a radiopaque reference indicator on the specimen before scanning. The bone blocks were inserted into foam and tilted mediolaterally to represent the jaw sides.

Preoperative panoramic radiographs (ProMax Planmeca, Helsinki, Finland) and CBCT images (ProMax 3-D Mid, Planmeca, Helsinki, Finland) were acquired for each specimen. Because of the operating principle of panoramic radiography, the objects located between the center of rotation and x-ray source can cast ghost images. For this reason, each specimen was placed separately with the prepared setting in the digital panoramic device to avoid the formation of ghost images and exposed at standard imaging parameters of 66 kVp and 6.3 mA. For CBCT images, 2 specimens were scanned simultaneously with a field of view (FOV) of 10 × 10 cm, 200 μm voxel size, and fixed exposure parameters of 90 kVp and 8 mA. The acquired panoramic images and CBCT volumes were extracted in DICOM (Digital Imaging and Communications in Medicine) format by using the Romexis software v3.8.3.R (Planmeca, Helsinki, Finland). The images and the volumes were imported to the Fiji image processing package, bundled with 64-bit Java for Windows (ImageJ v1.52 n; National Institutes of Health, Bethesda, MD).

Panoramic images were converted to 8-bit format for calculation of GVs and creation of binary images. Each region of interest (ROI) size was selected as 2 mm larger than the implant dimensions and placed at the level of the gutta percha (Figure 2). GVs were measured and noted. For each ROI, binarization was performed by using the ImageJ software's plugins. The FD values, which reflect the irregularity and complexity of bone tissue and the connectivity of the trabecular network, were estimated by using the software with the box-counting algorithm.[26] Trabecular bone consists of a network of numerous trabeculae in various types and sizes; the trabeculae intersect, forming enclosed marrow cavities or ending as disconnected trabeculae, demonstrating the connectivity of the trabeculae.[27] The connectivity plugin yielded 2 subresults: Co corresponded to the number of connected trabeculae, whereas CoD expressed the number of connected trabeculae per unit volume. An illustration of Co on a 2-D image with respect to 3-D volume is represented in Figure 3.

The CBCT DICOM images were converted to 8-bit format and each specimen was positioned such that all implant sites were aligned on the same axis. ROIs of the same length as the implant were selected in consecutive images and were represented as a stack of images comprising the volume of interest (VOI) (Figure 4). The BoneJ plugin was used to measure the thickness of the trabeculae (TbTh) and cortices (CTh), the 3-D asymmetry within the bone volume (DA), and the FD and Co in CBCT images.

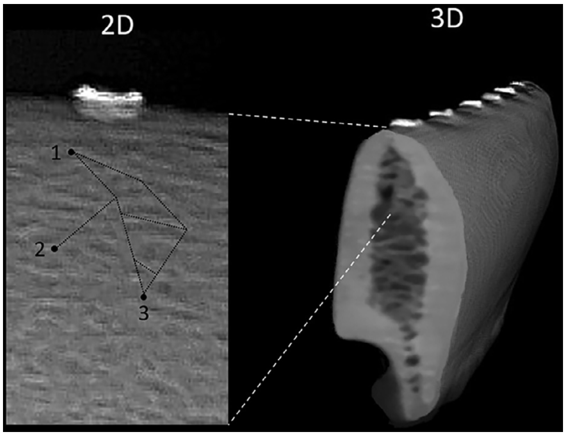

Fig. 3. 2-dimensional *(left)* and 3-dimensional *(right)* representations of the preimplant site. On the left, the connectivity parameter is demonstrated with the identification of several trabeculae on the cropped panoramic image. Note that there is only one path that connects the number 1 to number 3 and several paths exist between 1 and 2.

For the evaluation of trabecular bone parameters, the most important factor is the placement of the VOI. VOIs were selected inside the cortical borders. After each VOI was duplicated, the outside of the VOI was cleared to obtain binary images. The trabecular bone was isolated from the cortical bone by using a thresholding process, and a binary image was obtained. Afterward, the inversion of VOI trabecular bone was represented. TbTh, DA, FD, and Co were measured on inverted binary images (Figure 5).

For the measurement of CTh, another set of VOIs was used. In this case, the VOIs were positioned to

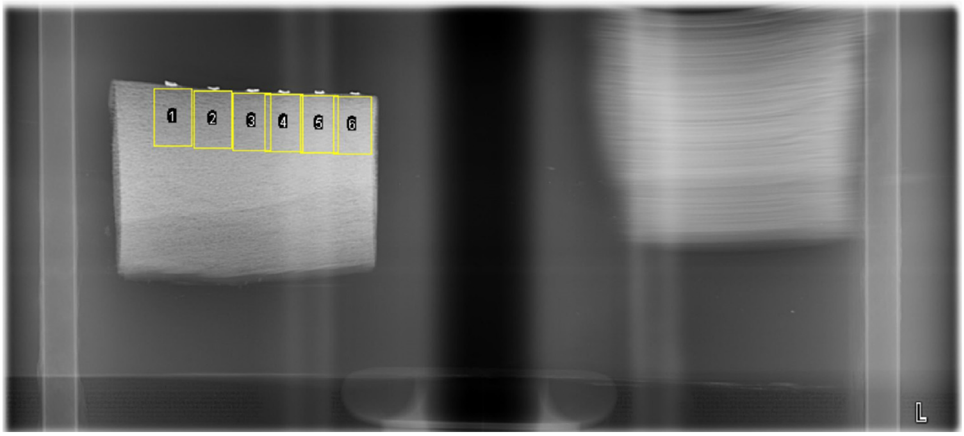

Fig. 2. Preoperative selection of regions of interest (ROIs).

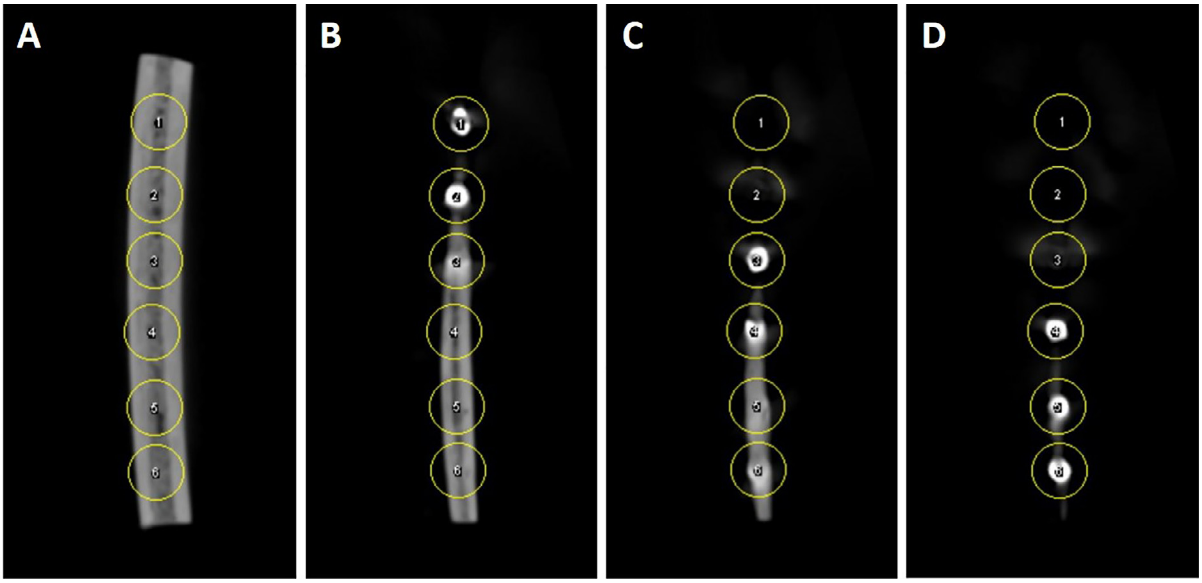

Fig. 4. Alignment and selection of the volumes of interest (VOIs) **(A)** according to implant sites, scrolling from the superior to the inferior aspect of the specimens **(B−D)**.

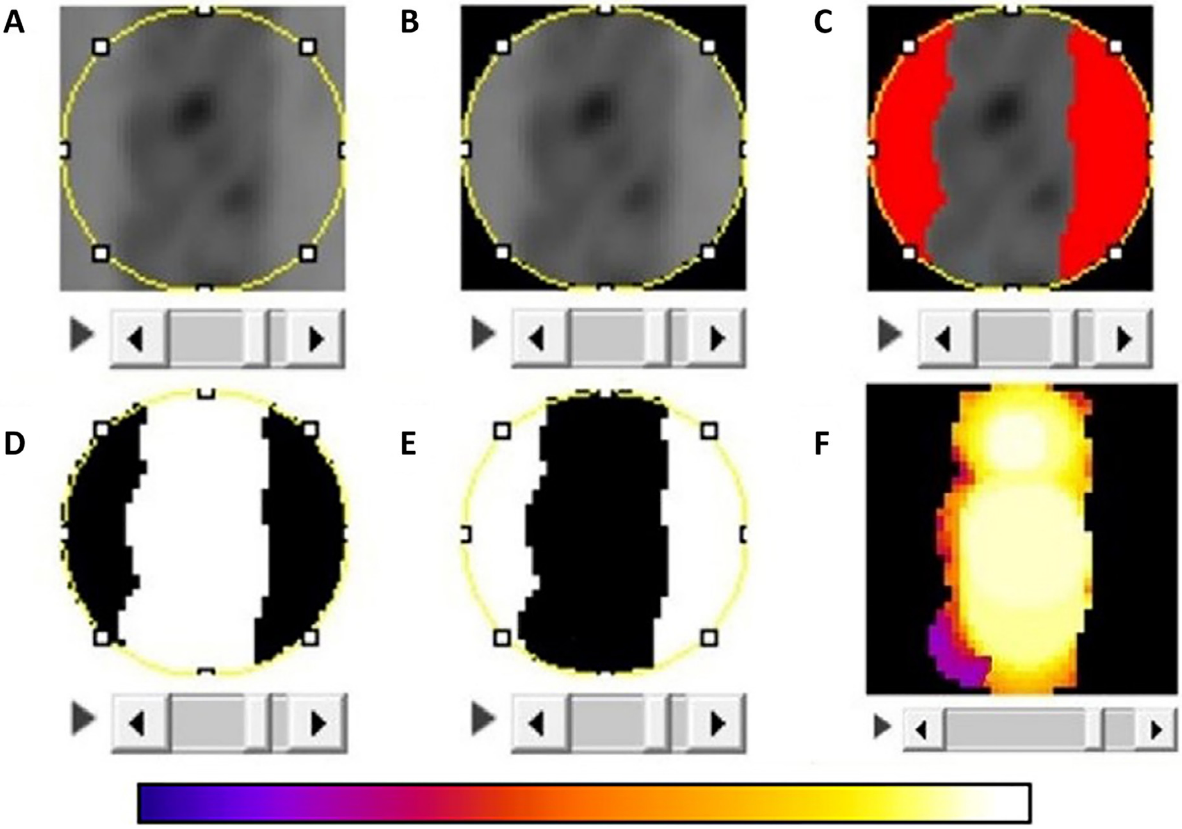

Fig. 5. **A,** Selection of a volume of interest (VOI). **B,** Clearing of areas outside the VOI. **C,** Binarization thresholding. **D,** Binary image. **E,** Inversion. **F,** Trabecular thickness. Colors indicate the thickness of trabecular bone, with blue indicating the thinnest and white indicating the thickest trabecular bone.

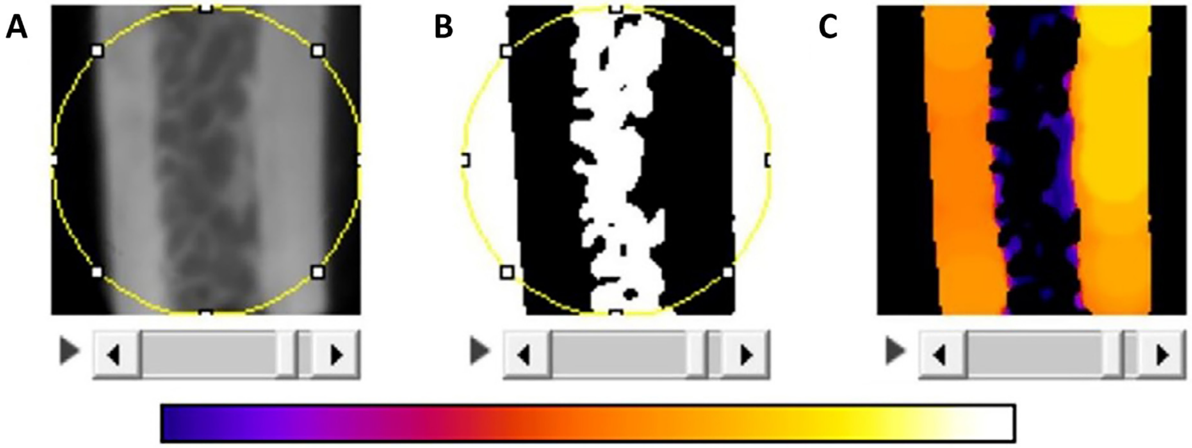

Fig. 6. **A,** Selection of a volume of interest (VOI). **B,** Binary image. **C,** Cortical thickness. Colors indicate the thickness of cortical bone, with blue indicating the thinnest and white indicating the thickest cortical bone.

reach beyond the cortical borders. The images were then processed in the same way as for the measurement of TbTh but without the inversion process (Figure 6).

In this experimental study, 2 implant systems were used: NobelParallel (Nobel Biocare, Karlskoga, Sweden) and Mode (Mode Medikal, Istanbul, Turkey). The diameters and lengths were 4.3 × 13 mm for Nobel Biocare implants and 4.1 × 13 mm for Mode Implants. For both the Nobel Biocare and Mode systems, 20 passive (non−self-drilling) implants were used. All implant sites were prepared according to the manufacturers' instructions, using the manufacturers' original surgical kits, and inserted by the same surgeon. Interimplant distance center to center was adjusted at 10 mm. During the insertion of the implants, the maximum IT value (newton-centimeters [N.cm]) for each implant was measured by using a digital torquemeter. Immediately after implant placement, ISQ values were recorded by using an Osstells Mentor device (Integration Diagnostics, Göteborg, Sweden) at the buccal (ISQ-B) and mesial (ISQ-M) sides of the implants.

The measurements were made by 2 dentomaxillofacial radiologists, one with 4 years of experience and the other with 24 years of experience. Images were analyzed independently under quiet, dim-light conditions. To calculate intraobserver agreement, 1 observer processed the images and did the measurements twice within a 1-week interval. For interobserver agreement, the results of the 2 maxillofacial radiologists were compared. Intraobserver agreement was measured by calculating Cronbach's alpha coefficient. Interobserver agreement was measured by calculating the intraclass correlation coefficient (ICC). The α values of intraobserver agreement were classified as poor (0.50 < 0.60), questionable (0.60 < 0.70), acceptable (0.70 < 0.80), good (0.80 < 0.90), or excellent (≥ 0.90).[28] The ICC values of interobserver agreement were classified as poor (< 0.40), fair (0.40 < 0.60), good (0.60 < 0.75), or excellent (0.75 ≤ 1).[29]

The obtained data were transferred and analyzed by using the Statistical Package for the Social Sciences (SPSS) V21 program (IBM Corp., Armonk, NY). The correlation between the variables was evaluated by using Pearson's correlation coefficient (r). Multiple regression analysis was performed to determine the interaction of bone parameters between the CBCT images and the panoramic radiographs. The level of significance was set at $P < .05$.

RESULTS

In total, 40 implant sites were evaluated. A good intraobserver agreement was found ($\alpha = 0.86$), and an excellent interobserver agreement was found (ICC = 0.78). A large proportion of the measurements were within the limits of agreement. Descriptive statistics of the results are demonstrated in Table I. Correlations between radiologic and surgical parameters are summarized in Table II.

2-D parameters

2-D parameters were significantly correlated with each other in panoramic images ($P \leq .027$) for all comparisons except the correlation between GV and FD ($r = -0.06$; $P = .731$). GVs were significantly correlated with all 3-D parameters and surgical parameters ($P \leq .029$), except Co of CBCT images ($r = -0.02$; $P = .907$). Significant correlations and linear relationships were found between GVs and both TbTh and CTh in the CBCT scans ($r = -0.73$ and $r = 0.84$, respectively; $P < .002$).

For panoramic radiographs, both Co and CoD values showed significant correlation with GV in the negative trend ($r = -0.59$; $P < .001$) and with FD in the positive trend ($r = 0.37$; $P \leq .027$). The Co and CoD values of panoramic radiographs showed significant and linear

Table I. Mean and standard deviation (SD) of evaluated parameters with minimum (Min) and maximum (Max) values*

	Mean	*SD*	*Min*	*Max*
2-D Parameters				
GV	159.82	20.37	106	190
FD	1.45	0.1	1.16	1.62
Co	4.47	3.52	0.25	15.75
CoD	2.75	2.16	0.15	9.67
3-D Parameters				
TbTh	14.8	3.68	11.5	27.5
CTh	16.88	3.71	4.5	22.62
DA	0.79	0.11	0.56	1
FD	2.27	0.11	2.06	2.53
Co	23.44	15.69	1.5	74.5
Surgical Parameters				
IT	75.68	35.59	21	168
ISQ-B	61.38	13.66	32	85
ISQ-M	65.45	15.32	43	88

Co, connectivity is the number of connected trabeculae; *CoD*, connectivity density is the number of connected trabeculae per unit volume; *CTh*, cortical thickness; *DA*, degree of anisotropy is the measure of asymmetry within a volume; *FD*, fractal dimension is the measure of irregularity; *GV*, gray value; *ISQ-B*, implant stability quotient (buccal); *ISQ-M*, implant stability quotient (mesial); *IT*, insertion torque, measured in newton-centimeters; *TbTh*, trabecular thickness.

**TbTh* and *CTh* values are in millimeters.

correlation with TbTh and CTh values on CBCT images (r = 0.69 and r = −0.60, respectively; $P < .001$).

3-D parameters

TbTh had significant correlations with all 2-D parameters ($P \leq .013$). Both CTh and DA showed significant correlations with 2-D parameters ($P \leq .003$) except FD (r = −0.20; $P = .219$ for CTh and r = 0.08; $P = .642$ for DA). CTh had significant correlations with 3-D parameters ($P \leq .047$), except Co (r = 0.19; $P = .33$). DA was significantly correlated with all other 3-D parameters ($P \leq .047$), except Co (r = −0.27; $P = .33$). Co in the 3-D data was significantly correlated only with FD in the 3-D data (r = 0.33; $P = .037$).

Surgical parameters

IT values were significantly correlated with all 2-D parameters and with TbTh and CTh in the CBCT data ($P \leq .047$). Both ISQ measurements showed a significant correlation only with GV in the panoramic images ($P \leq .029$). Neither ISQ-B nor ISQ-M had strong or significant correlations with FD values on panoramic radiographs (r = 0.19; $P = .249$ buccally; r = 0.13; $P = .432$ mesially). No significant correlation was observed between ISQ values and 3-D parameters.

A multiple linear regression was calculated to predict TbTh on CBCT images based on GV, FD, Co, and CoD on panoramic images. A significant regression equation was found with an R^2 of 0.69 ($P < .001$). GV, FD, Co, and CoD were significant predictors of TbTh ($P \leq .047$). Another multiple linear regression was calculated to predict GV on panoramic images based on

Table II. Correlation coefficients between radiologic and surgical parameters.

Pearson's correlation	*2-D parameters*				*3-D parameters*				*Surgical parameters*			
	GV	*FD*	*Co*	*CoD*	*TbTh*	*CTh*	*DA*	*FD*	*Co*	*IT*	*ISQ-B*	*ISQ- M*
2-D Parameters												
GV	1											
FD	−0.06	1										
Co	−0.59†	0.37*	1									
CoD	−0.59†	0.37*	1.00†	1								
3-D Parameters												
TbTh	−0.73†	0.39†	0.69†	0.69†	1							
CTh	0.84†	−0.20	−0.60†	−0.60†	−0.70†	1						
DA	−0.55†	0.08	0.45†	0.45†	0.51†	−0.64†	1					
FD	0.41†	−0.12	−0.26	−0.26	−0.19	0.3*	−0.52†	1				
Co	−0.02	0.22	0.10	0.10	0.19	−0.16	−0.27	0.33*	1			
Surgical Parameters												
IT	0.46†	−0.27*	−0.37*	−0.37*	−0.61†	0.47†	−0.24	0.18	−0.27	1		
ISQ-B	0.35*	0.19	−0.13	−0.13	−0.04	0.17	−0.24	0.18	0.24	−0.22	1	
ISQ-M	0.37*	0.13	−0.17	−0.17	−0.16	0.14	−0.19	0.04	0.24	−0.25	0.92†	1

Co, connectivity is the number of connected trabeculae; *CoD,* connectivity density is the number of connected trabeculae per unit volume; *CTh,* cortical thickness; *DA,* degree of anisotropy is the measure of asymmetry within a volume; *FD,* fractal dimension is the measure of irregularity; *GV,* gray value; *ISQ-B,* implant stability quotient (buccal); *ISQ-M,* implant stability quotient (mesial); *IT,* insertion torque, measured in newton-centimeters; *TbTh,* trabecular thickness.

*Correlation significant at $P < .05$.

†Correlation significant at $P < .01$.

TbTh, CTh, and FD on CBCT images. A significant regression equation was found with an R^2 of 0.78, ($P < .001$). TbTh, CTh, and FD were significant predictors of GV ($P < .011$; $P = .001$, and $P = .026$, respectively).

DISCUSSION

Although panoramic radiography has limitations in the assessment of the buccolingual depth of alveolar bone and the exact location of vital structures, it is recommended for the initial assessment of dental implant planning.[18] Chugh et al. concluded that GVs on panoramic radiographs were able to detect D4, D3, and D2 bone types, which are classified according to the ratio of trabecular and cortical bone thicknesses, with certain limitations.[7] Conversely, the GVs of CBCT images were considered to be unreliable and variable because of the use of different CBCT machines, exposure settings, the position of the evaluated site in the FOV, and the size of the FOV.[8,17] A clinical study showed that simulated HUs were derived from GVs of different CBCT devices by using each machine's specific linear attenuation coefficients.[16] Therefore, even though the viability of using attenuation coefficients is demonstrated in the findings, the presence of inconsistencies in GVs as a result of inherent deficiencies in flat panel detectors in some CBCT devices, scattered photons, and beam hardening artifacts will result in variations in recalculated HUs.[16]

The result of the present study showed that the thick cortical layers and complex trabecular network of the bone corresponded with lighter shades of gray (higher GVs). In other words, as the FD values of the trabecular network increased, lighter gray shades (higher GV numbers) were observed. Darker shades of gray (lower GV numbers) correlated with higher Co and CoD values of the preoperative site on panoramic images and increased TbTh in CBCT images. Considering all VOIs, there was a significant negative linear correlation between TbTh and CTh. IT values also showed correlation with Co and CoD on panoramic images, as well as with CTh and TbTh, in the same direction as GV. Therefore, a simple conclusion is drawn: Higher GVs are correlated with relatively thinner trabecular bone and higher CTh and IT values. Such results are expected because of the greater attenuation of x-ray photons in dense cortical bone, which reduces the number of x-ray photons reaching the detector, causing an increase of signal with higher GVs.

Another parameter proven to be useful for the estimation of the microarchitecture of the bone is FD. Trabecular and cortical bone are biologic fractals that have similar properties in a limited range of scale and are characterized by the fractal dimension.[30] FD values extracted from 2-D conventional radiographs have been found to be descriptive of 3-D connectivity, porosity, trabecular number, and spacing.[23,31] Connectivity is a measure of trabecular intersections in a 3-D structure—commonly mistaken as trabecular number and unable to be measured on 2-D sections.[27] In this experimental study, Co and CoD values from binary images of 2-D panoramic radiographs should be highlighted despite the limitations of some perpendicularly angled trabeculae, the edge problem of ROIs, and superimpositions that conceal the 3-D orientation. Both Co and CoD were significantly correlated with TbTh and CTh. Furthermore, the results demonstrated that TbTh could be predicted by GV, FD, and Co on panoramic radiographs. In fact, descriptive 2-D radiologic parameters of the trabecular bone carry the same information with different aspects. Co of 3-D data is related to FD of CBCT, which signifies the dependence of intersections of trabeculae with the complexity of architecture. Co on the 2-D plane does not give the actual 3-D morphology; however, it might be an indicator of how highly the trabeculae are interconnected. The positive significant correlation between FD, Co, and CoD values might be an indicator of such relevance. In addition, FD of 3-D data was found to be a contributing factor for GVs on panoramic radiographs, showing that the GVs of an implant site contained more information than just CTh and TbTh.

In accordance with other studies, the present results demonstrated that as TbTh increased, IT values decreased significantly, and as CTh increased IT values increased.[15,32] Suer et al. found that the FD values of implant sites on panoramic radiographs were significantly correlated with IT and concluded that it might add further information and increase the predictive potential of panoramic radiographs.[33] In our study, the FD of panoramic radiographs had significant correlations, but not as strong as with IT values.

Pre-evaluation of the implant recipient site, which determines whether the available bone has sufficient quality, could help predict the probability of failure or success.[18] Clinical studies have shown that implants inserted into the mandible have higher success rates compared with the posterior maxilla, and bone quality is thought to be the underlying reason.[34] It has been suggested that there should be a minimum IT of implants to be loaded immediately.[35] The study of Pauwels et al. showed that the local bone structure at the apical and coronal regions may determine IT and ISQ values.[36]

There is controversy in the literature about the minimum IT value required when loading implants immediately. An in vitro study on fresh bovine ribs showed that there was higher micromotion of implants inserted with different IT values in soft bone.[37] There are also clinical studies suggesting that lower IT values, such as 25 N.cm, could be sufficient for immediate restorations, but these studies were mainly performed with single-tooth implants and immediate restorations.[38,39] In a recent retrospective clinical study, Maló et al. compared implants inserted with IT values less than and greater than 30 N.cm in full-arch maxillary rehabilitation and concluded that implants inserted with less than 30 N.cm of IT in an "All-on-4" arrangement had similar short-term success and less marginal bone loss compared with implants inserted with greater than 30 N.cm.[40] Finally, a study by Chrcanovic et al. showed that low IT values could be a risk factor for implant failures.[41] In view of these controversial findings, dentists should be cautious when deciding on immediate loading of implants placed with low IT values into soft bone.

Furthermore, there are different implant treatment options for prosthetic rehabilitation. With regard to treatment modalities, immediate restoration and/or loading from single-tooth implants to full-arch rehabilitations are widely discussed topics in implant dentistry. Immediate prosthetic rehabilitation or provisionalization of implants provides many advantages to patients and dental practitioners. Such immediate fixed provisional restorations eliminate the need for and maintenance of a removable provisional prosthesis and provide emotional benefits for an edentulous patient. It has also been stated that immediate loading of dental implants could facilitate bone healing and improve soft tissue adaptation and contour before final restoration.[42,43]

These promising results highlight the information that radiographic images may provide for dental practitioners. In addition, the effect of overlying soft tissues is eliminated because all the analyses were performed on binary images, in line with previous studies.[19,21] Bornstein et al. found that even in a specialty clinic, 40% of the implant surgeries are performed on the basis of findings from clinical examination and 2-D radiography.[44] Obtaining more information about bone microarchitecture from radiographs before implant placement may help inform a surgeon's clinical decision about when to load the implants. If dental practitioners have information about bone quality before surgery, they can plan to modify the surgical technique—for example, to use underdrilling. Research indicates that drilling protocols are modified according to surgeons' tactile sense, but this is a subjective method.[45] Measuring the behavior of the bone via quantitative radiographic analysis could give dental practitioners more objective and reliable data.

It should be kept in mind that this investigation was a preliminary ex vivo study, and the problems of ghost images, distortion, and superimposed bony anatomic structures that are inherent in panoramic radiography were not considered. The influence of these factors may give false results when an actual patient's panoramic images are analyzed. The findings that lower GVs are associated with a deficient cortical layer and thicker trabecular bone may be obscured by superimpositions of bony structures when applied to clinical images. Further studies should be designed with a similar surgical protocol and retrospective implant site evaluation of actual patients with panoramic and CBCT data.

CONCLUSIONS

The results of this study showed that GV, Co, and CoD values on panoramic radiographs reflect the architecture of trabecular bone and the thickness of cortical bone, and might help predict implant stability in clinical situations. IT values of an implant correlate not only with TbTh and CTh but also with GV, FD, Co, and CoD values of 2-D images. These 2-D parameters may guide clinicians when considering implant treatment options.

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