

Cone Beam Computed Tomography and Preoperative Bone Quality Assessment for Dental Implants: Myth and Truth

Ali Fahd ^{1*}, Dina El Beshlawy ²

¹Assistant Professor of Oral and Maxillofacial Radiology, Faculty of Oral and Dental Medicine, Egyptian Russian University, Cairo, Egypt.

²Professor of Oral and Maxillofacial Radiology, Faculty of Dentistry, Cairo University and Galala University, Cairo, Egypt.

*Corresponding author: Ali Fahd, E-mail: dr.ali.fahd.dentist@gmail.com,

Tel: 20-100-5364733

Received 16th May 2023, Revised 22nd June 2023, Accepted 30th July 2023

DOI: 10.21608/ERURJ.2023.211464.1026

ABSTRACT

Cone beam computed tomography (CBCT) is the most used advanced digital dental imaging modality. It is designed for dentistry and its use is recommended in multiple dental specialties. One of its most common uses is in the field of dental implants where it is a useful preoperative tool for multiple purposes, including the evaluation of bone quantity and quality. Although there may be a wide acceptance of CBCT-based bone quantity assessment, there is a debate about the reliability of bone CBCT-based quality assessment. This is because CBCT measurements are based on the grayscale value rather than the true Hounsfield units (HU) or Computed Tomography (CT) numbers. The present review is a simplified approach to explain the inherent problems of CBCT regarding bone quality assessment and the proposed protocols to deal with the related limitations. Different techniques for numerical density assessment are presented. Also, supplementation with the visual technique for bone quality assessment is discussed.

Keywords:

Cone-Beam Computed Tomography – Dental Implants – Bone Density – CBCT Software.

Introduction

CBCT images are undistorted, dimensionally accurate, and viewed in three dimensions (1, 2). Also, the user can control the field of view (FOV), the resolution, the image orientation, and the slice thickness (3). All these merits and more make it the imaging modality of choice for preoperative dental implant planning (2, 4). Image data are in the form of DICOM format (Digital Imaging and Communications in Medicine) that can be imported into variable third-party software designed for implant planning (5). CBCT offers a less expensive lower dose single rotational image with dentist-friendly software in a compact machine with a suitable footprint for the dental office (6). Although all these advantages favored its use in the dental field in general and dental implants in particular, nothing comes without expenses. The disadvantages include decreased signal-to-noise ratio and inhomogeneous beam geometry (7, 8), among other factors affecting its reliability for bone quality assessment.

Although there is a clear definition for radiographic bone quantity assessment as the amount of remaining bone height and width with anatomical considerations, **Figure 1**, there is no clear consensus regarding bone quality which involves multiple factors such as the mineralization degree and the bone morphological characteristics (7).



Figure 1. CBCT cross-sectional and reformatted panoramic cuts showing bone quantity assessment for a suggested implant site.

Why radiographic assessment for bone quality?

Bone quality is one of the most critical factors regarding the predictable success of dental implants and is strongly recommended in preoperative radiographic planning (9). Testing bone quality and implant stability in bone by other techniques comes too late (during or after surgery) and is incomparable to radiographic prediction (10). From a clinical point of view, preoperative bone quality assessment is essential for the selection of the implant design, the drilling protocol, the prediction of implant success, and the expected time for loading.

CT Hounsfield units versus CBCT gray values

Dental clinicians misuse CBCT gray shades values as an equal representation of Hounsfield units (HU) which are specific density values linked to CT according to definite formula calibrated by including measurements of water (7, 11, 12).

How can CBCT, with the inherent low non-standardized uncalibrated soft tissue resolution, give a reliable HU measurement? Density, if measured by HU, should be based on calibrated normalized values for air (-1000 HU), water (0 HU), and dense bone (+1000 HU) (13). In light of that, the so-called HU values of CBCT (better-called pseudo-HU) are not absolute density measurements and are not equal statistically to CT numbers (13). The truth is that CBCT bone density measurement is based on grayscale values rather than HU even if it is called HU in different CBCT software (14). Gray scale values differ according to exposure parameters, object thickness, the position of the object in the field of view, and the image artifacts (14). In other words, the CBCT values are dependent on the degree of gray shades. For example, the whiter the image, the higher the numerical value, the denser the bone perception, and vice versa. It may be the difference in exposure parameters that causes the difference in gray shade degree rather than the true object density.

Causes of difference between CT and CBCT in bone density measurements

Factors affecting CBCT-based density measurements include the decreased X-ray exposure parameters (trade-off decreased radiation dose and machine cost) and the combination of cone beam geometry with area detector that increase the received scattering and decrease the X-rays homogeneity (trade-off single rotational time favorable scanning) (7, 13, 14). Another factor affecting the ability of CBCT in density measurement comes as a trade-off from the advantage of field of view (FOV) limitation in the axial plane. CBCT-limited FOV means that X-rays will pass through volume not constructed in the final image and that outside field volume will affect the result values (7, 13, 14). For example, during imaging of the right side only, the beam is passing through the left side as well, and that left side will affect the amount and direction (scattering) of X-rays reaching the area detector, hence modifying the values even if not visible in the final reconstructed image.

Another issue that complicates the measurements is that each CBCT model has its fingerprint; in other words, no two CBCT models are the same. They differ in terms of exposure parameters, the hardware of the machine, and the reconstruction algorithm so that research findings cannot be generalized (7).

Is the CBCT-derived bone quality assessment clinically accepted?

This area requires more research to reach an evidence-based conclusion if the statistically inaccurate CBCT-based quantitative and qualitative density measurements are clinically accepted or not. Literature differs in the methodology for testing the reliability of CBCT based assessed bone density (grayscale value) and its correlation with CT and clinical applications (as assessed by resonance frequency, drilling resistance, insertion torque, and implant stability), with recent literature shifting towards promising results (15-21). A recent systematic review of the literature addressing CBCT gray scale values as an assessor for bone density revealed a possible use in preoperative implant planning (22).

Different options for density measurement in CBCT software

There are multiple options for bone density measurements in CBCT software and the operator should choose the most suitable approach for measurements (23, 24). Fortunately, new more practical non-variable approaches are in continuous development (23) and automatic artificial intelligence-based techniques are incessantly investigated (25). Validation of different protocols for the evaluation of bone quantity and quality and their effects on treatment is recommended for researchers, not only for dental implants but also for other dental specialties. **Figures 2 and 3** represent multiple options available in the same software (Planmeca Romexis 5.3 - Planmeca Oy, Helsinki, Finland) for getting bone density estimates in numerical values. Values are translated to bone type as D1 if above 1250, D2 from 850 to 1250, D3 from 350 to 850, D4 from 150 to 350, and D5 if below 150 (immature nonmineralized bone) (26).

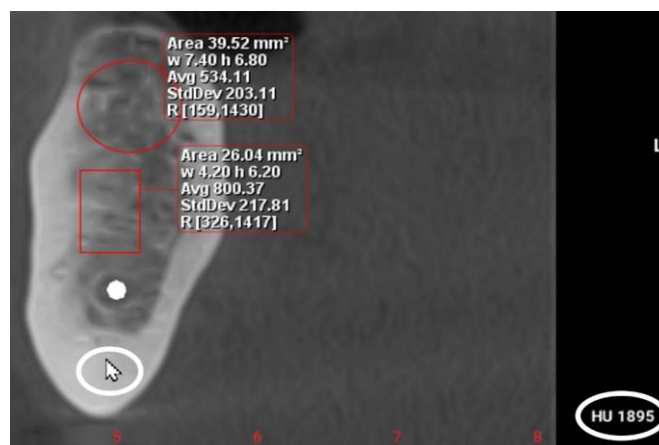


Figure 2. CBCT cross-sectional cut of a suggested implant site showing two-dimensional bone density assessment by different protocols as a point of cursor contact (found in the lower right corner), rectangular area measurement (presented as average), and ellipse area measurement (presented as average).

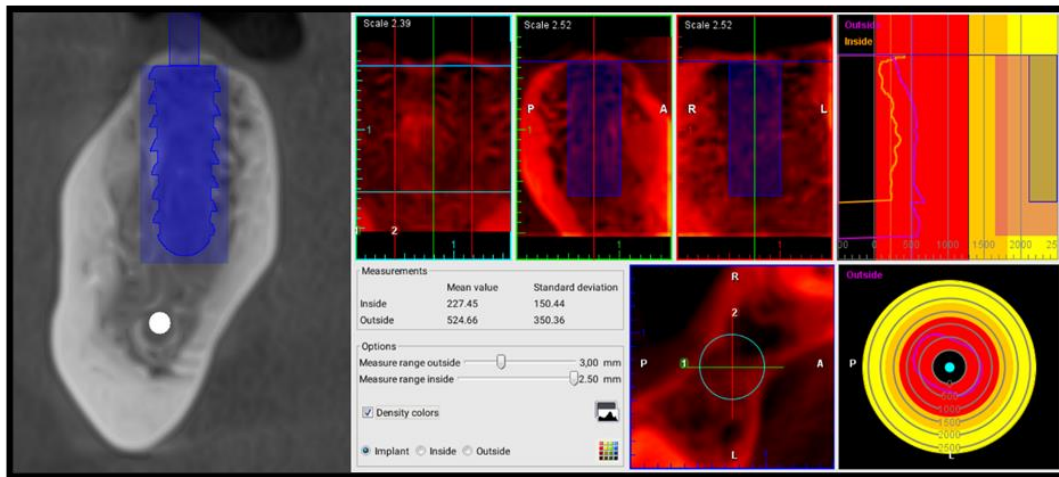


Figure 3. Three-dimensional color-coded bone density assessments through verification of virtually placed implants (inside and outside implant bone assessment).

Back to the question about the clinical acceptance of the variability of bone density measurements, as an assumption, a CBCT pseudo-HU value of 1000 where its true CT HU is 1150; quite a difference may be of no clinical significance since they both fall within the same category of D2 bone density. In the same context, an implant site with higher levels of D2 won't differ from being at a lower level of D1 bone density values as both may be managed nearly the same clinically.

Bone architecture-based assessment

The most reliable X-ray-based bone quality measurement is micro-CT (μ CT), but it can only be used for research purposes (animal specimens or human samples) (7, 27). μ CT is the gold standard for quality assessment based on bone architecture (28). Here comes a question. Why not benefit from CBCT's high spatial resolution in quality assessment using the same architecture-based approach of μ CT as a supplementation for the numerical density measurements? **Figure 4.** If this is applicable, D1 bone will be the homogenous cortical bone, D2 is the thick outer cortical bone with dense internal trabeculation, D3 is the thin outer cortex with a dense internal core, and D4 is with a low-density internal core (23). Unfortunately, this technique is operator dependent and is affected by multiple image-related factors. Also, a variable outer and inner bone combination should be addressed and clinically correlated (23). Al-Ekrish et al introduced a revised bone quality classification with a higher observers' agreement and recommended further research (23).

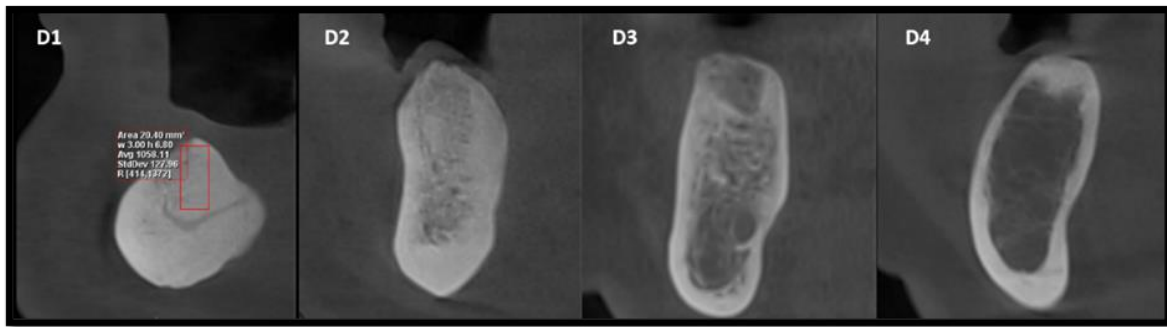


Figure 4. CBCT-based visual bone quality assessment on different cross-sectional cuts as a supplementation for the numerical values (note that the numerical values of the left image give numbers corresponding to D2 rather than the visually detected D1).

Despite the limited scientific evidence regarding CBCT-related evaluation of quality in terms of bone structure, some studies have shown potential for clinical applications (7, 27, 28). The problem is that sometimes the image is not clear enough (due to low resolution or increased noise) to judge bone microstructure as this procedure is subjective and affected by the operator's ability to interpret the image depending on his skills and the scan parameters (resolution, FOV, and exposure factors) (28, 29).

Researchers are encouraged to focus on the research gap of clinical validation of CBCT-based bone quality assessment using different protocols, machines, FOV, exposure parameters, and object location.

It is worth mentioning that image artifacts that can also obscure the vision of adjacent anatomy are frequently encountered in CBCT images of cases with dental implants (30, 31). This makes it sometimes impossible to evaluate bone in close proximity to the placed dental implants. This is a factor that, if added to the higher comparable radiation dose (if compared to dental 2D images), makes CBCT not selected for postoperative assessment unless it is needed for justified evaluation of the three-dimensional position of dental implants or in symptomatic cases where other imaging modalities are not helpful (5, 31, 32).

Conclusion

Although CBCT is not statistically as reliable as CT in bone quality assessment, it may be clinically accepted. Recent literature shows promising results with advanced calibrated machines. It is recommended that the numerical values produced by the software be

supplemented by the trained operator visual evaluation. This area should attract researchers to reach evidenced-based best practice reliable protocols in different situations.

Acknowledgment

Special thanks to Prof Dr Khaled Tawfik, Dean of the Faculty of Oral and Dental Medicine, Egyptian Russian University for his valuable support.

Conflict of Interest

The Authors declare no conflict of interest.

References

1. Fahd A, Temerek AT, Kenawy SM. Validation of different protocols of inferior alveolar canal tracing using cone beam computed tomography (CBCT). *Dentomaxillofacial radiology*. 2022;51(4):20220016.
2. Fahd A, Abd-El Ghaffar Y, El-Shenawy H, Khalifa M, Dahaba M. Bone Changes in dental implant combined with laser therapy: a split mouth study. *Researcher*. 2017;9:68-74.
3. Fahd A, Temerek AT, Ellabban MT, Adam SAN, Shaheen SDAE-w, Refai MS, et al. Cone-beam computed tomography–based radiographic considerations in impacted lower third molars: Think outside the box. *Imaging science in dentistry*. 2023;53.
4. AbdElGhaffar Y, Temerek AT, Hammad HG, Fahd A. Flapless Dental Implant Surgery as a Successful Patient Relevant Treatment Option: A 5-Year Retrospective Clinical and Radiographic Evaluation. *Egyptian Dental Journal*. 2019;65(1-January (Oral Surgery)):197-204.
5. Tyndall DA, Price JB, Tetradis S, Ganz SD, Hildebolt C, Scarfe WC. Position statement of the American Academy of Oral and Maxillofacial Radiology on selection criteria for the use of radiology in dental implantology with emphasis on cone beam computed tomography. *Oral surgery, oral medicine, oral pathology and oral radiology*. 2012;113(6):817-26.
6. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? *Dental clinics of North America*. 2008;52(4):707-30, v.
7. Pauwels R, Jacobs R, Singer SR, Mupparapu M. CBCT-based bone quality assessment: are Hounsfield units applicable? *Dentomaxillofacial radiology*. 2015;44(1):20140238.
8. Ibrahim N, Parsa A, Hassan B, van der Stelt P, Aartman IH, Nambiar P. Influence of object location in different FOVs on trabecular bone microstructure measurements of human mandible: a cone beam CT study. *Dentomaxillofacial radiology*. 2014;43(2):20130329.
9. de Oliveira RC, Leles CR, Lindh C, Ribeiro-Rotta RF. Bone tissue microarchitectural characteristics at dental implant sites. Part 1: identification of clinical-related parameters. *Clinical oral implants research*. 2012;23(8):981-6.
10. Ribeiro-Rotta RF, Lindh C, Pereira AC, Rohlin M. Ambiguity in bone tissue characteristics as presented in studies on dental implant planning and placement: a systematic review. *Clinical oral implants research*. 2011;22(8):789-801.
11. Pauwels R, Araki K, Siewerdsen JH, Thongvigitmanee SS. Technical aspects of dental CBCT: state of the art. *Dentomaxillofacial radiology*. 2015;44(1):20140224.

12. Molteni R. Prospects and challenges of rendering tissue density in Hounsfield units for cone beam computed tomography. *Oral surgery, oral medicine, oral pathology and oral radiology*. 2013;116(1):105-19.
13. Gupta J, Ali SP. Cone beam computed tomography in oral implants. *National journal of maxillofacial surgery*. 2013;4(1):2-6.
14. Campos MJ, de Souza TS, Mota Júnior SL, Fraga MR, Vitral RW. Bone mineral density in cone beam computed tomography: Only a few shades of gray. *World journal of radiology*. 2014;6(8):607-12.
15. Tatli U, Salimov F, Kürkcü M, Akoğlan M, Kurtoğlu C. Does cone beam computed tomography-derived bone density give predictable data about stability changes of immediately loaded implants?: A 1-year resonance frequency follow-up study. *The Journal of craniofacial surgery*. 2014;25(3):e293-9.
16. Song YD, Jun SH, Kwon JJ. Correlation between bone quality evaluated by cone-beam computerized tomography and implant primary stability. *The International journal of oral & maxillofacial implants*. 2009;24(1):59-64.
17. Lee S, Gantes B, Riggs M, Crigger M. Bone density assessments of dental implant sites: 3. Bone quality evaluation during osteotomy and implant placement. *The International journal of oral & maxillofacial implants*. 2007;22(2):208-12.
18. Fuster-Torres M, Peñarrocha-Diago M, Peñarrocha-Oltra D, Peñarrocha-Diago M. Relationships between bone density values from cone beam computed tomography, maximum insertion torque, and resonance frequency analysis at implant placement: a pilot study. *The International journal of oral & maxillofacial implants*. 2011;26(5):1051-6.
19. Brosh T, Yekaterina BE, Pilo R, Shpack N, Geron S. Can cone beam CT predict the hardness of interradicular cortical bone? *Head & face medicine*. 2014;10:12.
20. Valiyaparambil JV, Yamany I, Ortiz D, Shafer DM, Pendrys D, Freilich M, et al. Bone quality evaluation: comparison of cone beam computed tomography and subjective surgical assessment. *The International journal of oral & maxillofacial implants*. 2012;27(5):1271-7.
21. Sennerby L, Andersson P, Pagliani L, Giani C, Moretti G, Molinari M, et al. Evaluation of a Novel Cone Beam Computed Tomography Scanner for Bone Density Examinations in Preoperative 3D Reconstructions and Correlation with Primary Implant Stability. *Clinical implant dentistry and related research*. 2015;17(5):844-53.
22. Selvaraj A, Jain RK, Nagi R, Balasubramaniam A. Correlation between gray values of cone-beam computed tomograms and Hounsfield units of computed tomograms: A systematic review and meta-analysis. *Imaging science in dentistry*. 2022;52(2):133-40.
23. Al-Ekrish AaA, Widmann G, Alfadda SA. Revised, Computed Tomography-Based Lekholm and Zarb Jawbone Quality Classification. *International Journal of Prosthodontics*. 2018;31(4).
24. Mikic M, Vlahovic Z, Stevanović M, Arsic Z, Mladenovic R. The Importance of Correlation between CBCT Analysis of Bone Density and Primary Stability When Choosing the Design of Dental Implants-Ex Vivo Study. *Tomography (Ann Arbor, Mich)*. 2022;8(3):1293-306.
25. Xiao Y, Liang Q, Zhou L, He X, Lv L, Chen J, et al. Construction of a new automatic grading system for jaw bone mineral density level based on deep learning using cone beam computed tomography. *Scientific reports*. 2022;12(1):12841.
26. White SC, Pharoah MJ. *Oral radiology-E-Book: Principles and interpretation*: Elsevier Health Sciences; 2014.
27. González-García R, Monje F. The reliability of cone-beam computed tomography to assess bone density at dental implant recipient sites: a histomorphometric analysis by micro-CT. *Clinical oral implants research*. 2013;24(8):871-9.

28. Van Dessel J, Huang Y, Depypere M, Rubira-Bullen I, Maes F, Jacobs R. A comparative evaluation of cone beam CT and micro-CT on trabecular bone structures in the human mandible. *Dentomaxillofacial radiology*. 2013;42(8):20130145.
29. Ibrahim N, Parsa A, Hassan B, van der Stelt P, Aartman IH, Wismeijer D. The effect of scan parameters on cone beam CT trabecular bone microstructural measurements of the human mandible. *Dentomaxillofacial radiology*. 2013;42(10):20130206.
30. Nagarajappa AK, Dwivedi N, Tiwari R. Artifacts: The downturn of CBCT image. *Journal of International Society of Preventive & Community Dentistry*. 2015;5(6):440-5.
31. Draenert FG, Coppenrath E, Herzog P, Müller S, Mueller-Lisse UG. Beam hardening artefacts occur in dental implant scans with the NewTom cone beam CT but not with the dental 4-row multidetector CT. *Dentomaxillofacial radiology*. 2007;36(4):198-203.
32. Terrabuio BR, Carvalho CG, Peralta-Mamani M, Santos P, Rubira-Bullen IRF, Rubira CMF. Cone-beam computed tomography artifacts in the presence of dental implants and associated factors: an integrative review. *Imaging science in dentistry*. 2021;51(2):93-106.