ORIGINAL RESEARCH

Effect of Bone Graft on the Correlation between Clinical Bone Quality and CBCT-determined Bone Density: A Pilot Study

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Abstract

Aim and objective: The aim of this pilot study is to explore the possible correlation between radiographic bone density and clinical bone quality in edentulous implant sites with and without a history of bone grafting.

Materials and methods: A retrospective evaluation of 273 surgically placed dental implants with adequate preoperative cone-beam computed tomography (CBCT) between 2017 and 2019. Misch classification was used to assess the bone quality, and CBCT grayscale values, utilizing Hounsfield units (HU), were used for radiographic bone density assessment.

Results: Sixty-six patients (mean age, 58 years; 43 [65%] female and 23 [35%] male) with 118 implant sites were included. A total of 38 sites with bone grafts were evaluated. Controlling for location, sites with previous bone graft had softer bone quality ($p = 0.003$) and greater bone density ($p < 0.001$) compared to sites without previous bone grafts. A significant correlation existed between radiographic bone density and clinical bone quality ($p \leq 0.01$). The magnitude of the relationship increased in the absence of bone graft ($p < 0.001$) and became nonsignificant in sites with previous grafting. In sites with allograft, the relationship was not statistically different than those without bone graft (both $p \geq 0.07$), while it was statistically different in sites with xenograft when sites assumed independent ($p = 0.02$).

Conclusion: CBCT-determined radiographic bone density was correlated to clinical bone quality in the absence of previous bone grafting, while in the presence of previous bone graft, the radiographic bone density of the edentulous sites seemed to be not associated with the clinical bone density, especially in sites with history of xenograft bone grafting.

Clinical significance: CBCT could be utilized to predict preoperative clinical bone quality in sites without previous bone grafting. When assessing sites with history of bone grafting, the CBCT should be interpreted with caution, especially if xenografts were used.

Keywords: Allograft, Bone density, Bone quality, CBCT, Hounsfield unit, Xenograft.

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Introduction

Primary biomechanical stability of dental implants is largely achieved through mechanical engagement of an implant with cortical bone. This intimate engagement between the implant and bone prevents a connective tissue formation between the two entities, in turn supporting bone healing.[1] Approximately 3 weeks after implant placement, primary stability shifts to secondary stability whereby bone regeneration and remodeling occur.[2] This secondary stability phenomenon through healing and remodeling around the implant is also known as osseointegration.[3]

Literature supports the assertion that primary implant stability is a prerequisite for successful osseointegration and that implant instability results in fibrous encapsulation;[4] it is considered one of the most critical factors that predict implant success.[5] Research demonstrates that bone density and cortical thickness have a significant influence on implant primary stability.[6] There is a positive association between implant primary stability and bone mineral density of the implant site;[7] furthermore, sites with low radiographic bone density showed lower dental implant success rates.[8-10]

Primary stability is influenced by multiple factors, including bone quantity, bone density, design of the implant, and surgical technique.[5] Traditionally, bone quality is evaluated either through the Lekholm and Zarb class I to class IV radiographic bone density classification,[11] which is based on the assessment of cortical and cancellous bones, or through the Misch class D1–D4 bone quality clinical classification,[12] a tactile assessment of clinical hardness of the bone during osteotomy preparations.

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Traditionally, conventional computerized tomography-derived Hounsfield unit (HU) gray scale has been used to objectively measure the bone radiodensity.[13,14] With increased use of cone-beam computed tomography (CBCT) in implant dentistry, numerous studies have assessed the reliability of the CBCT-estimated bone density values. While the use of the absolute CBCT HU values was not recommended,[15] the CBCT-estimated bone density values were closely correlated to the ones obtained by microcomputed tomography[16,17] and computerized tomography.[18,19] It has also been demonstrated that cortical bone with higher HUs is correlated with higher implant primary stability, and CBCT can be used preoperatively to predict the bone density[20] and primary implant stability.[21–23] In addition, studies have confirmed the positive correlation between CBCT bone density HU measurements and the tactile sensation of the perceived surgical bone quality.[24–27]

To ensure adequate bone quantity for surgical dental implant placement, bone grafting is sometimes necessary for extraction sites[28] or deficient ridges.[29] Studies showed different types of bone graft remodel with variable percentages of remaining nonresorbed bone particles,[30,31] which would affect the radiographic appearance and clinical bone quality of the implant site. Despite the current literature documenting the common use of bone graft for implant site preparation, to the best of our knowledge, none of the previous studies have investigated the relationship between radiographic bone density and clinical bone quality determined by tactile sensation in the presence and absence of previous bone grafting.

The aim of this pilot study is to explore the possible correlation between radiographic bone density and clinical bone quality in edentulous implant sites with and without a history of bone grafting, thus aiding in providing clinical guidance on evaluating implant placement preoperatively via CBCT methods, in addition to traditional tactile sensation evaluation during surgical implant placement.

Materials and Methods

This cross-sectional, retrospective pilot study was conducted after obtaining the appropriate Institutional review board acceptance. Dental patient records between November 2016 and October 2019 identified 273 dental implants surgically placed and were reviewed without age, sex, or medical history bias. All dental implant cases with preoperative CBCT, captured at least 5 months postextraction, were considered for evaluation except for implant sites with reported dehiscence or fenestration at the time of implant placement, sites with history of simultaneous maxillary sinus grafting, or sites with significant radiographic scatter. Surgical dental implant placements that were performed using NobelParallel™ Conical Connection system, Creos™ allo.gain, and Creos™ xenogain were utilized for bone grafting. Data were collected based on age, sex (male and female), reported clinical bone quality [Misch classification (D1–D4)], presence of bone grafting, type of grafting (allograft and xenograft), and location (anterior, posterior, mandibular, and maxillary). Preoperative CBCT scans of patients' jaws were taken using a CBCT scanner (i-CAT FLX V17, 1910 North Penn Road Hatfield, Pennsylvania, United States). Invivo5™ software (Anatomage, 303 Almaden Blvd, Suite 700 San Jose, California) was used to retrospectively evaluate the radiographic bone density (gray scale) utilizing the medians of Hu values on coronal CBCT sections of the proposed implant sites (Fig. 1A). Bone quality analysis was conducted as follows. All dental implant surgeries were performed under standardized protocol by one surgeon (H.A). Tactile sensation was recorded as a routine clinical evaluation of resistance to osteotomy drillings during dental implant site preparations utilizing Misch (D1–D4) bone quality classification system.[12] Radiopaque radiographic or surgical stents were utilized to ensure the consistency of the evaluated radiographic and surgical areas (Fig. 1B).

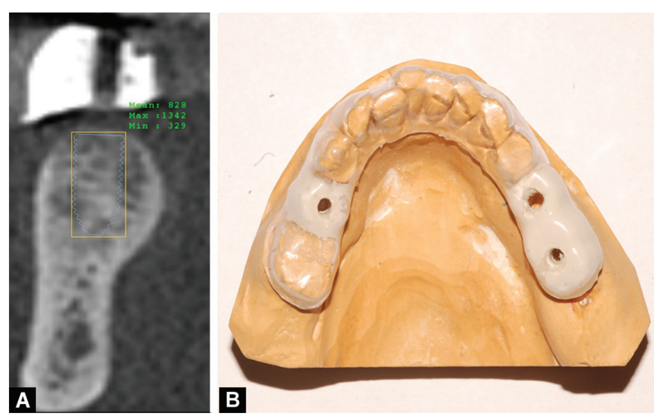
Statistical Analysis

Frequency and percentage for sex and mean age were reported at the patient level. Frequency and corresponding means and standard deviations for both clinical bone quality and CBCT bone density were reported at implant site level by sex, presence and type of bone grafting, location, and combinations of location and bone grafting. Logistic regression models were used to evaluate the distribution of implant location and relationships between bone graft prevalence with both sex and location. Regression models with clinical bone quality and CBCT bone density as outcomes were used to assess the effect of sex, bone graft, and location. Regression models with CBCT bone density as the outcome were used to assess the relationship with clinical bone quality and its interaction with bone graft presence and types. We fit all models with a random patient effect that allows for correlation among sites within individual patients (sites conditionally independent on patient) and report results conditional on the average patient. For relationships between CBCT and bone quality, we additionally fit models without a random patient effect (sites independent) and report results unconditional of the patient. We report model estimates and their associated standard errors or confidence intervals with significance levels. SAS version 9.4 software (SAS Institute, Inc) was used to conduct the analyses. A $p < 0.05$ was considered statistically significant.

Results

Sixty-six patients (mean age, 58 years; 43 [65%] female and 23 [35%] male) with 118 implant sites were included in the study. A total of 38 sites with bone grafts were evaluated, and among those, 29 sites were grafted with allograft bone graft and 9 sites were grafted with xenograft bone graft. Table 1 shows sex, bone grafting, and location distributions and the corresponding means for both clinical bone quality and CBCT bone density at the site level. Conditional on the average patient, male sites had nonsignificantly better clinical bone quality (2.5 vs 2.9; $p = 0.06$) and lower CBCT bone density (504 vs 722; $p = 0.002$). Female sites were more likely to have bone graft (probability = 0.50) than males (0.13; $p = 0.004$).

Both mandibular and maxillary posterior areas were more common implant site locations (probability = 0.36 and 0.38) compared to maxillary anterior (0.19; both $p < 0.003$), and all were more common than mandibular anterior areas (0.07; all $p < 0.009$) (Table 1). Anterior locations were more likely to have a bone graft



Figs 1A and B: (A) Coronal view. Implant site HU grayscale measurement using Invivo5™ software captured with a radiographic or surgical stent; (B) Occlusal view of the radiographic or surgical stent

Table 1: Frequency and means and standard deviations for both clinical bone quality and CBCT bone density by variable at implant site level

Variable	*N*	*Bone quality* *Mean (SD)*	*Bone density* *Mean (SD)*
Sex			
Female	63	2.9 (0.8)	708 (289)
Male	55	2.5 (0.6)	511 (215)
Previous bone graft			
No	80	2.6 (0.7)	517 (216)
Yes	38	3.0 (0.7)	826 (267)
Allograft	29	2.9 (0.7)	878 (267)
Xenograft	9	3.2 (0.7)	657 (195)
Location (transverse)			
Anterior	30	2.7 (0.6)	769 (314)
Posterior	88	2.7 (0.8)	564 (240)
Location (coronal)			
Mandibular	51	2.2 (0.5)	642 (234)
Maxillary	67	3.1 (0.7)	597 (302)
Location (all)			
Mandibular/posterior	43	2.2 (0.5)	633 (206)
Mandibular/anterior	8	2.5 (0.5)	691 (365)
Maxillary/posterior	45	3.2 (0.7)	498 (253)
Maxillary/anterior	22	2.8 (0.6)	798 (298)
Previous bone graft and location			
No			
Mandibular/anterior	6	2.5 (0.6)	547 (295)
Mandibular/posterior	33	2.1 (0.5)	583 (186)
Maxillary/anterior	7	2.3 (0.5)	587 (69)
Maxillary/posterior	34	3.1 (0.7)	433 (228)
Yes			
Mandibular/anterior	2	2.5 (0.7)	1122 (40)
Mandibular/posterior	10	2.3 (0.5)	801 (183)
Maxillary/anterior	15	3.0 (0.5)	896 (315)
Maxillary/posterior	11	3.6 (0.5)	699 (228)

than posterior (probability = 0.59 vs 0.24; $p = 0.02$). Conditional on the average patient and controlling for bone graft, the difference in clinical bone quality between maxillary and mandibular arches was significant in posterior locations (3.3 vs 2.3; $p < 0.001$), but not in anterior locations (2.6 vs 2.7; $p = 0.67$) (Table 1). Controlling for location, sites with previous bone graft had softer clinical bone quality (2.9 vs 2.5; $p = 0.003$). Similarly, controlling for bone graft, the difference in CBCT bone density between maxillary and mandibular arches was significant in posterior locations (562 vs 710; $p = 0.003$), but not in anterior locations (783 vs 704; $p = 0.41$). Controlling for location, sites with previous bone graft had greater CBCT bone density (806 vs 573; $p < 0.001$).

Table 2 shows the estimates of the regression coefficients on the relationship between CBCT bone density and clinical bone quality. When all sites with and without bone grafts were considered, there was a negative linear relationship between CBCT bone density and clinical bone quality both when modelling the sites as independent and conditionally independent on the patient (Table 2; Figs 2A and 3A). The magnitude of the relationship increased in the absence of bone graft (Table 2; Figs 2B and 3B). In cases with previous grafting, the relationship became nonsignificant. Conditional on the average patient and controlling for bone quality equal to 3, the mean bone density is estimated to be 341 (SE 43) units greater for sites with a bone graft than without ($p < 0.001$). In considering bone types, the relationship between CBCT bone density and clinical bone quality in allograft group was not significant in either model (Table 2; Figs 2C and 3C) and was not statistically different than those without bone graft (both $p \geq 0.07$). However, the relationship between clinical bone quality and CBCT bone density was statistically different compared to those with xenograft and those without a bone graft when we model sites as independent ($p = 0.02$) but not as conditionally independent on patient ($p = 0.052$) (Table 2) (Figs 2C and 3C).

Table 2: CBCT bone density and clinical bone quality by subgroups and model

Subgroup	*Site independence* *β (SE)*	*p*	*Site independence conditional on patient* *β (SE)*	*p*
Overall ($n = 118$)	−83 (33)	0.01	−139 (31)	<0.001
In the absence of bone graft	−174 (32)	<0.001	−200 (30)	<0.001
In the presence of bone graft	−74 (48)	0.13	−73 (45)	0.11
In sites with allograft bone	−83 (53)	0.12	−96 (51)	0.06
In sites with xenograft bone	91 (108)	0.40	9 (100)	0.93

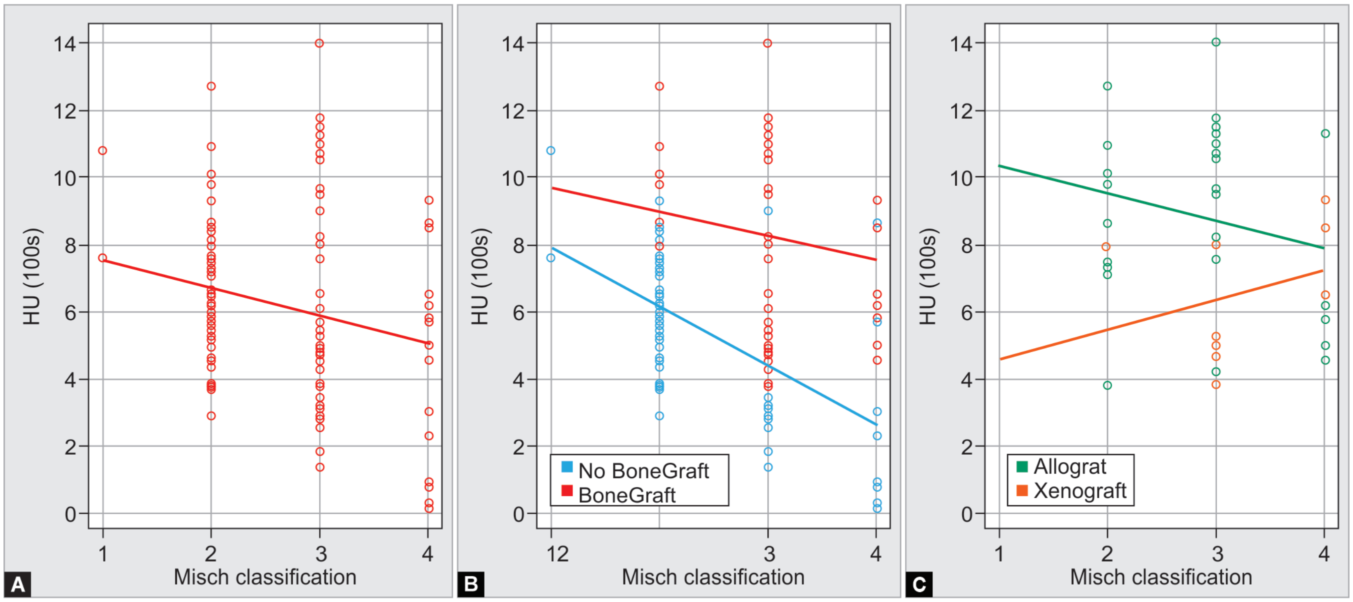
Note: Data were modelled assuming site independence within patient and allowing for dependence within patient using patient random effects

With site independence, given a one-unit increase in the Misch classification, the predicted HU would decrease by 174 units (95% CI, −238 to −110; $p < 0.001$) for those without a bone graft, decrease by 83 units (95% CI, −188 to 22; $p = 0.13$) among those with an allograft, and increase by 91 units (95% CI, −123 to 304; $p = 0.40$) among those with a xenograft (Table 2).

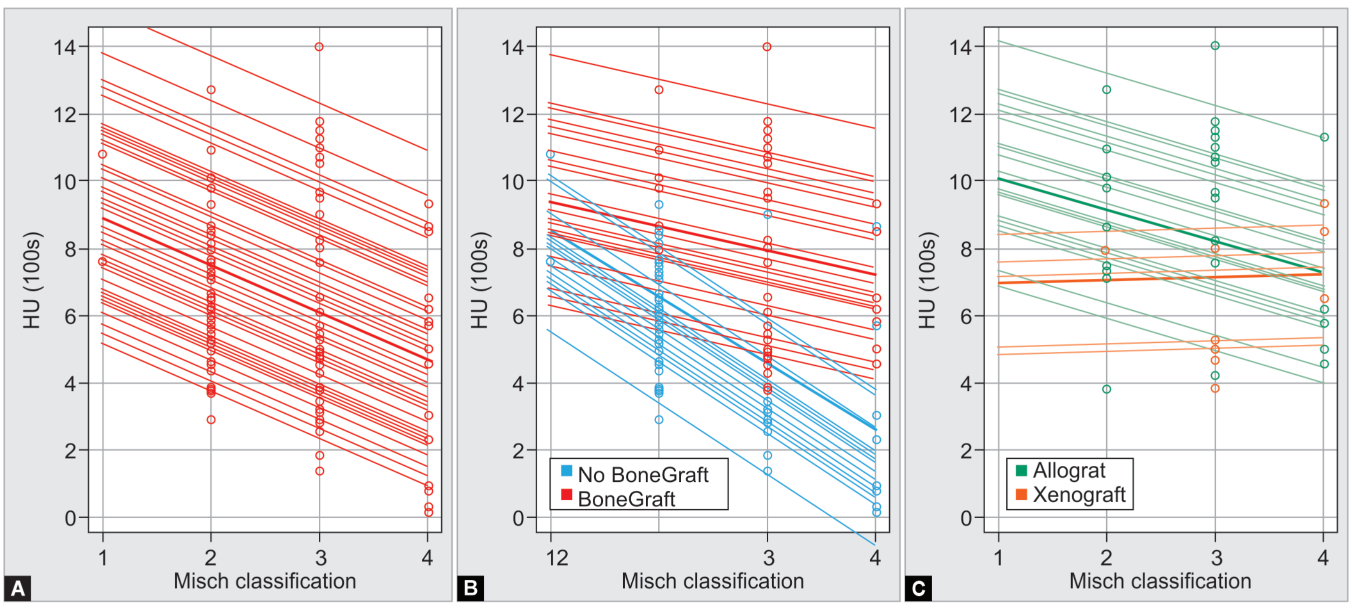
Discussion

In agreement with previous studies,[24–27] our pilot study showed a potential association between the clinical bone quality as determined by surgical tactile sensation and radiographic bone density using CBCT. During implant site preparation, the harder the tactile sensation, the denser it appeared radiographically. This can be of significant clinical value in treatment planning by allowing preoperative prediction of clinical bone quality based on CBCT-determined bone density. This evaluation of the implant site would affect the long-term survival of dental implants placed in soft bone,[32] decisions for immediate loading,[33] splinting,[34] surgical osteotomy protocol,[35,36] implant design,[37] and implant size determination.[38]

Understanding the effect of previous bone grafting on CBCT-estimated bone density and clinical bone quality is crucial for the practical utilization of CBCTs in the field of implant dentistry, while bone grafts are commonly utilized for dental implant site preservation;[28,39] this pilot study, to the best of our knowledge, is considered the first study of the relationship between preoperative



Figs 2A to C: Relationship between HU and BQ assuming site independence within patient (implant level). (A) Overall; (B) Bonegraft or no previous bonegraft, and (C) Allograft or xenograft. Thick lines are the estimated regression lines



Figs 3A to C: Relationship between HU and BQ accounting for site dependence within patient (patient level). (A) Overall; (B) Bone graft or no previous bone graft, and (C) Allograft or xenograft. Thick lines are the estimated regression lines. Thin lines represent the predicted random intercepts for the patient effect

radiographic bone density and clinical bone quality in the presence and absence of previous bone grafts.

Previous studies suggested not all bone graft particles are remodeled and replaced by native bone, containing a spectrum of remaining vital bone and fibrous encapsulated bone particles with no direct contact to the adjacent native bone.[30,31] This may help account for the findings in our study, which showed sites with previous bone grafting as denser on CBCT but suggested softer clinically by tactile sensation.

Comparing allograft to xenograft, a few studies suggest that xenograft may interfere with vital bone formation, resulting in higher percentage of residual bone graft particles un-remodeled into vitalized bone that may delay healing, compared to sites with no bone grafts.[40–42] Other studies showed that allograft sites demonstrated less remaining bone particles and higher percentage of vital bone compared to xenograft sites.[30,31,43–45] In addition, it is demonstrated that allograft resorb at faster rate, with lower percentage of un-remodeled bone graft.[30]

In this study, the presence and absence of previous bone grafting appeared to influence the relationship between radiographic bone density and clinical bone quality, since the relationship became stronger in the absence of previous bone grafting and nonsignificant in the presence of previous bone grafting. Implant sites previously grafted with xenograft showed little to no relationship between density and bone quality that was significantly different than the relationship observed among sites without bone grafting. On the contrary, sites grafted previously with allograft did not significantly differ from sites without bone grafting. This difference and change in relationship may be explained by the higher percentage of the remaining and un-remodeled bone graft particles with xenograft compared to allograft. It should be noted that although we evaluated the relationship between clinical bone quality and radiographic bone dentistry both with and without consideration to patient variability, implications from this study should be weighed more heavily toward models under the assumption of site independence results, as it is well-known that even within the same patient, bone quality and density varies dramatically depending on location and planned future implant site.[12,13]

The maxillary posterior locations showed softer bone quality compared to the mandibular locations, which is consistent with previous studies.[12,46,47] This is due to the structural and functional differences between the two arches.[48,49] In addition, although nonsignificant, our study indicated that male patients had better bone quality than female patients, which is consistent with few studies that showed female patients showed less trabecular bone compared to male patients,[50–52] but conflicting with the findings of other studies.[53] Age did not appear to affect CBCT-determined bone density and clinical bone quality relation in our study, which is in agreement with other previous studies.[52,54] Previous studies also reported an average difference of 180 in HU between progressive classes in Lekholm and Zarb[55,56] and Misch bone density classification systems.[25,57] This is in close agreement with our study in sites without bone grafting demonstrating 170 HU increase.

The limitations of our study include a small sample size of implant sites with xenografts; in addition, the effect of healing time was not investigated, although few studies reported no significant changes in the healing of bone grafts between 4.5 months and 9 months postbone grafting;[58,59] to address this concern, our healing time protocol was at least 5 months postextraction. Similar to all studies that incorporated clinical methods to assess bone quality, the subjective nature of bone quality assessment utilizing Misch classification poses another limitation to the study.[60] We believe since all of the surgical procedures were performed by one surgeon, the subjectivity effect is slightly diminished.

Utilizing the initial results of our pilot study, further prospective studies, with larger samples and longer healing times, can be conducted to evaluate the influence of different types of bone grafts on the radiographic bone density and clinical bone quality of future implant sites.

Conclusion

Within the limitation of our pilot study, it was suggested that the radiographic bone density was closely related to clinical bone quality in the absence of previous bone grafting, while in the presence of previous bone grafting, the radiographic bone density of the edentulous site was not associated with the clinical bone density.

Clinical Significance

This pilot study provided initial data indicating CBCT could be used to predict the clinical bone quality in the absence of previous bone grafts for the treatment planning purposes. In addition, the CBCT-determined bone density should be interpreted with caution in the presence of bone graft, especially in cases with xenografts.

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