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The ability to predict primary implant stability using Cone-Beam Computed Tomography

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Abstract:
Introduction:*Primary implant stability plays an important role in determining implant success. Several methods have been used to determine primary stability during implant placement. The ability to determine primary stability preoperatively would enable implant planning with higher predictability.*
Aim*: This study was performed to evaluate the reliability of CBCT in predicting primary implant stability by preoperative bone density measurement, through its correlation with clinical parameters of implant stability including insertion torque (IT) and resonance frequency analysis (RFA).*
Materials And Methods*: A total of 30 implants placed in 24 patients were evaluated. The bone density values of the implant sites were assessed preoperatively using CBCT. The maximum insertion torque and RFA expressed in implant stability quotient (ISQ)value, were recorded for each implant. Data were analyzed statistically. Spearman's correlation coefficient was calculated to evaluate the correlations between preoperative density values, IT and RFA.*
Results: *Statistically significant correlations were found between preoperative bone density and ISQ values ($r= 0.891$, $p<0.001$), bone density and IT ($r= 0.848$, $p<0.001$) and ISQ and IT ($r= 0.831$, $p<0.001$).*
Conclusion*: CBCT could be used as a reliable diagnostic tool to predict primary implant stability prior to implant placement.*
Key words: *primary stability, bone density, CBCT, dental implant stability, resonance frequency analysis, insertion torque*

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I. Introduction

Nowadays oral rehabilitation is being increasingly dependent on the use of dental implants. High success rates and patients' acceptance have rendered the use of dental implants the treatment of choice for most dentists [1]. Several factors have been reported to influence the success of dental implants including implant geometry and preparation technique[2,3]. Local bone quality and quantity are believed to influence primary stability which is one of the main factors influencing implant survival rates [3,4].Studies have shown higher failure rates for implants placed in bone of poor quality and quantity [5,6]. Hence, acquiring accurate knowledge about local bone quality is considered an integral part of implant planning.

Cone beam computed tomography (CBCT) has become widely used in dentistry. CBCT offers the advantage of decreased radiation dose and lower cost, at the same time providing images with high spatial resolution. It allows a three-dimensional and cross-sectional analysis of the jaw bone which enables the measurement of bone dimensions[7]. In addition, Bone mineral density can be quantified, and expressed in Hounsfield units (HU) using CBCT[8]. Patients with extremely low bone density values, are reported to have low primary stability of the dental implant. Osseointegration may also be jeopardized in poor quality bone during the healing period[9].

Several methods have been used to asses implant primary stability including; insertion torque, the periotest, and resonance frequency analysis [9-12]. The insertion torque measurement technique records the torque during implant placement in N cm, where it has been postulated that the resistance during implant site preparation correlates well with the bone density[10]. Another method is the Periotest, which is used to measure both; the degree of the periodontal integration of teeth and the stiffness of the bone/implant interface. The Periotest measures the deflection of the implant that has been struck by a small pistil from the instrument's hand piece. The contact time of the accelerated pistil to the implant, is calculated into a value called the Periotest value on a scale ranging from -8 to +50. The lower the Periotest value, the higher the stability[11]. In resonance frequency analysis (RFA), the stiffness of the implant-tissue interface is calculated as a reaction to oscillations exerted onto the implant/ bone system. The unit of measurement in this approach is the implant stability quotient

(ISQ) that is calculated from the resonance frequency and ranges with increasing stiffness of the interface from 0 to 100 units. The higher the ISQ number, the higher the stability[12].

These methods give useful information about implant primary stability during implant installation procedure. However, it does not provide any information regarding bone quality until an osteotomy is already performed or implants have already been screwed. However, the ability to predict primary implant stability and bone quality during the presurgical phase of implant planning may help to achieve a treatment protocol with higher predictability. Cone beam computed tomography could, therefore offer a radiographic method for the assesment of bone quality before implant placement. This study was performed to examine the correlations between the local bone density obtained from CBCT, and the primary implant stability parameters including insertion torque and resonance frequency analysis.

II. Material And Methods

A total of 24 patients receiving thirty implants were included in the study. Patients were selected from those enrolled in the comprehensive dental implant certificate program CDICP faculty of dentistry, Alexandria University, Egypt from the period of 2017-2018. The patients provided the following inclusion criteria: a) adequate bone volume for placement of dental implants b) age range 25- 50 years. c) good oral hygiene with attitude for compliance to perform strict oral hygiene measures. Exclusion criteria were: a) uncontrolled diabetes or other systemic conditions affecting bone quality; b) radiation to head and neck; c) need to bone graft for the implant recipient site due to inadequate bone volume; d) local infection. All patients were thoroughly informed about the procedure and signed a written consent. Also, local ethic approval was obtained for the main study (IRBNO:00010556-IORG0008839).

Pre-operative bone density evaluation

A preoperative CBCT scan (Soredex SCANORA® 3D, Tuusula, Finland) was used to evaluate bone density for each patient. A standardized protocol was used for all patients using the same machine with the following exposure parameters: 120 Kvp, 5 mA. Data from CBCT scans was exported in Digital Imaging and Communications in Medicine (DICOM) format into the OnDemand 3D™ software (Cybermed Inc.) to reconstruct 3D volumes. Three cross-sectional cuts 1mm apart at the middle of each previously designated implant area were selected. Trabecular bone density was obtained using the region of interest measuring tool (ROI) for a triangular area in each cut and their mean was calculated. Cross-sectional slice thickness and measured area size was standardized in all cases.

Surgical procedures

Standard two-stage surgical technique was utilized to prepare the surgical sites for implant installation. Full-thickness mucoperiosteal flaps were raised while the patients were under local anesthesia. 30 implants (Dentium superline, Dentium CO, Ltd. South Korea) were placed under sterile saline irrigation. Drilling sequence was followed according to the surgical kit until the final drill was reached for all installed implants.

Insertion torque

The maximum insertion torque value of each implant was measured using a manual torque wrench prosthetic (Nobel Biocare USA, LLC) during implant placement. Torque values were recorded as (<15, 15≥25, 25≥35, >35)

Resonance frequency analysis (RFA)

Resonance frequency measurements were recorded using Osstell™ mentor (Integration Diagnostics, Go¨ teborg, Sweden). The SmartPegs™ were mounted on the implants and tightened by hand with a screw. Each implant was measured twice from two different angles, around 90 degrees and parallel to the crestal line. RF values were represented by a quantitative unit called the implant stability quotient (ISQ) on a scale from 1 to 100. The results were expressed in ISQ and averaged for each implant. After analyzing the primary stability of each implant, the Smartpeg™ was then removed and the flap was sutured.

Post operative management

Post operative medications included; Antibiotics 1 gm tablet (Augmentin, GlaxoStmith Kline, UK) (Amoxicillin 875mg clavulanic acid 125mg), once every 12 hours for 5 days postoperatively; Non-steroidal anti-inflammatory drugs Diclofenac potassium 50 mg tablets (Cataflam 50mg), (Novartis, Swiss multinational pharmaceutical company, Novartis, New Jersey) every 8 hours for 5 days, chlorhexidine HCL (0,12%) mouth wash (Hexitol, the Arab Drug Company, Cairo, ARE) three times daily for 2 weeks. Sutures were removed two weeks post operatively.

Statistical analysis of the data

Statistical analysis were performed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The Kolmogorov- Smirnov test was used to verify the normality of distribution of variables, Comparisons between groups for categorical variables were assessed using Chi-square test (Fisher or Monte Carlo). ANOVA was used to compare more than two groups for normally distributed quantitative variables. Kruskal Wallis test was used to compare different groups for notnormally distributed quantitative variables and followed by Post Hoc test (Dunn's for multiple comparisons test) for pairwise comparison. Spearman coefficient was used to correlate between quantitative variables.

III. Results

The mean bone density in this study was 595.3±340.9 ranging from (157–1200). The anterior mandible showed the highest mean (885.5±36.7) followed by the anterior maxilla (529.3±388.6), while the posterior mandible and maxilla showed the lowest values (514.3±325.) and (5523.7±360.2) respectively. Regarding the resonance frequency analysis values, mean ISQ was 70.9 ± 5.6 ranging from (62 – 80). Comparable values were reported in different implant sites (p>0.05) however, highest value was similarly reported for the anterior mandible 73.5 ± 3.3 followed by anterior maxilla 71.1±6.4, while the lowest values were reported by posterior mandible and maxilla 70.4±5.9 and 69.4±6.2 respectively. For the insertion torque; 15 implants (50%) were inserted with a torque exceeding 35 Ncm, 9 implants (30%) from 25≥35, 5 implants (16.7%) 15≥25 and only one implant was inserted with a torque less than 15 Ncm. All implants placed in the anterior mandible showed insertion torques exceeding 25 Ncm, and all implants placed in the anterior maxilla and posterior mandible exceeded 15 Ncm.(Table 1)

Statistically significant correlations were found between bone density and ISQ values (r= 0.891, p<0.001), bone density and IT (r= 0.848, p<0.001) and ISQ and IT (r= 0.831, p<0.001). Positive correlations were found between all variables in different implant sites. Correlating implant stability parameters to implant dimensions (width and length), positive correlation was found in relation to implant length, while no correlation was found in relation to implant diameter. Implants with the following dimensions were used in the study (mean length 10.8±2.0 , mean diameter 4.0±0.6). (Table 2)

Table (1): Shows mean bone density, insertion torque and ISQ values in different implant sites

	Total (n = 30)	Implant Site				Test of sig.	p
		Posterior mandible (n = 9)	Posterior maxilla (n = 7)	Anterior maxilla (n = 8)	Anterior mandible (n =6)		
Preoperative bone density							
Median (Min. – Max.)	620(157–1200)	300(167–1015)	445(157–988)	375(176–1200)	898(833–921)	H= 4.658	0.199
Mean ± SD.	595.3±340.9	523.7±360.2	514.3±325.5	529.3±388.6	885.5±36.7		
D2	13(43.3%)	4^{a}(44.4%)	1^{a}(14.3%)	2^{a}(25%)	6^{b}(100%)		
D3	5(16.7%)	0^{a}(0%)	3^{b}(42.9%)	2^{ab}(25%)	0^{ab}(0%)	χ^2= 13.406*	0.015*
D4	12(40.0%)	5^{a}(55.6%)	3^{ab}(42.9%)	4^{a}(50%)	0^{b}(0%)		
Implant Initial Stability							
IT							
<15	1(3.3%)	0(0%)	1(14.3%)	0(0%)	0(0%)		
15 ≥25	5(16.7%)	1(11.1%)	1(14.3%)	3(37.5%)	0(0%)	χ^2= 7.572	^{MC}p= 0.652
25 ≥35	9(30.0%)	4(44.4%)	2(28.6%)	1(12.5%)	2(33.3%)		
>35	15(50.0%)	4(44.4%)	3(42.9%)	4(50.0%)	4(66.7%)		
ISQ							
Median (Min. – Max.)	70(62 – 80)	69(62 – 79)	70(62 – 80)	71(62 – 80)	74(70 – 78)	F= 0.622	0.607
Mean ± SD.	70.9 ± 5.6	69.4±6.2	70.4±5.9	71.1±6.4	73.5 ± 3.3		

χ^2: Chi square test MC: Monte Carlo
H: H for Kruskal Wallis test, Pairwise comparison bet. each 2 groups was done using Post Hoc Test (Dunn's for multiple comparisons test)
F: F for ANOVA test
p: p value for Comparison between the implant sites
Common letters are not significant (i.e. Different letters are significant)
*: Statistically significant at p ≤ 0.05

Table (2): Correlation between different studied parameters (bone density, IT, ISQ and implant dimensions)

	Implant Site								Total	
	Posterior mandible		Posterior maxilla		Anterior maxilla		Anterior mandible			
	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
Preoperative bone density vs.										
IT	0.917*	0.001	0.954*	0.001	0.848*	0.008	0.828*	0.042	0.848*	<0.001
ISQ	0.975*	<0.001	0.919*	0.003	0.952*	<0.001	0.406	0.425	0.891*	<0.001
IT vs. ISQ	0.917*	0.001	0.878*	0.009	0.782*	0.022	0.840*	0.036	0.831*	<0.001
ISQ vs.										
Length (mm)	0.449	0.225	0.334	0.464	0.756*	0.030	0.531	0.278	0.453*	0.012
Diameter (mm)	-0.445	0.230	-0.028	0.952	0.507	0.200	-0.564	0.244	-0.158	0.404
IT vs.										
Length (mm)	0.531	0.142	0.495	0.259	0.552	0.156	0.632	0.178	0.438*	0.016
Diameter (mm)	-0.427	0.251	-0.265	0.566	0.679	0.064	-0.224	0.670	-0.024	0.902

r_s: Spearman coefficient
*: Statistically significant at $p \leq 0.05$

IV. Discussion

Primary stability is defined as the biometric stability immediately after implant insertion. The role of primary implant stability is crucial for the long-term success of dental implants[13]. The relation between primary stability and pre-surgical measurements of bone density could help in dental implant treatment planning. Modification of the surgical technique, the loading protocol or the implant design and surface characteristics could be performed according to the preoperatively obtained data.

In the current study, significant correlations were observed between density value and insertion torque, density value and ISQ, and insertion torque and ISQ, with correlation coefficients of 0.848, 0.891 and 0.831 respectively. These findings suggest a high correlation between the density values obtained by CBCT and primary implant stability. Previous studies also reported significant correlations between bone density and implant stability. Bone density values obtained from pre-operative CT showed strong correlation to cutting torque values and resonance frequency analysis[14,15]. However, these studies evaluated bone density using helical computed tomography (CT). Considering the recent wide increase in the use of CBCT in implant therapy, studies correlating bone density obtained by CBCT and primary implant stability were therefore required. High correlation between bone density values obtained by CBCT and HU of multi-slice CT have been reported in several studies [8,16,17]. The local bone density therefore, might be estimated by the density values obtained from CBCT. Using CBCT Song et al. obtained a strong correlation between bone density and resonance frequency analysis values in a study conducted on 61 implants placed in 20 patients [18]. Similarly, Salimov et al found significant correlations between CBCT density values and implant stability parameters including insertion torque, and ISQ values [19]. Implant stability parameters were also evaluated on 18 fresh femoral heads of swine, and positive correlation to CBCT bone density was also obtained [20].

Primary implant stability has been reported to influence implant survival rate [21]. This probably reflects the importance of an undisturbed healing in achieving successful osseointegration. Several studies have demonstrated good correlation between implant stability and the biological events leading to osseointegration[22,23]. Similarly, failure in the osseointegration has been associated with low primary stability measured by resonance frequency analysis [24,25]. On the other hand, several studies have demonstrated no correlations between bone density and implant stability[26,23]. Twenty-two implants were inserted into the maxillae and mandibles of human cadavers, and no correlations were found between ISQ and histomorphometric parameters of trabecular bone analyzed by micro-CT[26]. A previous study reported similar findings in 13 patients [23].

When evaluating the correlation between ISQ and HU values, moderate correlation was reported in some studies with a correlation coefficient of 0.46 [27], and high correlation was reported in others 0.882 [28] in accordance to the current study. Different methodologies used in these studies might explain this variation. Studies considering only the trabecular bone for density evaluation, found the lowest value [27]. However, others considering the cortical and trabecular bone as a unit, obtained stronger correlations [28]. Although this study considered only trabecular bone, high correlation was yet obtained. When evaluating the correlation between IT and HU values, correlation coefficients were strong, and ranged from 0.768 29 to 0.859 [29] comparable to the result reported in the current study.

In the current study the highest bone density value was reported for the anterior mandible, while the lowest for the posterior maxilla in accordance to previous studies [29,310]. Some investigators identified a higher mean bone density in the anterior region of the maxilla than in the posterior region of the mandible similar to the current study[30]. Whereas, others identified higher density values in the posterior of the mandible than in the anterior of the maxilla [29].

Regarding implant dimensions, Boronat- Lopez et al. found that greater implant diameter was associated with greater ISQ values [30]. Increased primary stability parameters in implants with greater diameter have been attributed to increased surface area [31,19]. On the other hand, in the current study no correlation was found between implant diameter and implant stability parameters, correlation was found regarding implant length. However, in the aforementioned study the implant length was standardized for all implants which might explain variation in results. Hence, implant dimensions together with different implant sites should be considered when predicting implant stability.

Within the limitations of this study a significant positive correlation was found between density values measured by CBCT and primary implant stability. These findings signify the importance of CBCT as a diagnostic tool in predicting primary implant stability.

V. Conclusion

This study demonstrated a strong correlation between density values obtained by CBCT and primary implant stability parameters recorded by IT and ISQ. Hence, CBCT could be used as a reliable diagnostic tool to predict primary implant stability.

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