Journal of Cranio-Maxillo-Facial Surgery 47 (2019) 461–467

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

Correlation of cone beam CT-derived bone density parameters with primary implant stability assessed by peak insertion torque and periotest in the maxilla

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ARTICLE INFO

Article history:
Paper received 7 August 2018
Accepted 4 January 2019
Available online 10 January 2019

Keywords:
Bone mineral density
Cone beam CT
Dental implants
Insertion torque
Maxilla
Resonance frequency analysis

ABSTRACT

Purpose: Primary implant stability is crucial to osseointegration. The aim of this study was to assess correlation of preoperative radiologic parameters with intraoperatively obtained biomechanical tests in the maxilla.
Materials and methods: A total of 259 implants were inserted in the maxilla of 99 patients. Cone-beam computed tomography (CBCT)-derived Hounsfield units (HU), voxel grey values and computed tomography mental index (CTMI) performed preoperatively were correlated with insertion torque and Periotest (obtained intraoperatively and 12 weeks later) to assess their prognostic value for primary implant stability.
Results: Voxel grey values and insertion torque showed a low correlation ($r = 0.329$, $p = 1.055 \times 10^{-7}$). Likewise, a low correlation was found between HU measured preoperatively and insertion torque as well as intraoperative Periotest values ($r = 0.297$, $p = 4 \times 10^{-6}$ and $r = -0.234$, $p = 4.35 \times 10^{-4}$, respectively). A moderate correlation could, however, be assessed between insertion torque and intraoperative as well as Periotest values 12 weeks later. ($r = -0.555$, $p = 1.022 \times 10^{-20}$ and -0.465. $p = 1.150 \times 10^{-13}$). On contrast, a high correlation was observed between the voxel grey values of CBCT and related HU ($r = 0.710$, $p = 6.486 \times 10^{-37}$) so that a conversion from grey values into HU could be suggested. According to regression analysis, an intraoperative negative Periotest value could be expected at an insertion torque of 40 N/cm upwards.
Conclusion: CBCT-based bone density parameters correlate with each other and allow conversion of grey scales into HU preoperatively. Both insertion torque and Periotest showed a significant correlation which enables regression analysis to predict implant stability for related insertion torque. On contrast, for HU the distribution curves do not allow a reliable assignment into certain Periotest values.

1. Introduction

Primary stability plays a major role in osseointegration and long-term survival of dental implants. The time period required for osseointegration and subsequent prosthetic rehabilitation varies according to bone quality in the insertion site, which in turn depends on local anatomic bony structures.

As a clinical indicator for primary implant stability, Aparicio assessed a direct correlation between Periotest-values measured intraoperatively and initial primary stability and subsequent osseointegration of enossal implants (Aparicio, 1997). Comparable results have also been demonstrated in a resonance frequency analysis (Zix et al., 2008; Oh et al., 2009).

While some studies have been carried out to elucidate the role of maximal insertion torque on primary implant stability and healing for orthodontic mini-implants (Meursinge Reynders et al., 2012) only a few experimental data are available on its reliability for dental implants (Greenstein et al., 2017).

These measurements, however, since they are first available during or after implant insertion, cannot be used for preoperative surgical planning. Therefore, preoperative radiologic assessment of bone quality prior to implant placement in a certain region may predict primary implant stability and facilitate choosing appropriate loading protocols.

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https://doi.org/10.1016/j.jcms.2019.01.002
1010-5182/

Effort has been spent to evaluate bone quality preoperatively by computed tomography (CT) (Homolka et al., 2002; Roze et al., 2009) and more recently by cone beam CT (CBCT) (Isoda et al., 2012).

A systematic review concerning detection of low bone mineralization by CBCT indicated a certain potential of CBCT for screening individuals with a low degree of bone mineralization (Guerra et al., 2017).

Furthermore, it has been demonstrated that low bone mineral density is frequently observed in the maxilla, and therefore an impaired primary healing and disturbed osseointegration is often observed in the upper jaw. Along with the reduced vertical bone availability in the posterior region of the maxilla, this may further limit the stability of enossal implants for dental rehabilitation (Raghoebar et al., 2014).

In contrast to dental CT (Homolka et al., 2002), however, there is a lack of evidence on the correlation of bone mineralization measured by CBCT and primary implant stability as well as the related clinical course.

As far as we know, this is the first study to address the correlation among bone mineral density parameters (voxel grey scales in CBCT and CBCT-based HU) and related biomechanical parameters of dental implants inserted in the maxilla, including peak insertion torque and intraoperative Periotest values.

2. Materials And Methods

Data from 99 patients (aged 22–71 years, mean = 53.2 years) were included in the study. They received 259 enossal implants of a single system (tioLogic®, Dentaurum Implants, Ispringen, Germany) in the maxilla. Implant length and diameter are given in Fig. 1.

Cases were included when preoperative CBCT was performed, dynamic insertion torque was assessed during implant insertion, and Periotest values were measured directly intraoperatively after implantation and upon uncovering 12 weeks later.

2.1. CBCT

CBCT was performed using Sirona GALILEOS Comfort CBCT scanner with standard scan using 85 KV and 35 mAS (Galaxis/Galileos Implant, Sirona Dental Systems GmbH, Bensheim, Germany). For evaluation of bone density, the CBCT device was calibrated by the recommended three-dimensional–two-dimensional image registration, and each scan was exported as Digital Imaging and Communications in Medicine (DICOM) format, and used with specific diagnostic software (Simplant Pro 17.01, Dentsply Sirona, Mannheim, Germany). Bone density was likewise evaluated by software (Fig. 2).

Bone quality was assessed in the planned implant site (region of interest [ROI]) at three levels using the voxel grey values and corresponding Hounsfield units (HU) values by the software mentioned above (Mah et al., 2010; Parsa et al., 2012; Valiyaparambil et al., 2012).

Bone density was calculated according to the computed tomography mental index (CTMI) method (Koh et al., 2011); Hounsfield units were obtained according to Lee et al. (2007) (Fig. 3). Data are given as mean ± standard deviation.

2.2. Measurement of maximal insertion torque

The insertion torque was measured by Elcomed SA-200C from W&H Dentalwerk Bürmoos GmbH, Bürmoos, Austria).

This surgical drive unit allows torque calibration between 2 and 70 N/cm at 20 rpm and measures the insertion torque during insertion of the implant and compensates for torque loss so that a high torque accuracy can be achieved. The IT was continuously registered and data saved on a memory card in the unit. This procedure resulted in a torque/time dataset for each implant, from which mean and peak IT values in Ncm could be calculated.

The maximum insertion torque value was determined by the contact resistance between the implant surface and the alveolar bone.

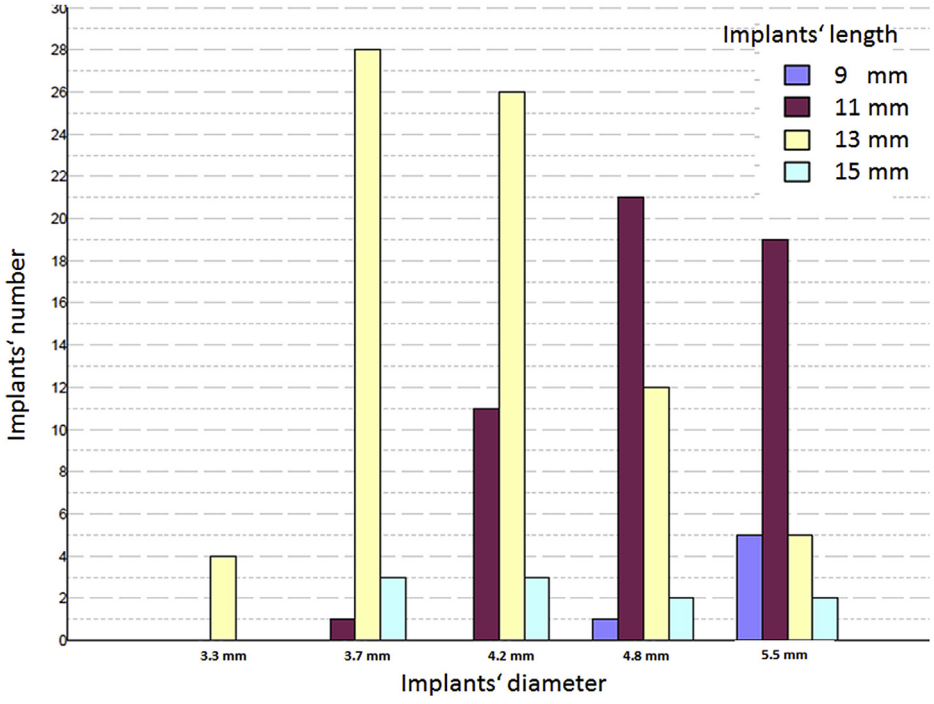

Fig. 1. Distribution of implant number, length and diameter and in the maxilla of 99 patients.

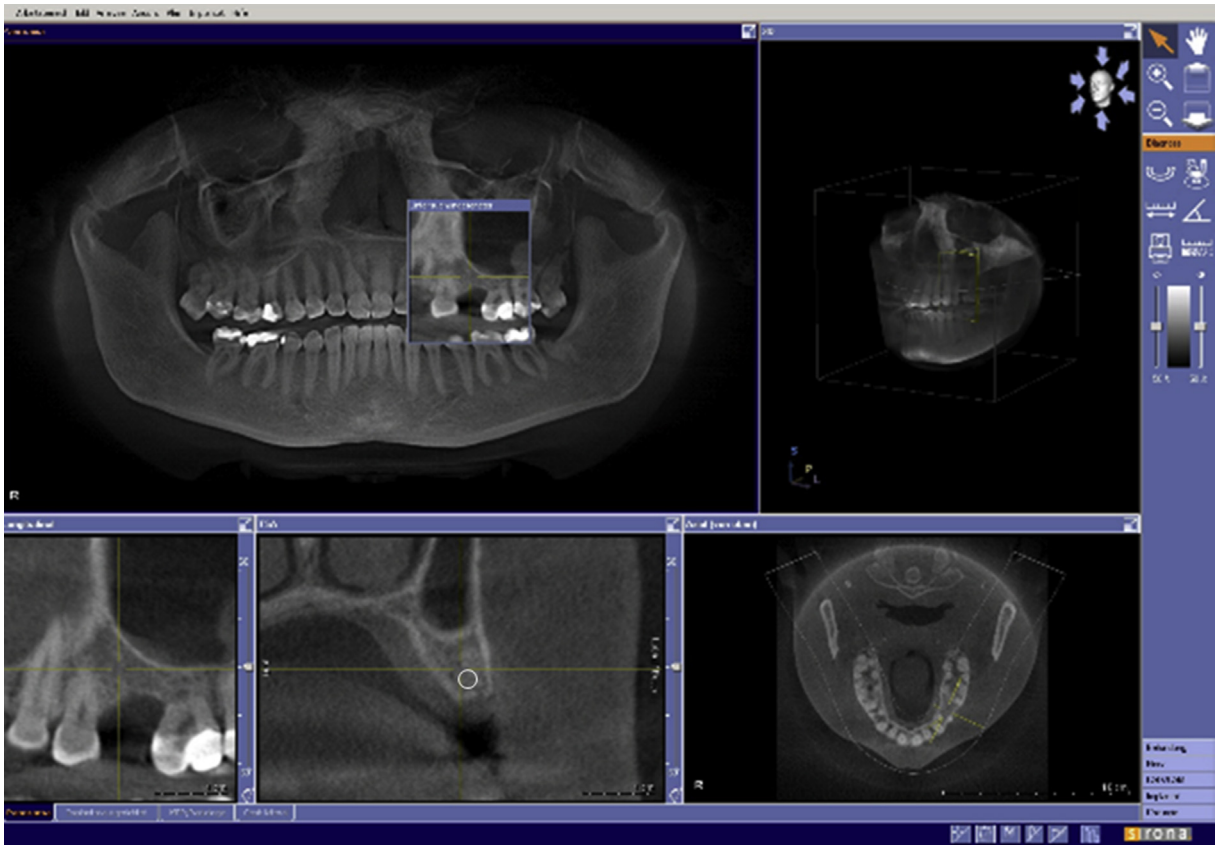

Fig. 2. Measurement of voxel grey values and Hounsfield units by CBCT.

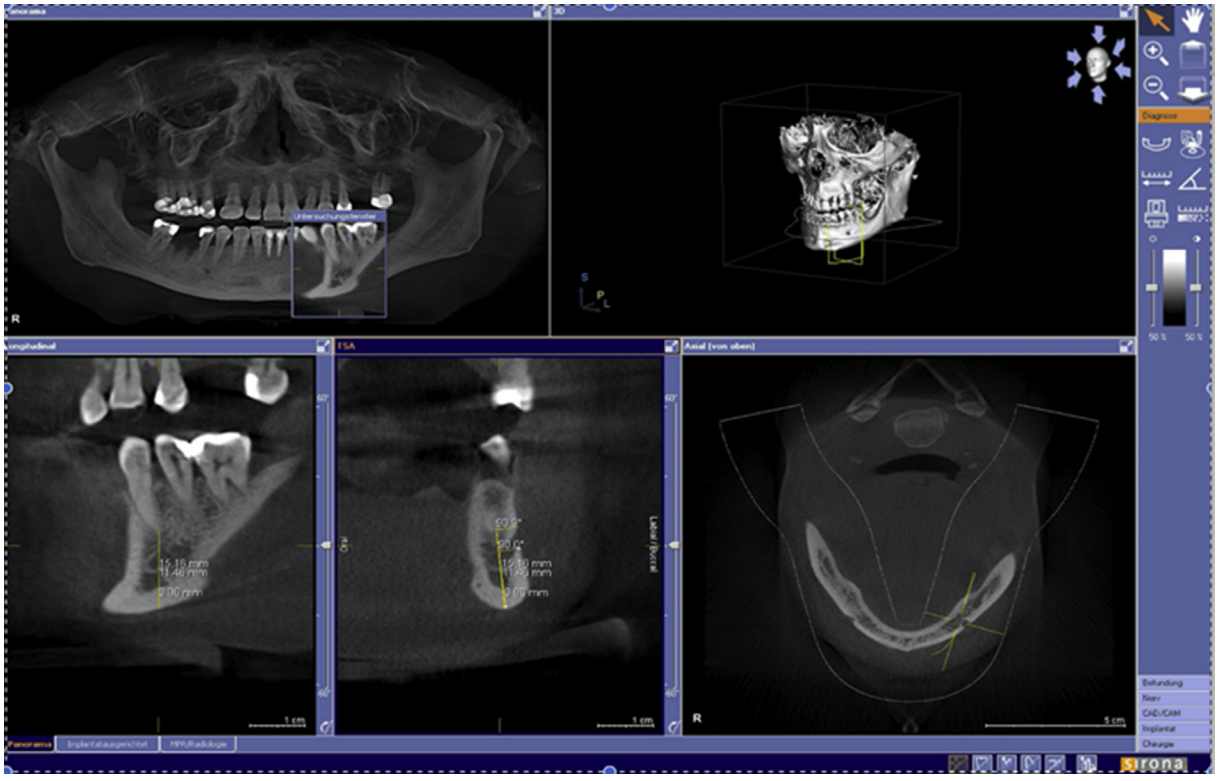

Fig. 3. Assessment of CT Mental Index (CTMI) by morphometric analysis of the mandible.

2.3. Biomechanical assessment

The Periotest® device (Medizintechnik Gulden e. K, Modautal, Germany) was used to assess the primary stability of the implants. Values were given according to the instructions of the manufacturer and ranged from 0 to −8 PTV for sufficient and from +1 to +9 PTV for insufficient implant stability. This is one of the noninvasive methods and offers the possibility to prove implant stability *in vivo*.

2.4. Statistical evaluation

Mean values and standard deviation of peak torque, Periotest and the CTMI values as well as the Hounsfield units were demonstrated to have normal distribution using the Shapiro–Wilk test.

The correlation between the peak torque values, Periotest values, the averaged grey values and the averaged Hounsfield units according to Lee as well as the CTMI values according to Koh were visualized by a scatter plot.

Correlation test according to Spearman and regression analysis were performed after adjustment of significance level by the Bonferroni–Holm correction.

For correlation coefficients, values with $r \leq 0.2$ indicated a very weak correlation, $0.2 < r \leq 0.5$ a low correlation, $0.5 < r \leq 0.7$ a moderate correlation, $0.7 < r \leq 0.9$ a high correlation, and $0.9 < r \leq 1$ a very high correlation.

Logistic regression analysis was performed and the area under the curve (AUC) was obtained to prove sensitivity, specificity and cut-off value (Lu et al., 2002).

The statistical evaluation was carried out with the SPSS 22 software program (IBM Corp, Armonk, NY).

All procedures are in compliance with the appropriate EQUATOR guidelines and were approved by the Ethical committee of the University of Luebeck, Germany.

3. Results

3.1. Distribution of implant length and diameter in the maxilla

Implants 3.3–4.2 mm in diameter and 11–13 mm in length were mostly inserted in the maxillary front, whereas thicker and shorter implants (4.2–4.8 mm in diameter and 9–13 mm in length, respectively) were frequently placed in the posterior region.

3.2. Distribution of voxel grey, Hounsfield units according to Lee and CTMI values

The voxel grey values ranged from 1175 to 2596 with a mean = 1514 ± 161, the Hounsfield units according to Lee from 148 to 831with a mean of 436 ± 130 HU. CTMI values were 3.96 ± 0.80 mm.

3.3. Distribution of peak insertion torque and Periotest values

A maximum insertion torque of 29.2 ± 21.8 N/cm was assessed during implantation along with Periotest values of 1.7 ± 5.6 PTV afterwards.

3.4. Correlation analysis

A surprising very low and non-significant correlation between the implant diameter and length on one side and insertion torque on the other side attests to a limited effect of implant geometry on insertion torque ($p = 0.435$ for implant diameter and correlation coefficient = 0.192, $p = 0.002 < \propto_{adj.} = 0.00714$ for implant length).

Voxel grey values and peak insertion torque showed only a low correlation (correlation coefficient = 0.329, $p = 1.055 \times 10^{-7} < \propto_{adj.} = 0.00714$). Likewise, a similar low correlation was found between Hounsfield units measured preoperatively and insertion torque as well as Periotest values (correlation coefficient = 0.297, $p = 4 \times 10^{-6}$ and correlation coefficient = 0.234, $p = 4.35 \times 10^{-4} < \propto_{adj.} = 0.00714$, respectively)

Hounsfield units further correlated low with the CT mental index values (CTMI) as two independent variables (correlation coefficient = 0.215, $p = 0.001$). A moderate correlation could however be assessed between grey values and Periotest values encountered after implant insertion ($p = 0.047 > \propto_{adj.} = 0.00714$).

Further moderate correlation was found between insertion torque and Periotest values measured intraoperatively and those assessed 12 weeks later upon exposure of implants (correlation coefficient = −0.555, $p = 1.022 \times 10^{-20}$ and − 0.465. $p = 1.150 \times 10^{-13}$, respectively).

In contrast, a high correlation was observed between the voxel grey values of CBCT and related Hounsfield units calculated according to Lee (correlation coefficient = 0.710, $p = 6.486 \times 10^{-37} < \propto_{adj.} = 0.00714$) (Table 1, Fig. 4).

Neither of the following investigated parameters showed any significant correlation: voxel grey values and CTMI values ($p = 0.009$), grey values and Periotest values at any time ($p = 0.047$), insertion torque and CTMI values ($p = 0.033$), Periotest values at any time and implant diameter ($p = 0.313$), Periotest values at any time and implant length ($p = 0.153$, each $> \propto_{adj.} = 0.00714$) (Table 2).

3.5. Regression analysis

Linear regression between voxel grey values and Hounsfield units according to Lee.

The regression model is significant ($F = 264.18$, $p = 4.536 \times 10^{-40} < \propto_{adj.} = 0.00714$).

The t-tests for the regression coefficient of the grey values ($t = 16.25$, $p = 4.536 \times 10^{-40}$) und the constant ($t = -9.75$, $p = 5.095 \times 10^{-19}$) are significant so that the following regression calculation emerges:

Hounsfield units = − 655.932 + 0.728 × voxel grey values.

Regression analysis for further parameters could not be assessed since the requirements for normal distribution of residual values were not met.

3.6. Prediction of primary stability by HU and insertion torque

Provided that a negative Periotest value measured intraoperatively predicts sufficient primary stability, a threshold of the torque values for division into a positive or negative Periotest cannot be determined, since the normal distribution curves are almost superimposed. An intersection of the curves is at 40 N/cm and the obtained AUC amounted to 0.782 for intraoperative Periotest values and 0.779 for Periotest assessed upon uncovering the implants 12 weeks later (Figs. 5 and 6). Hence, a negative intraoperative Periotest value could be expected by an insertion torque of 40 N/cm upwards. The positive intraoperative Periotest values show a clear left shift to lower torque values. For the negative Periotest values however, a right shift of the torque to higher values would be expected, but is not quite as obvious as for the positive values.

In contrast, for HU the normal distribution curves of the positive and negative Periotest values at both investigation time points do not allow a reliable assignment into a positive or negative Periotest values.

4. Discussion

Success of implant restoration depends on various factors such as the cortical thickness, the structure of the trabecular bone and

Table 1
Correlation coefficient ***r*** and related ***p***-values for investigated radiologic and biomechanical parameter.

		Grey scale	Intraoperativeperiotest	Periotestafter 12 Weeks	Insertion torque	HU	CTMI
Grey scale	r	1.000	−0.129	−0.133	**0.329**	**0.710**	0.167
	p		0.047	0.044	**1.055×10^{-7}**	**6.486×10^{-37}**	0.009
Periotest0	r	−0.129	1.000	-	**−0.555**	**−0.234**	−0.101
	p	0.047			**1.022×10^{-20}**	**4.35×10^{-4}**	0.119
Periotest 10	r	−0.133	-	1.000	**−0.465**	−0.171	−0.153
	p	0.044			**1.150×10^{-13}**	0.012	0.021
Insertion torque	r	**0.329**	**−0.555**	**−0.465**	1.000	**0.297**	0.135
	p	**1.055×10^{-7}**	**1.022×10^{-20}**	**1.150×10^{-13}**		**4×10^{-6}**	0.033
HU	r	**0.710**	**−0.234**	−0.171	**0.297**	1.000	**0.215**
	p	**6.486×10^{-37}**	**4.35×10^{-4}**	0.012	**4×10^{-6}**		**0.001**
CTMI	r	0.167	−0.101	−0.153	0.135	**0.215**	1.000
	p	0.009	0.119	0.021	0.033	**0.001**	

($\propto_{adj.} = 0.00714$; Significant values are given in bold).

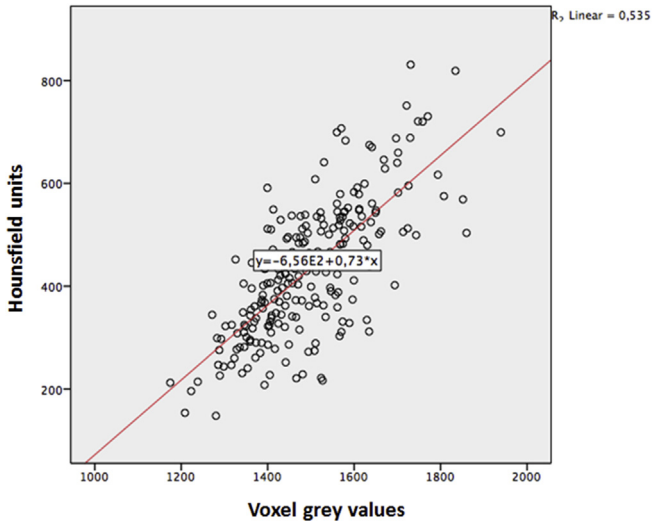

Fig. 4. Scatterplot for correlation of CBCT derived voxel grey values and calculated Hounsfield units.

the anatomical composition around the implant. These radiologic criteria could be assessed preoperatively by simple panoramic tomography, CT or cone beam CT (CBCT) (Akca et al., 2006).

It is widely accepted, albeit not evident experimentally, that bone clinical quality assigned D1 to D4 corresponds to bone density ranging from 100 to 1500 HU as measured by computer tomography (Misch, 1999). Nevertheless, preoperative assessment of bone quality and related primary stability of enossal implants still represent a challenging clinical problem.

Recently, several studies addressed this question in clinical cohorts and particularly investigated CT and CBCT based bone mineral density parameters along with implant insertion toque (IT), as well as implant stability quotient (ISQ) measured by resonance frequency analysis (RFA) (Ikumi et al., 2005; Turkyilmaz et al., 2008; Bergkvist et al., 2010; Merheb et al., 2010, 2018; Sencimen et al., 2011; Tatli et al., 2014; Akoglan et al., 2017) (Table 3).

Among the numerous methods used in the literature, the present study is the first to investigate the correlation between CBCT-derived HU and voxel grey scales on one hand and their correlation with primary implant stability assessed by insertion torque (IT) and Periotest values (PTV) on the other hand.

4.1. Voxel grey scales and Hounsfield units for preoperative bone density assessment.

In view of radiologic investigations we could show that voxel grey values highly correlates with the HU ($p = 6.486 \times 10^{-37}$), which in turn correlates with bone density as previously demonstated (Norton et al., 2001). This result is in accordance with a recent experimental study which assessed a high correlation between voxel grey scales in CBCT and HU in CT scans (Norton et al., 2001; Homolka et al., 2002; Khojastepour et al., 2017).

Table 2
Correlation coefficient ***r*** and related ***p***-values for insertion torque, implant length and diameter.

	p	r
Insertion torque/Implant length	**0.002**	**0.192**
Insertion torque/Implant diameter	0.435	−0.050
Intraoperative Periotest/Implant length	0.153	−0.093
Intraoperaive Periotest/Implant diameter	0.313	−0.065
Periotest after 12 weeks/Implant length	0.221	−0.081
Periotest after 12 weeks/Implant diameter	0.610	−0.034

($\propto_{adj.} = 0.00714$; Significant values are given in bold).

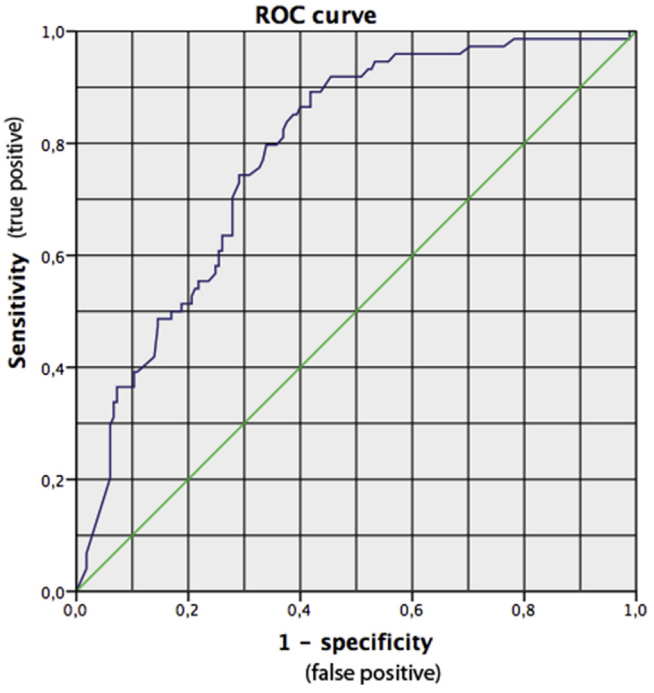

Fig. 5. Receiver operating characteristic (ROC) analysis for logistic regression of peak insertion torque and related intraoperative Periotest values. Area under the curve (AUC) = 0.782.

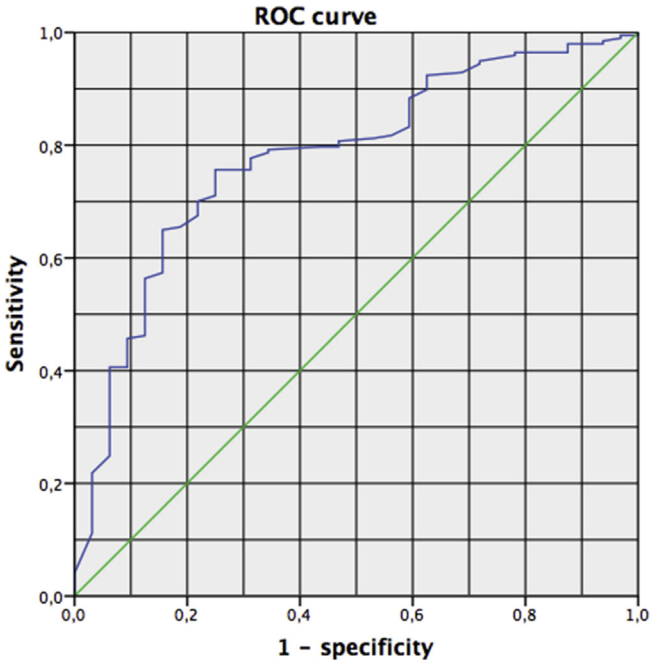

Fig. 6. Receiver operating characteristic (ROC) analysis for logistic regression of peak insertion torque and related Periotest values upon implant exposure 12 weeks later. Area under the curve (AUC) = 0.779.

Accordingly, we could introduce a regression model that allows mathematical inference from voxel grey scales measured in a routine CBCT into a HU value which in turn gives preoperative information on bone quality in a planned insertion site. Our regression model (Hounsfield unit = −655.932 + 0.728 × voxel grey value) implicates that if the independent variable voxel grey value increases by 1 unit, the dependent variable Hounsfield unit increases by 0.728 units.

Similar results have been shown for other CBCT scanners such as the Newtom VG (R^2 = 0.997, HU = 14.621 + 1.088 × grey scale), Scanora Soredex (R^2 = 0.989, HU = −24.052 + 1.146 × grey scale, and Planmeca (R^2 = 0.979, HU = −61.098 + 1.178 × grey scale) (Cassetta et al., 2014; Razi et al., 2014).

4.2. Peak insertion torque and Periotest for assessment of primary implant stability.

Both insertion torque (IT) and Periotest (PTV) methods for assessment of primary implant stability correlated significantly with each other ($p = 1.022 \times 10^{-20}$), which *a priori* proves validity of the experimental study design. However, only peak IT but not PVT correlated with both CBCT grey scales and HUs (Table 1).

There are a few reliable reports on correlation of CBCT-retrieved HU and peak IT of tapered enossal implants (Fuster-Torres et al., 2011; Sennerby et al., 2015). However, they evaluated both maxillary and mandibular bone in a lower number of patients than in the present study. Nevertheless our results are in line with the results of this study, which assessed significant correlation of CBCT-derived bone density with peak insertion torque as well as ISQ values.

Bone density measured as grey scales from CBCT and its correlation with IT has been a subject of a clinical study with a 23 patients, who received 77 implants in the maxilla and/or mandible. The authors concluded a high correlation of voxel values and IT (Tatli et al., 2014). Instead of PVT values used in the current study, the authors applied RFA measurements and assessed a significant correlation between ISQ values and CBCT-derived bone density.

Recently, Merheb et al. reported a strong correlation between HU measured by CT and RFA of inserted implants on one side and PVT values on the other side (Merheb et al., 2018).

They even postulated a formula in an effort to predict primary stability based on preoperative radiological assessment.

Both Periotest values (intraoperatively and 12 weeks later) and maximal insertion torque correlated with each other on one hand, and on the other hand with the HU measured by CBCT in our study. Furthermore, we could evolve a threshold peak insertion torque value (40 N/cm) indicating negative Periotest values and adequate primary implant stability.

Lee et al. reported that cortical bone density does not have a significant effect on the success of orthodontic implants, but cancellous and total bone densities were significantly related to their success (Lee et al., 2016). This may also explain the incomplete compatibility between the subjective judgment on bone quality according to Lekholm and Zarb during implant insertion—mostly influenced by cortical bone thickness—and bone density evaluated by CT or CBCT (Lekholm et al., 1985). Concordant findings have been also obtained in the present study, since we did not assess any correlation between pure radiomorphologic criteria encountered in the CTMI, taking cortical bone thickness at several sites into consideration, and the applied biomechanical tests (Table 1). This may also raise the question as to whether osteoporosis alone may limit the primary stability, primary healing and long-term prognosis of enossal implants.

Although CBCT-voxel values are generally vulnerable and affected by noise levels, scattered radiation, high heel effect, and beam hardening artifacts and thus are device-dependent, they seem to correlate with CBCT-derived HU as assessed in the present

Table 3
Overview of recent clinical studies investigating correlation between radiologic bone density criteria and related primary implant stability.

Authors and year of publication	Patients' number	Implants' number	Implant dimension and manufacturer	Region of implant insertion	Radiologic investigation	Assessment of implant stability	Time of radiologic assessment
Ikumi et al. (2005)	13	56	Nobel BioCare TiUnite MKIII	Maxilla and mandible	CT	IT	Preoperative
Turkyilmaz et al. (2008)	111	300	Nobel BioCare TiUnite MKIII	Maxilla and mandible	CT	IT, ISQ	Preoperative
Bergkvist et al. (2010)	31	137	Straumann SLActive	Maxilla and mandible	CT	ISQ	Preoperative
Merheb et al. (2010)	24	136	Straumann SLActive	Maxilla	CT	ISQ	Preoperative
Sencimen et al., 2011	19	106	SPI, Swiss	Maxilla and mandible	CT	ISQ	Preoperative
Tatli et al., 2014	23	77	Implantium Dentium	Maxilla and mandible	CBCT (VGS)	IT, ISQ	Preoperative
Akoglan et al., 2017	39	39	Implantium Dentium	Maxilla	CBCT	ISQ	post-operative
Merheb et al. (2018)	48	195	AstraTech, Dentsply	Maxilla and mandible	CT	ISQ, PTV	Preoperative
Present study	**99**	**259**	TioLogic, Dentaurum	**Maxilla**	**CBCT(HU/VGS)**	**IT, PTV**	**Preoperative**

Features of the present study are given in bold and point out the distinct difference in patients' and implants' number, region of implant insertion and kind of radiologic as well as biomechanical assessment.
IT = insertion torque, ISQ = implant stability quotient, PTV = Periotest value, CBCT = cone beam CT, HU = Hounsfield units, VGS = voxel grey scale.

study. Furthermore, their correlation with the both IT and PTV provides a valuable instrument to predict primary implant stability and estimate prognosis in the follow-up.

As far as we know, the present study is the first to investigate all four radiologic and biomechanical parameters simultaneously in a relatively high number of patients in the maxilla, providing valid data on their correlation.

5. Conclusion

The results presented here provide an essential component for CBCT-based preoperative radiologic assessment of critical density values and proved the reliability of intraoperative peak insertion torque as a prognostic factor for primary implant stability, potential early or direct loading, as well as long-term prognosis of dental implants in the maxilla.

Ethical approval

All procedures performed in studies involving human participants were conducted in accordance with the ethical standards of the institutional and national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Funding

This study was supported partially by Dentaurum Implants, Ispringen, Germany and by the Department of Oral & Maxillofacial Surgery, University of Luebeck, Germany.

Conflicts of interest

The first and senior authors (S. G. Hakim, P. Sieg) received financial support from Dentaurum Implants, Ispringen, Germany. All other authors (J. Glanz, M. Ofer, D. Steller) declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcms.2019.01.002.

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