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CBCT fractal dimension changes at the apex of immediate implants placed using undersized drilling

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Abstract

Objectives: To evaluate, on the base of cone beam computed tomography (CBCT) fractal dimension, bone quality changes surrounding the apical portion of immediate implants placed under higher insertion torque utilizing an undersized drilling technique.

Materials and methods: Three patients were enrolled in this study. Single implants were placed into fresh extraction sockets in the anterior maxilla and provisionalized immediately. Adequate stability was ensured on all the implants by a 28.5% undersizing of the apical portion of the osteotomy. Bone quality at the most apical 1.15 mm peri-implant bone portion were measured by CBCT at placement and after 6 months. This analysis was carried out by evaluating the box counting fractal dimension of 15 consecutive CBCT slices related to the most apical part of each implant.

Results: All the three implants were successful after an 18-month follow-up period. The mean fractal dimension at the implant apex exhibited a 3% increase 6 months following placement.

Conclusions: Within the limitations of an explorative study, an undersized drilling resulting in high insertion torque would seem to induce no adverse changes in radiographic bone quality after 6 months of follow-up. The most favorable entity of drilling undersizing and its effect on peri-implant bone remodeling, should be evaluated on a larger patient population.

Introduction

Mechanical injury to bone results in an increase of its volume and density (Amsel et al. 1969; Lundgren et al. 1995). This effect, however, appears to be transitory (Brånemark et al. 1964). Conversely, after an implant is placed in a surgical wound, the expected result is an increased peri-implant bone density consequent to the osseointegration process (Slotte et al. 2003). However, when considering the healing process at undersized implant preparations, frequently utilized as a higher torque alternative to standardized drilling sequences, less data are available. When evaluated in an animal model, undersized drilling produced an increased early fixation of oral implants as assessed by removal torque (Shalabi et al. 2007). Similarly, the osteogenic response to titanium implants appeared enhanced by the above-mentioned technique in an *ex vivo* human bone study (Tabassum et al. 2010b). From a clinical point of view, it has been shown that by using an undersized drilling sequence it is possible to achieve a good primary stability regardless of the bone quality encountered (Östman et al. 2006). Despite the above-mentioned benefits, however, there have been sporadic reports of bone necrosis due to severe compression of the trabecular spaces occurring when an implant is placed in an undersized preparation (Piattelli et al. 1998; Bashutski et al. 2009). Such necrosis could ultimately lead to implant ''periapical'' lesions that would be solved with treatments of various invasiveness, including implant removal (Bashutski et al. 2009). Therefore, it would be interesting to measure *in vivo* changes in bone density at implants placed in undersized sites to assess if this surgical technique causes deviations from the normal peri-implant bone response.

At present, it is possible to measure bone quality with radiological techniques. The most documented procedure for this purpose is the evaluation of Computed Tomography voxel values (Hounsfield Units) (Norton & Gamble 2001). However, because of the high radiation dose involved, there is an increasing attention to alternatives such as the use of cone beam computed tomography (CBCT). In particular because voxel values from CBCT are unstable, the use of fractal analysis in combination with CBCT has been suggested as useful for bone quality evaluation (Hua et al. 2009). The present study was undertaken to evaluate bone changes on implants placed in fresh extraction sockets utilizing a modified drilling sequence and immediately provisionalized. In this instance, implant stability may be compromised due to decreased initial bone to implant contact within the alveolus. Consequently, alternative techniques were proposed to achieve optimal primary stability in these circumstances (Wohrle 1998; Cannizaro et al. 2007; Lee et al. 2009). The key objective of a modified preparation technique is the reduction of the size of the final osteotomy as compared with the implant diameter (Skalak & Zhao, 2000).

This study will evaluate, in a series of patients, changes in the CBCT fractal dimension around the portion of implants surrounded by native bone 6 months following immediate placement in combination with undersized drilling and immediate temporary restoration.

Table 1. **Inclusion and exclusion criteria**

Key inclusion criteria
1. Subjects must be between the ages of 18 and 80
2. Subjects must require removal of any one of their four upper front tooth (maxillary incisors)
3. Subjects should benefit from an implant-supported crown
4. Subjects must exhibit sufficient alveolar bone to allow the placement of an endosseous implant without the need for bone grafting
5. Subjects must be free of other oral infections including dental caries and periodontal disease
6. Subjects must have opposing lower teeth (or prosthesis)
7. Subjects must have voluntarily signed the informed consent form
8. Subjects must be in good physical health as assessed by a member of the research team to adequately tolerate implant surgery and to promote optimal healing

Key exclusion criteria
1. Presence of conditions requiring chronic routine prophylactic use of antibiotics
2. Pregnancy
3. Medical conditions requiring the use of steroids
4. History of leukocyte dysfunction or deficiencies, bleeding deficiencies, renal failure, uncontrolled endocrine disorders (diabetes), acquired immunodeficiency syndrome or hepatitis
5. History of neoplastic disease requiring the use of chemotherapy or irradiation to head and neck
6. Subjects who have undergone administration of any investigational drug or device within 30 days of enrollment in the study
7. Subjects receiving intravenous or oral bisphosphonates
8. Alcohol or drug abuse
9. Subjects who are heavy smokers (greater than 10 cigarettes per day or cigar equivalents) or chew tobacco
10. History of non-compliance or unreliability

Materials and methods

Three consecutive patients requiring replacement of a single maxillary incisor were enrolled in this study according to inclusion and exclusion criteria described in Table 1. Available bone volumes were assessed by preoperative CBCT examination. The study protocol was approved by the institutional review board of the University of Pennsylvania (Protocol number # 809472) as part of an observational prospective investigation on immediate implant placement. Following explanation of the study protocol, all patients signed an informed consent.

Implant treatment

The incisors involved were carefully extracted via a flapless approach. The sockets were copiously irrigated with sterile saline. A careful examination of the alveolus was performed to verify that the buccal bone wall was intact. Subsequently, the socket was measured using a surgical depth gauge (Astra Tech, Mölndal, Sweden). An implant of adequate length was subsequently selected, so that upon placement, the apex of the implant would engage a minimum of 3 mm of native bone beyond the alveolus. Implants were then placed following a modified drilling sequence to undersize the osteotomy and increase the insertion torque. A precision initial drill allowed accurate positioning of the osteotomy within the palatal alveolar wall. Once the direction of drilling was established, the site was enlarged with a 2 mm pilot drill. Subsequent twist drills were used to widen the osteotomy following the manufacturer's instructions. The final drill however, was only utilized to a depth of approximately two/thirds of the implant length. With specific regard to the enlargement of the apical portion of the implant, a 2.5 mm twist drill was the last drill used. Therefore, a 28.5% undersized preparation resulted, given the apical implant diameter of 3.5 mm. Efforts were made to apply pressure towards the palatal aspect during drilling to avoid any labial shift of the osteotomy as the drilling sequence was completed. Implant placement (Table 2) was then performed using a surgical motor (Implantmed, W&H GmbH, Bürmoos, Austria) at a speed of 15 rpm and a torque setting of 45 N cm. In all cases a ratchet wrench (Astra Tech) was used to fully seat the implants because the torque required exceeded the 45 N cm set on the motor. The implant stability resulting from this insertion torque >45 N cm (although not precisely quantified) appeared to be sufficient for immediate placement of a provisional restoration, which was delivered following surgery. The provisional restoration was adjusted to avoid centric and excursive occlusal contacts, and remained in place during the follow-up period. Postoperative medications were prescribed according to routine clinical protocols. Patients were provided with home-care maintenance instructions including recommendation of a 2-week soft diet and avoidance of incisal biting for 6–8 weeks. Patients were scheduled for post-operative check-ups on an individual basis and follow-up visits were planned every 6 months.

Table 2. **Implant size and distribution (Osseospeed, Astra Tech)**

Patient	Position	Implant	Bone quality[†]
1	22	3.5 × 13	3
2	21	4.5 × 13*	3
3	12	3.5 × 11	2–3

*Astra Tech implants with a diameter of 4.5 mm feature an apical portion of 3.5 mm in diameter.
[†]Classification of Lekholm & Zarb (1985).

Radiographic examination

CBCT examination of the anterior maxilla was repeated after implant placement and provisional restoration and after 6 months of follow-up. The equipment used (Kodak 9000 3D, Kodak Eastman Co., Rochester, New York, US) was set to 74 KV, 10 mA, 76 μm voxel resolution and to a 50 × 37 mm field of view. A radiologist aware of the aim of the study performed all the examinations.

Measurements of fractal dimension around the implants

Fifteen bit DICOM data, as exported from the radiological machine, were then imported into the MevisLab programming environment (MeVis Research GmbH, Bremen, Germany) and reformatted so that the implant was oriented perpendicularly. Afterwards the data sets were elaborated with the ImageJ software (Image J, US National Institutes of Health, Bethesda, MD, USA). A circular region of interest (ROI) (10.7 mm^2) was selected around each implant; from the implant apex it extended coronally for 15 slices. These ROIs corresponded to the implant's most apical 1.15 mm that engaged the portion of the undersized implant site beside the alveolus as ascertained intrasurgically. Afterwards, to remove large variations in brightness from the image, a filtering procedure was implemented. First, a Gaussian filter was applied ($\Sigma = 10$ pixels) so that fine and medium structures were eliminated and only large variations in density remained (low-pass filtering). The resulting blurred image was then subtracted from the original and 128 was added to the resulting image at each pixel location. The image was then transformed into a binary image so that the segmented object identified the bone pattern (Fig. 1). After the above-mentioned preprocessing the fractal dimension was calculated for each of the 15 consecutive CBCT slices per implant that individuated the implant most apical 1.15 mm. The box-counting fractal analysis was computed using an algorithm featured in ImageJ as described in a previous study (Veltri et al. 2011). Overall, from the three implants the fractal dimension of 45 CBCT slices relative to the apexes were obtained. Such a process was repeated for the radiographic examination made at implant placement and for the one made after 6 months of function.

Statistical evaluation

Changes in peri-implant bone fractal dimension at the two time points were assessed with descriptive statistics. At each time point, for each of the three implants analyzed, the mean fractal dimension from the 15 CBCT slices related to the implant apex was calculated. No statistical tests were applied because of the small sample size. All calculations were made with the aid of software for statistical analysis (SPSS 19, IBM, Somers, NY, USA).

Results

All the implants were permanently restored 6 months following implant placement. They have remained in function and symptom free through an 18-month follow-up period. No complications have been reported and the patients were satisfied with the treatment outcome. After 6 months of loading a tendency for increased fractal dimension of the peri-implant bone was found (Table 3).

Discussion

CBCT is a radiographic technique that allows consistent visualization of the bone volume with a much smaller radiation dose (in this study approximately 170 mGy per examination) compared with conventional CT. With regard to bone density, voxel values from CT, called Hounsfield Units, are calibrated absolute values providing reliable assessment within established bone density scales (Norton & Gamble 2001). Conversely, voxel values from CBCT are arbitrary gray values without HU calibration that do not allow an absolute bone quality evaluation similar to that performed with HU in medical CT (Norton & Gamble 2001). On the contrary it has been shown that fractal analysis can be applied to CBCT images to estimate bone quality (Hua et al. 2009). What is particularly appealing from this technique is that it is unaffected by variations in image exposition (Shrout et al. 1997; Jolley et al. 2006) that conversely are quite common in CBCT due to artifacts that might affect such radiological technique (Schulze et al. 2010). Fractal analysis allows a bone texture analysis that is significantly related to bone mineral density (Southard et al. 2000; Southard et al. 2001). In fact, when evaluating decalcified bone samples, a drop in CBCT fractal dimensions resulted in a significant correlation with decreasing bone density as measured with dual energy X-ray absorptiometry (Hua et al. 2009), the standard exam for evaluation of the bone densitometric profile. When considering conventional 2D radiography, fractal dimension was shown to be related to bone quality as assessed by implant insertion torque (Veltri et al. 2011) in an *in vitro* setting. In addition, it was significantly related to periodontitis-induced bone changes with healthier patients showing higher fractal dimensions (Updike & Nowzari 2008). In the medical field, fractal analysis is currently employed for evaluation of trabecular microarchitecture, a predictor of bone quality in the assessment of fracture risk (Link & Majumdar 2004; van der Linden & Weinans 2007). Fractal analysis was therefore applied in the present study to assess changes in bone structure following immediate implant placement in combination with undersized drilling and immediate temporary restoration.

In esthetic areas, implant placement into fresh extraction sockets followed by an immediate provisional restoration might be helpful to preserve gingival height and profile (Kan et al. 2003; De Rouck et al. 2009). However, even though immediate loading has been shown to be successful in a variety of clinical situations (Esposito et al. 2009), the single implant remains the most challenging scenario. This may be due to the fact that splinting is not available as a mechanism to ameliorate the distribution of occlusal forces. As a result, single implants placed into extraction sockets and immediately loaded may require a higher degree of stability, to prevent micromotion and subsequent fibrous tissue proliferation along the implant surface, which may finally result in decreased bone-to-implant contact (BIC) and potential failure (Szmukler-Moncler et al. 1998; Trisi et al. 2009). However, the minimum insertion torque required for successful integration of immediately loaded single-tooth implants placed into fresh extraction sockets has not been determined. An insertion torque of 45 N cm has been described in some reports as adequate to achieve sufficient primary stability for immediate loading of single-tooth implants (Wohrle 1998; Cannizaro et al. 2007; Lee et al. 2009). Conversely, a high degree of failures resulted when single implants where placed at 20 N cm and immediately loaded (Pinheiro Ottoni et al. 2005). A common method of achieving increased insertion torque is to undersize the osteotomy preparation relative to the diameter of the implant to be placed (Skalak & Zhao 2000). However, there are reports in the literature that warn against potential healing impairment resulting from bone compression generated by the above-mentioned surgical technique (Piattelli et al. 1998; Bashutski et al. 2009).

In the three present cases, it was evaluated how implant placement in 28.5% undersized sites, resulting in insertion torques higher than 45 N cm (although not quantified precisely), would influence the osteogenic response in maxillary bone of medium quality. This same degree of undersizing was investigated in two previous animal models. In the first study it resulted that a 25% undersizing promoted less BIC after 3 weeks

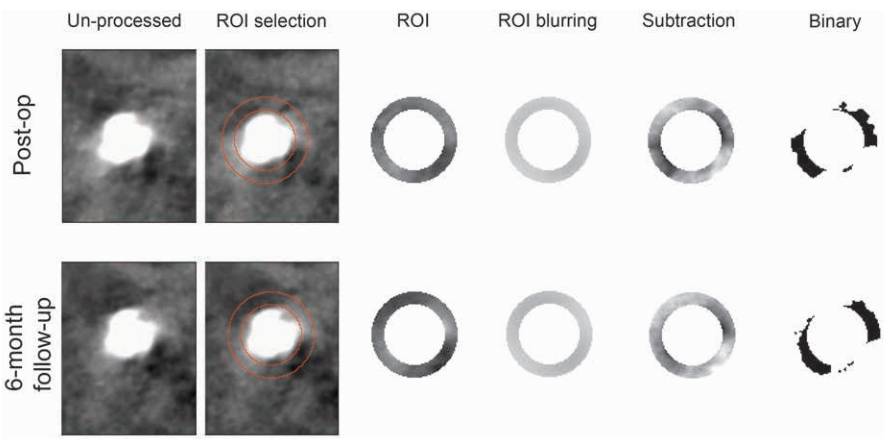

Fig. 1. From left to right: Original image. Selection of the region of interest (ROI). Cropped ROI. Blurred ROI. Result of subtraction of the blurred ROI from original image and subsequent addition of 128 to each pixel location. Final binary ROI obtained from the previous step. Fractal dimension was calculated on the final binary image.

***Table 3.* Mean fractal dimension recorded at implant placement and after 6 months.**

	Placement	6 months	Change	% change
Mean	1.327	1.368	0.041	3
SD	0.02	0.07		

of healing compared with 5% and 15% undersizing (Tabassum et al. 2010a). Conversely in the second one, where the evaluation was carried out at 4 months, no significant differences in BIC were seen between the standard and 25% undersized sites (Pantani et al. 2010).

From a clinical point of view, it has been previously reported that undersized preparations could at times be associated with compression necrosis (Piattelli et al. 1998; Bashutski et al. 2009). In the present study, the area of osteogenic response to implant placement analyzed corresponded to the bone surrounding the most apical 1.15 mm extent of the implant. The reason for selecting this area was its previously reported relation to this phenomenon (Piattelli et al. 1998; Bashutski et al. 2009). A tendency for increased CBCT fractal dimension was observed after a 6-month healing period. According to previous studies both in conventional (Southard et al. 2000) and CBCT (Hua et al. 2009) radiography an increase in fractal dimension indicates a greater bone mineralization. As a consequence, the tendency to increased bone architecture here measured with fractal analysis would seem to be in agreement with a previous animal experiment, where implant placement by itself resulted in a significant increase of quality in the surrounding bone (Slotte et al. 2003).

In this explorative patient series, no adverse changes in the osteogenic response, as measured quantitatively with fractal analysis, combined with a satisfactory clinical outcome, were observed at immediate implants with immediate restoration placed in undersized sites in the anterior maxilla. However, it is not possible to formulate any clinical recommendation based on the present study because besides the very few implants investigated, no precise evaluation of the placement torque achieved was available. In conclusion, the most favorable entity of drilling undersizing allowing enhanced stability at immediate implants, and its effect on peri-implant bone remodeling, deserves assessment on a larger patient population.

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