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Guest Editors: Dogan Dolanmaz, Figen Cizmeci Senel, and Zafer Özgür Pektas

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Editorial Board

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Editorial

Dental Implants in Posterior Maxilla: Diagnostic and Treatment Aspects

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Dental implantology is one of the most popular and intensively researched topics of current dental medicine. The necessity for the former complicated preprosthetic surgical procedures to facilitate the partial dentures has recently been decreased with the widespread construction of implant-supported prosthesis. Nevertheless, the alveolar deficiency that impedes the insertion of dental implants makes a number of similar reconstructive procedures inevitable. The posterior maxilla is one of the most challenging anatomic locations for the implant placement that requires adjunctive surgical procedures. This special issue covers leading researches and reviews on this topic that we believe would contribute to clinicians.

Insufficient bone quality and quantity in posterior maxilla is a common clinical state which makes the implant applications challenging in this site. The main reason for that is the pneumatization of sinus subsequent to the tooth loss and the concomitant excessive alveolar resorption. Insufficient subantral bone and coexisting increased interarch distance necessitate a combined sinus lifting and augmentation procedures. T. Kanno et al. reported the results of their retrospective study entitled "Simultaneous sinus lifting and alveolar distraction of a severely atrophic posterior maxilla for oral rehabilitation with dental implants" in which they performed combined sinus lifting and alveolar distraction osteogenesis in a case series with 27 individuals. The study revealed a histomorphometric similarity between the new bone formed by the presented technique and the bone generated via the sinus lifting only. They also accomplished stable implant rehabilitations within this topic.

The quality and the quantity of the host bone are the key determinants for successful dental implants. The quantity of the bone may be estimated via advanced radiological techniques in a high precision. However, a definitive accuracy cannot be pronounced although a number of techniques are available to evaluate the quality of bone. H. Bilhan et al. have reviewed the current techniques used for the estimation of the quality of the host bone while they simultaneously reported the results of a pilot experimental study that compares the densitometric evaluation of the dental volumetric tomography (DVT) with micro CT with their study entitled "How precise is dental volumetric tomography in the prediction of bone density?". The results of this study revealed that the Hounsfield unit evaluation via DVT is not a reliable method to evaluate the density of bone.

C. Riben and A. Thor have published their review on "graftless augmentation procedures" which became a popular topic on sinus floor elevation, regarding a conventional surgical approach for the posterior maxillae. Their study entitled "The maxillary sinus membrane elevation procedure: augmentation of bone around dental implants without grafts—a review of a surgical technique" includes the technical details of the procedure.

The alveolar bone loss principally initiates with the tooth loss and this state may complicate the ideal placement of the implants. A number of surgical methods is advocated to prevent the bone loss. G. Pagni et al. reviewed these

techniques in their study entitled "Postextraction alveolar ridge preservation in the molar area: biological basis and treatments". The study provides comprehensive information about the socket healing and biology of the alveoloar bone resorption subsequent to extraction. They stated that the improvements in the grafting technologies would give rise to less invasive surgical interventions.

The recent advances in the implant surface characteristics led to major modifications in former fundamentals. An increased osseointegration rate with the improvement of the surface characteristics of dental implants resulted in a numerous successful reports for the implants shorter than 10 mm. Today, many companies appear in the dental market with their recently introduced 6 mm or shorter dental implants. Owing to this, clinicians now can be able to offer effective and noninvasive remedies to their patients avoiding advanced complicated surgeries in case of severe alveolar atrophy. Although a number of clinical reports reveals high success rates for the mandible, the use of short implants in the maxilla is still debatable especially for the single-tooth replacements due to its porous nature. D. Lops et al. compared the clinical success rates for 8 mm. Implants with that of 10 mm. In their long-term study entitled "Short implants in partially edentulous maxillae and mandibles: a 10 to 20 years retrospective evaluation". In general, they declared similar success rates for 8 mm and longer implants. The results of this study revealed that the use of 8 mm implants seems to be safe in the posterior maxilla.

Acknowledgments

D. Dolanmaz would like to thank the guest editors Dr. F. Şenel and Dr. Z. Özgür Pektaş, whom are each important expert in their particular subjects, for their valuable contributions to this issue. D. Dolanmaz would also like to thank the colleagues whom helped us in this process for their rigorous evaluations. We wish this special issue would contribute to the clinicians concerned to dental implantology in their clinical practice.

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Clinical Study

Short Implants in Partially Edentulous Maxillae and Mandibles: A 10 to 20 Years Retrospective Evaluation

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Purpose. Evaluation of the short implant (8 mm in height) long-term prognosis and of the implant site influence on the prognosis. *Methods.* A longitudinal study was carried out on 121 patients (57 males and 64 females) consecutively treated with 257 implants. 108 implants were short. *Results.* Four (3.6%) short implants supporting fixed partial prostheses failed. Similarly, three standard implants supporting fixed partial prostheses and one supporting single-crown prosthesis failed. Mean marginal bone loss (MBL) and probing depth (PD) of short and standard implants were statistically comparable ($P > .05$). The 20-year cumulative survival rates of short and standard implants were 92.3 and 95.9%, respectively. The cumulative success rates were 78.3 and 81.4%. The survival rates of short implants in posterior and anterior regions were comparable: 95 and 96.4%, respectively. The difference between survival rates was not significant ($P > .05$). *Conclusions.* The high reliability of short implants in supporting fixed prostheses was confirmed. Short and standard implants long-term prognoses were not significantly different. The prognosis of short implants in posterior regions was comparable to that of in anterior regions. Nevertheless, a larger sample is required to confirm this trend.

1. Introduction

Actual patient's expectations for prosthetic rehabilitation are increasingly high, especially with regard to quality of life and functionality. The introduction of dental implants has led to a turning point in the rehabilitation of partially or totally edentulous patients [1]. However, not always, the placement of dental standard length implants is possible or feasible in the first instance. Several anatomical conditions affect the rehabilitation treatment and have an impact on costs and morbidity for the patient. An example is the rehabilitation of the maxillary posterior regions. Excessive pneumatization of the maxillary sinus or marked resorption of the edentulous alveolar ridge are factors that may lead to look for different solutions. Thus, techniques such as the elevation of the maxillary sinus or the use of length-reduced implants have been introduced to allow an implant rehabilitation even though these anatomical peculiarities [2].

The risk of morbidity, the cost, and time for the treatment of sinus elevation should be taken into account when an implant rehabilitation in the maxilla is necessary.

So the use of short implants can be an alternative in these cases although, historically, they were associated with low success rates. Recent studies in fact show that short implants can reach satisfactory clinical levels of reliability and survival [3–8]. These results were also due to the introduction of rough-surface implants that permit the decrease of implant length while ensuring an adequate contact between bone and fixture.

Therefore, the use of short implants allows an implant rehabilitation for the patient without the surgical involvement of delicate structures such as the maxillary sinus.

The aim of the present longitudinal study was to evaluate the survival of short implants when compared to that of standard implants in a long-period follow-up. A secondary

aim was to compare the prognosis of short implants placed in posterior regions (molars and second premolar) to that of short implants placed in anterior regions (incisors, canine, and first premolar).

2. Materials and Methods

2.1. Patients. Between April 1990 and June 2010, 121 patients (57 males and 64 females) with a mean age of 54 years (range 22 to 69 years) were consecutively treated in the Dental Clinic, Department of Medicine, Surgery and Dentistry, University of Milan, Italy. The follow-up after prosthesis installation ranged from 10 to 21 years (mean 13.2 years).

Criteria for implant placement included: good general health at the time of surgical procedure, favourable intermaxillary relationship, and adequate bone volume on implant site (at least for 8 mm in length) radiographically evaluated.

Exclusion criteria were: alcohol or tobacco abuse; sever renal or liver disease; history of radiotherapy in the head and neck region; chemotherapy for malignant tumors at the time of surgical procedure; uncontrolled diabetes; periodontal disease involving the residual dentition; mucosal disease, such as lichen planus in the area to be treated; poor oral hygiene; noncompliant patients; patients with a need for prostheses supported by combined short and standard implants used in combination; narrow-diameter implants (i.e., 3.3 mm).

Patients received no more than 1 implant-supported prosthesis each.

Calibrated plastic probe and juxtagingival radiographs taken before treatment were used to evaluate crown-to-implant ratio. Implant distribution according to opposing teeth or prostheses was considered: short and standard implants opposing mobile partial or total prostheses were excluded from the study.

The routine treatment of patients was documented as follows.

(i) Panoramic radiographs taken before treatment.

(ii) Periapical radiographs taken before treatment, at the time of implant placement at the time of prosthetic rehabilitation, and every year thereafter.

(iii) Computed tomography (CT) scans whenever radiographs were not sufficient to plan the implant treatment (27 patients showing severe atrophic ridges).

2.2. Examinations. Two hundred fifty-seven straight, 2-part, grade IV, pure titanium, solid screw, ITI (Institute Straumann, Waldenburg/BL, Switzerland) plasma-spayed dental implants were placed. One hundred and eight of them were short (8 mm in length), while 149 were standard (10 mm). Implant distribution by diameter and length is reported in Table 1.

Fourty-two and 66 short implants were placed in the maxilla and mandible, respectively. On the hand, 63 and 86 standard implants were placed in the maxilla and mandible, respectively. The following regions were considered: anterior and posterior maxilla, anterior and posterior mandible. Anterior region included the canine and incisive districts; posterior region included premolars and molars (Table 2).

Table 1: Implant distribution by diameter, length, and type.

Length	Diameter	No.
8 mm	3.75 mm	21
	4.1 mm	66
	4.8 mm	21
		108
10 mm	3.75 mm	33
	4.1 mm	89
	4.8 mm	37
		149

Table 2: Implant lengths and locations.

Implant length	District	Implants
8 mm	maxillary anterior	18
	maxillary posterior	24
	mandibular anterior	10
	mandibular posterior	56
10 mm	maxillary anterior	16
	maxillary posterior	47
	mandibular anterior	17
	mandibular posterior	69

Table 3: Implant distribution by prosthesis type.

Prostheses type	Implants	
	(8 mm)	(10 mm)
FPD	56 (24)*	38 (16)*
FCD	26 (4)*	22 (4)*
ST	26 (26)*	11 (11)*
Total	108 (54)*	71 (67)*

* Number of prostheses supported by the implants are in brackets.
ST: single tooth prosthesis.
FCD: fixed complete dentures.
PFD: partial fixed dentures.

Overall, 44 and 77 prostheses were positioned in the maxilla and mandible, respectively. The following prostheses were used (Table 3): 52 fixed single-tooth prostheses (ST), 58 fixed partial prostheses (FPD), and 11 fixed complete dentures (FCD).

If a patient could not be followed at consecutive annual examination, the corresponding implants were classified as "drop-out implants." The reasons for dropouts were lack of interest in attending the examinations ($n = 9$) and moving out of the area ($n = 7$). Moreover, 14 patients could not be reached. Thus, a total of 30 patients with 50 implants were excluded from the follow-up protocol. The prostheses included 11 FPDs and 19 STs.

2.3. Prosthetic Treatment. Following a healing period of 3 to 4 months in the mandible and 4 to 6 months in the

maxilla, patients were recalled for a preprosthetic evaluation; healing duration was based on bone quality [9]. After healing abutments removal (three to six months from implant placement), the prosthetic abutments were connected as recommended by the manufacturers.

Prosthesis frameworks and aesthetic veneer were fabricated in gold alloy and porcelain, respectively. No welding was performed. Cemented prostheses were fixed with zinc oxyphosphate cement (32 FPD, 44 ST, and 3 FCD prostheses) or zinc-oxide eugenol cement (14 FPD prostheses), while screw-retained prostheses (8 FCD, 12 FPD, and 8 ST prostheses) were secured to the abutments by means of abutment-framework screws using a manual torque driver. Twenty-one temporary prostheses were used to restore anterior teeth. Opposite dentition was natural teeth and fixed prostheses for 185 and 72 implants, respectively.

2.4. Assessments. Implants were followed with Annual clinical examinations and juxta-gingival radiographs were carried out. The following parameters were evaluated.

(1) Radiographic assessment of peri-implant bone resorption (MBL) mesial and distal to each implant. MBL was determined by comparing juxta-gingival radiographs taken at the time of prosthetic loading, and every year thereafter. The distance between the apex of the implant and the most coronal level of direct bone-to-implant contact was measured mesially and distally to each implant by means of computerized analysis (Canoscan radiograph scanner and Image-J software) [10]. Intraoral radiographs (Kodak Ekta-speed EP-22, Eastman Kodak Co., Rochester, NY, USA) were taken with parallel technique to control projection geometry: the following exposure parameters (65–90 kV, 7.5–10 mA, and 0.22–0.25 s) were used. Dimensional distortion related to the juxta-gingival radiographs was corrected comparing the actual dimensions of the loaded implants to the image on film.

(2) Peri-implant soft tissue parameter such as Probing Depth (PD) was measured with a calibrated plastic probe (TPS probe, Vivadent, Schaan, Liechtenstein) at the time of prosthetic loading and every year thereafter. Probing depth scores were recorded at 4 sites for each implant (mesial, distal, buccal, and lingual).

2.5. Prognostic Criteria. Implant stability, peri-implant conditions, marginal bone loss, and other treatment-related complications, as well as success and survival criteria were evaluated according to Albrektsson et al. [11] and Roos et al. [12].

Implant success was calculated on the following parameters: absence of mobility, painful symptoms, or paresthesia; absence of radiolucency during radiographic evaluation and progressive marginal bone loss (Bone resorption in measurement areas not greater than 1 mm. during the first year of implant positioning, and 0.2 mm per year in subsequent years); peri-implant probing depth ≤ 3 mm on each peri-implant site (mesial, distal, buccal, and oral).

Implant Survivals Included. Therapeutic implant successes; functional and asymptomatic in situ implants thought showing a peri-implant probing MBL rate that exceed the maximum limits established by the present study; functional and asymptomatic in situ implants after peri-implantitis treatment [13, 14].

Clinical mobility (due to implant overloading, implant fracture, or peri-implantitis not successfully treated) was mandatory for implant removal. Implants showing mobility were regarded as "failures."

2.6. Statistical Analysis. The statistical life analysis was performed as described by Kalbleish and Prentice and Colton at end of June 2010 [15, 16]. Life tables were calculated on short implants supporting different types of prostheses.

All restored implants completed at least 10 years clinical examination. Cumulative survival and success rates were calculated for the entire group of 265 implants according to the criteria fixed by Albrektsson et al. [11], van Steenberghe et al. [9]. Internal survival rate for each time interval and the entire 20 years period was considered.

Life tables included the following parameters: time period (observation time); number of implants at interval start; number of early failed implants (not loaded implants); number of loaded implants; number of implants lost to follow-up as a result of patients dropout; number at risk (it represented the "harmonic mean" of the implants at the beginning of an interval and the ones remaining at the end of the same interval); number of failed implants during the interval; annual survival and success rates; cumulative survival and success rates [16, 17].

Chi-square test was performed to compare the survival and success rates of short and standard implants, respectively. Also the prognosis of implants placed in posterior segments was compared to those in anterior segments. A 95% significance level was fixed.

3. Results

No early failures were observed, thus all the positioned implants were loaded (Figures 1 and 2).

During the 20 years follow-up period, 4 short and 4 standard implants were found mobile due to severe peri-implantitis and therefore removed. No implant fractures occurred. Failed short and standard implants are reported in Table 4. Five of these were positioned in the maxilla and 3 in the mandible (Table 4).

Life table analyses recorded as "complications" 9 short and 11 standard implants on the whole. Peri-implant probing depth (PD) was recorded: for 4 short and 5 standard implants, respectively, it was greater than 3 mm on each peri-implant site (measurements were performed with a calibrated plastic probe). Ten peri-implantitis, respectively, for five short and 6 standard implants, were observed and successfully treated [14, 18, 19].

Table 4: Short and standard implants distribution: compliances and failures.

Site	Implant size (mm)	Type of prosthesis	Cause of compliance	Cause of failure
24	3.75 × 8	FCD	—	Mobility due to severe peri-implantitis
36	4.1 × 8	FPD	—	Mobility due to severe peri-implantitis
16	4.1 × 8	FPD	—	Mobility due to severe peri-implantitis
15	4.1 × 8	FPD	—	Mobility due to severe peri-implantitis
46	4.8 × 8	ST	Pathologic periimplant bone resorption	—
35	4.1 × 8	FPD	Successfully treated periimplantitis	—
24	4.1 × 8	ST	Successfully treated periimplantitis	—
15	4.1 × 8	FPD	Successfully treated periimplantitis	—
25	4.1 × 8	ST	Successfully treated periimplantitis	—
24	4.1 × 8	FCD	Pathologic periimplant bone resorption	
16	4.1 × 8	ST	Pathologic periimplant bone resorption	—
24	4.1 × 8	FPD	Successfully treated periimplantitis	—
45	4.1 × 8	FPD	Pathologic periimplant bone resorption	
16	4.8 × 10	ST	—	Mobility due to severe peri-implantitis
24	4.1 × 10	FCD	—	Mobility due to severe peri-implantitis
25	3.75 × 10	FPD	—	Mobility due to severe peri-implantitis
36	4.1 × 10	FPD	—	Mobility due to severe bone resorption
37	4.1 × 10	FPD	Successfully treated periimplantitis	—
14	4.1 × 10	FPD	Pathologic periimplant bone resorption	—
25	4.8 × 10	FPD	Successfully treated periimplantitis	—
16	4.1 × 10	ST	Successfully treated periimplantitis	—
46	4.1 × 10	FPD	Successfully treated periimplantitis	—
25	4.1 × 10	FPD	Successfully treated periimplantitis	—
35	4.1 × 10	ST	Pathologic periimplant bone resorption	—
25	4.1 × 10	ST	Pathologic periimplant bone resorption	—
34	4.1 × 10	FPD	Pathologic periimplant bone resorption	—
16	4.8 × 10	FPD	Pathologic periimplant bone resorption	—
44	4.1 × 10	FPD	Successfully treated periimplantitis	—

Tooth numbers: 14: maxillary right first premolar, 15: maxillary right second premolar, 16: maxillary right first molar, 24: maxillary left first premolar, 25: maxillary left second premolar, 35: mandibular right second premolar, 36: mandibular left first molar, 37: mandibular left second molar, 44: mandibular right first premolar, and 46: mandibular right first molar. ST: single tooth prosthesis, FCD: fixed complete dentures, PFD: partial fixed dentures.

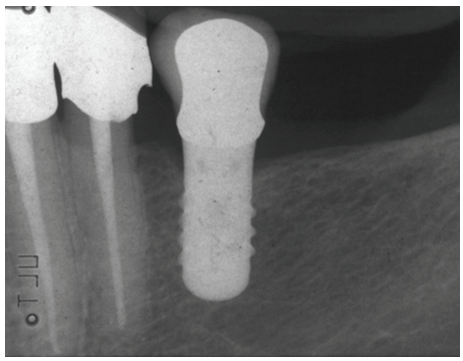

Figure 1: Single-tooth fixed prosthesis supported by a short implant (4.1 × 8 mm), 0 years loading. Periapical radiograph.

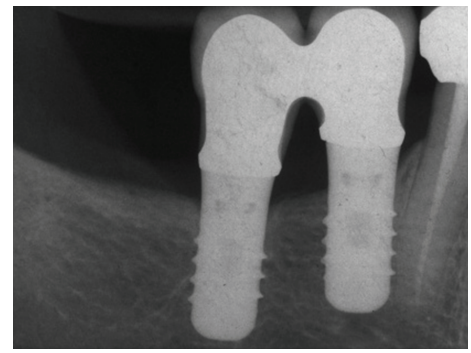

Figure 2: Partial fixed prosthesis supported by short implants (4.1× 8 mm), 0 years loading. Periapical radiograph.

Mean MBL and PD values were recorded for short and standard implants at the beginning of prosthetic load and at time of last control (Table 5): at time of the last evaluation MBL mean values were 1.8 and 1.9 mm for short and standard implants, respectively. So, the authors recorded small changes of MBL and PD scores as compared to those recorded at last evaluation: this trend was noted both for short and standard implants (Figures 3 and 4). No

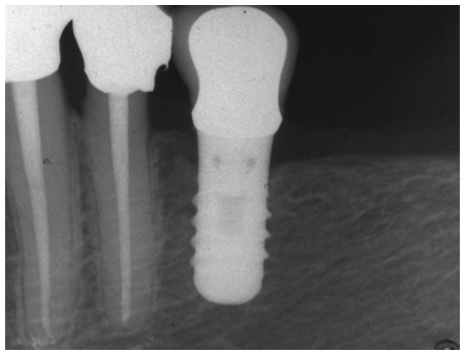

Figure 3: Single-tooth fixed prosthesis supported by a short implant (4.1 × 8 mm): 12 years after loading. Periapical radiograph.

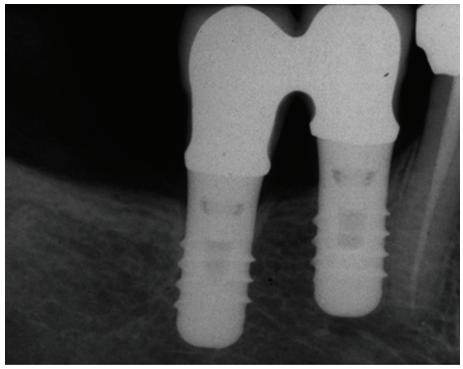

Figure 4: Partial fixed prosthesis supported by short implants (4.1× 8 mm): 14 years loading. Periapical radiograph.

statistically significant differences in MBL and PD values were observed between short and standard implants ($P > .05$) and no relationship between implant length and these parameters was observed.

Moreover, no statistically different mean MBL values ($P > .05$) were measured for short implants placed in posterior regions (1.9 ± 1.4 mm) when compared to those of short implants placed in anterior regions (1.7 ± 1.5 mm).

Short and standard implants showed 20-years implant cumulative survival rates of 92.3% and 95.9%, respectively. Besides, the 20 years implant cumulative success rates were 78.3% and 81.4%, respectively, for short and standard implants. The difference between these rates were not significant ($P > .05$).

Only one short implant placed in anterior region failed after 20-years of function (Table 4), while complications were recorded for 3 and 6 short implants placed in anterior and posterior regions, respectively. Instead, the survival rate for short implants in posterior regions was comparable to that in anterior regions: 95 and 96.4%, respectively. The difference between these survival rates was not significant ($P > .05$).

4. Discussion

Factors involved in the survival rates seem to be independent of the implant length. These rates, for both standard and short implants, were similar. Despite the limited sample of short implants that followed similar conclusion could be drawn when short implants in posterior regions were compared to those in anterior region. Nevertheless, more researches are needed to confirm this trend since the low number of short implants followed, particularly when short implants placed in posterior region were compared to those in anterior region [20].

Jaffin and Berman [21], and Quirynen and colleagues [22] reported that implant length was directly related to failure rates. By contrast, these conclusions were not clearly observed in the clinical experience of Straumann implants [23–25]. These findings were confirmed by recent reviews on short implants [26–28]. Nevertheless, 8 mm implants were used for placement in sites with limited bone height, especially when observed in the lateral parts of the mandible and the maxilla, where the mandibular nerve and the maxillary sinus had to be avoided. Such an implant length was considered as "short," even if today short implants are often 6 mm or even less; instead, 6 mm implants are actually not validated by a long-term prognosis in the literature yet [26–28]. Long-term clinical prospective studies on 6 mm implants adequate prognosis are needed to consider 8 mm implants as "standard."

An obvious conclusion could be that implant design characteristics and the implant-bone interface are important factors in this respect [29, 30].

Draenert et al. in their retrospective analysis have provided, as a recommended option, the association of short and standard implants in fixed prosthetic rehabilitation constructs [31]. It is widely agreed upon that the use of short implants would be better in cases of severely atrophic mandibles and/or pneumatization of the maxillar sinus, due to the fact that if a standard implant were to be inserted it would lead to a more invasive, expensive, and complex surgery (i.e., sinus lift, bone grafting procedures) [32]. In the present report, no association of short and standard implants was included in the follow-up sample, because of the eventual influence of different implant lengths on the long-term implant function; further prospective controlled researches are needed to clarify the real benefit provided by the association of short and standard implants supporting fixed prostheses.

In contrast, as reported by literature on implant therapy, bone quality seems to affect the implants survival rates [33] and long-term prognosis [34]. The implant failures observed in the present study are more frequent in the upper back jaw, where there is a higher chance of the bone being type III-IV [35]. The outcomes seem to agree with other studies, in which implant failure rates in the upper back jaw have been shown to be statistically significant [36]. In a recent systematic paper, Sun et al. reported that most failures of short implants can be attributed to poor bone quality in the maxilla and a machined surface [27]. Although short implants in atrophied jaws can achieve similar long-term prognoses as standard dental implants with a reasonable prosthetic design according to this paper, stronger evidence is essential to confirm this finding.

Table 5: Radiographic and clinical assessments at time of prosthetic loading and at last evaluation.

Implants		MBL (marginal bone loss)*			PD (probing depth)*	
		Loading	Last evaluation		Loading	Last evaluation
		$X \quad \sigma$	$X \quad \sigma$		$X \quad \sigma$	$X \quad \sigma$
Short $n = 108$	Mesial	0.5 ± 0.4	1.7 ± 1.4	Mesial	1.8 ± 1.4	2.4 ± 1.1
	Distal	0.4 ± 0.6	1.9 ± 1.5	Distal	1.7 ± 1.2	2.4 ± 1.6
	Mean	0.5 ± 0.5	1.8 ± 1.5	Buccal	2.1 ± 1.3	2.1 ± 1.5
				Lingual	1.6 ± 1.3	2.0 ± 1.5
				Mean	1.8 ± 1.4	2.3 ± 1.4
Standard $n = 149$	Mesial	0.2 ± 0.4	1.7 ± 1.5	Mesial	1.5 ± 1.1	1.8 ± 1.7
	Distal	0.3 ± 0.5	2.0 ± 1.1	Distal	1.5 ± 1.2	2.4 ± 1.5
	Mean	0.3 ± 0.5	1.9 ± 1.6	Buccal	1.9 ± 1.2	1.6 ± 1.5
				Lingual	1.3 ± 1.4	2.3 ± 1.4
				Mean	1.5 ± 1.3	2.1 ± 1.5

* Marginal bone loss and probing depth were measured in millimetres.
n: implants, X: mean, σ: standard deviation.

Several authors confirmed these assumptions: bone quality, surgeon technique, characteristics of the implant's surface [4], width of bone-to-implant contact, parafunctions and overcontact in lateral direction [37], and primary stability [38] seem to significantly influence the prognosis of implants, particularly with reduced bone-to-implant contact, as a reduced fixture length [26].

Furthermore, the literature review by Telleman et al. highlighted how the implant failures in the studies that have excluded smokers were lower when compared to those that included this patients [39]. In the present study no heavy smokers were included in the follow-up sample, so that this possible bias was avoided.

5. Conclusions

The results of this study lead to the following conclusions.

(i) The long-term prognosis of short implants is consistent with those reported in the literature concerning short implants.

(ii) Cumulative success and survival rates of short and standard implants were not statistically different: the high reliability of short implants is confirmed.

(iii) The prognosis of short implants in posterior regions was comparable to that in anterior regions. Nevertheless, a larger sample is required to confirm this trend.

This study obtained positive results for 8 mm long dental implants. The results of this study may indicate the reliability of short implants, although further research is required to elucidate the most appropriate implant distribution as well as the most favourable prosthetic restoration [40]. Nevertheless, more researches are needed to confirm this trend since the low number of short implants followed, particularly when short implants placed in posterior region were compared to those in anterior region.

Conflict of Interests

The authors declare that they have no conflict of interests.

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References

[1] T. Berglundh, L. Persson, and B. Klinge, "A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years," *Journal of Clinical Periodontology*, vol. 29, supplement 3, pp. 197–212, 2002.

[2] C. E. Misch, J. Steigenga, E. Barboza, F. Misch-Dietsh, and L. J. Cianciola, "Short dental implants in posterior partial edentulism: a multicenter retrospective 6-year case series study," *Journal of Periodontology*, vol. 77, no. 8, pp. 1340–1347, 2006.

[3] P. A. Fugazzotto, J. R. Beagle, J. Ganeles, R. Jaffin, J. Vlassis, and A. Kumar, "Success and failure rates of 9 mm of shorter implants in the replacement of missing maxillary molars when restored with individual crowns: preliminary results 0 to 84 months in function. A retrospective study," *Journal of Periodontology*, vol. 75, no. 2, pp. 327–332, 2004.

[4] E. Menchero-Cantalejo, C. Barona-Dorado, M. Cantero-Álvarez, F. Fernández-Cáliz, and J. M. Martínez-González, "Meta-analysis on the survival of short implants," *Medicina Oral, Patologia Oral y Cirugia Bucal*, vol. 16, no. 4, pp. e546–e551, 2011.

[5] F. Rossi, E. Ricci, C. Marchetti, N. P. Lang, and D. Botticelli, "Early loading of single crowns supported by 6-mm-long implants with a moderately rough surface: a prospective 2-year follow-up cohort study," *Clinical Oral Implants Research*, vol. 21, no. 9, pp. 937–943, 2010.

[6] F. Renouard and D. Nisand, "Short implants in the severely resorbed maxilla: a 2-year retrospective clinical study," *Clinical*

Implant Dentistry and Related Research, vol. 7, no. 1, pp. S104–S110, 2005.

[7] P. Maló, M. De Araújo Nobre, and B. Rangert, "Short implants placed one-stage in maxillae and mandibles: a retrospective clinical study with 1 to 9 years of follow-up," *Clinical Implant Dentistry and Related Research*, vol. 9, no. 1, pp. 15–21, 2007.

[8] M. A. Sánchez-Garcés, X. Costa-Berenguer, and C. Gay-Escoda, "Short implants: a descriptive study of 273 implants," *Clinical Implant Dentistry and Related Research*. In press.

[9] D. van Steenberghe, U. Lekholm, C. Bolender et al., "Applicability of osseointegrated oral implants in the rehabilitation of partial edentulism: a prospective multicenter study on 558 fixtures," *The International Journal of Oral & Maxillofacial Implants*, vol. 5, no. 3, pp. 272–281, 1990.

[10] E. Romeo, D. Lops, E. Margutti, M. Ghisolfi, M. Chiapasco, and G. Vogel, "Implant-supported fixed cantilever prostheses in partially edentulous arches. A seven-year prospective study," *Clinical Oral Implants Research*, vol. 14, no. 3, pp. 303–311, 2003.

[11] T. Albrektsson, G. Zarb, P. Worthington, and A. R. Eriksson, "The long-term efficacy of currently used dental implants: a review and proposed criteria of success," *The International Journal of Oral & Maxillofacial Implants*, vol. 1, no. 1, pp. 11–25, 1986.

[12] J. Roos, L. Sennerby, U. Lekholm, T. Jemt, K. Gröndahl, and T. Albrektsson, "a qualitative and quantitative method for evaluating implant success: a 5-year retrospective analysis of the Brånemark implant," *International Journal of Oral and Maxillofacial Implants*, vol. 12, no. 4, pp. 504–514, 1997.

[13] A. Mombelli and N. P. Lang, "Clinical parameters for the evaluation of dental implants," *Periodontology 2000*, vol. 4, pp. 81–86, 1994.

[14] A. Mombelli and N. P. Lang, "The diagnosis and treatment of peri-implantitis," *Periodontology 2000*, vol. 17, no. 1, pp. 63–76, 1998.

[15] J. D. Kalbleish and R. L. Prentice, *Failure Time Data. The Statistical Analysis of Failure Time Data*, John Wiley & Sons, New York, NY, USA, 1st edition, 1980.

[16] T. Colton, *Calcolo delle Tabelle di Sopravvivenza. Statistica in Medicina*, Piccin, Padova, Italy, 1st edition, 1988.

[17] B. Barberi, *Rappresentazione Statistica delle Distribuzioni di Frequenze. Nozioni di Calcolo Statistico*, P. Borlingheri, editor, Florence, Italy, 1st edition, 1962.

[18] A. Mombelli, "Prevention and therapy of peri-implant infections," in *Proceedings of the 3rd European Workshop on Periodontology. Implant Dentistry*, pp. 281–303, Quintessence, Berlin, Germany, 1999.

[19] U. Lekholm, I. Ericsson, R. Adell, and J. Slots, "The condition of the soft tissues at tooth and fixture abutments supporting fixed bridges. A microbiological and histological study," *Journal of clinical periodontology*, vol. 13, no. 6, pp. 558–562, 1986.

[20] A. Jokstad, "The evidence for endorsing the use of short dental implants remains inconclusive," *Evidence-Based Dentistry*, vol. 12, no. 4, pp. 99–101, 2011.

[21] R. A. Jaffin and C. L. Berman, "The excessive loss of Branemark fixtures in type IV bone: a 5-year analysis," *Journal of Periodontology*, vol. 62, no. 1, pp. 2–4, 1991.

[22] M. Quirynen, I. Naert, and D. van Steenberghe, "Fixture design and overload influence marginal bone loss and fixture success in the Brånemark system," *Clinical oral implants research*, vol. 3, no. 3, pp. 104–111, 1992.

[23] S. Szmukler-Moncler and J. P. Bernard, "Short implants in the posterior region," in *Proceedings of the Annual ITI Meeting*, Films, Swizerland, 1999.

[24] R. Nedir, M. Bischof, J. M. Briaux, S. Beyer, S. Szmukler-Monder, and J. P. Bernard, "A 7-year life table analysis from a prospective study on ITI implants with special emphasis on the use of short implants. Results from a private practice," *Clinical Oral Implants Research*, vol. 15, no. 2, pp. 150–157, 2004.

[25] E. Romeo, M. Ghisolfi, R. Rozza, M. Chiapasco, and D. Lops, "Short (8-mm) dental implants in the rehabilitation of partial and complete edentulism: a 3- to 14-year longitudinal study," *International Journal of Prosthodontics*, vol. 19, no. 6, pp. 586–592, 2006.

[26] A. B. Carr, "Survival of short implants is improved with greater implant length, placement in the mandible compared with the maxilla, and in nonsmokers," *Journal of Evidence-Based Dental Practice*, vol. 12, no. 1, pp. 18–20, 2012.

[27] H. L. Sun, C. Huang, Y. R. Wu, and B. Shi, "Failure rates of short ($\leq$ 10 mm) dental implants and factors influencing their failure: a systematic review," *The International Journal of Oral & Maxillofacial Implants*, vol. 26, no. 4, pp. 816–825, 2011.

[28] E. Raviv, A. Turcotte, and M. Harel-Raviv, "Short dental implants in reduced alveolar bone height," *Quintessence International*, vol. 41, no. 7, pp. 575–579, 2010.

[29] H. Wilke, L. Claes, and S. Steinemann, "The influence of various titanium surfaces on the interface shear strenght between implant and bone," in *Clinical Implant Material Advances in Biomaterials*, U. Heimke and A. Lee, Eds., vol. 9, Elsevier Science, Amsterdam, The Netherlands, 1990.

[30] D. Buser, R. K. Schenk, S. Steinemann, J. P. Fiorellini, C. H. Fox, and H. Stich, "Influence of surface characteristics on bone integration of titanium implants. A histomorphometric study in miniature pigs," *Journal of Biomedical Materials Research*, vol. 25, no. 7, pp. 889–902, 1991.

[31] F. G. Draenert, K. Sagheb, K. Baumgardt, and P. W. Kämmerer, "Retrospective analysis of survival rates and marginal bone loss on short implants in the mandible," *Clinical Oral Implants Research*. In press.

[32] O. A. Etöz, M. Ulu, and B. Kesim, "Treatment of patient with Papillon-Lefevre syndrome with short dental implants: a case report," *Implant Dentistry*, vol. 19, no. 5, pp. 394–399, 2010.

[33] M. Morand and T. Irinakis, "The challenge of implant therapy in the posterior maxilla: providing a rationale for the use of short implants," *The Journal of oral implantology*, vol. 33, no. 5, pp. 257–266, 2007.

[34] S. Annibali, M. P. Cristalli, D. Dell'Aquila, I. Bignozzi, G. La Monaca, and A. Pilloni, "Short dental implants: a systematic review," *Journal of Dental Research*, vol. 91, no. 1, pp. 25–32, 2012.

[35] U. Lekholm and G. Zarb, "Patient selection and preparation," in *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry*, P. I. Brånemark, G. Zarb, and T. Albrektsson, Eds., pp. 199–209, Quintessence, Chicago, Ill, USA, 1985.

[36] B. Pommer, S. Frantal, J. Willer, M. Posch, G. Watzek, and G. Tepper, "Impact of dental implant length on early failure rates: a meta-analysis of observational studies," *Journal of Clinical Periodontology*, no. 9, pp. 856–863, 2011.

[37] S. H. Chang, C. L. Lin, S. S. Hsue, Y. S. Lin, and S. R. Huang, "Biomechanical analysis of the effects of implant diameter and bone quality in short implants placed in the atrophic posterior maxilla," *Medical Engineering and Physics*, vol. 34, no. 2, pp. 153–160, 2012.

[38] G. O. Eduardo Anitua, J. J. Aguirre, and I. Andía, "Five-year clinical evaluation of short dental implants placed in posterior areas: a retrospective study," *Journal of Periodontology*, vol. 79, no. 1, pp. 42–48, 2008.

[39] G. Telleman, G. M. Raghoebar, A. Vissink, L. Den Hartog, J. J. R. Huddleston Slater, and H. J. A. Meijer, "A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient," *Journal of Clinical Periodontology*, vol. 38, no. 7, pp. 667–676, 2011.

[40] Y. S. Yi, K. M. Emanuel, and S. K. Chuang, "Short (5.0 × 5.0 mm) implant placements and restoration with integrated abutment crowns," *Implant Dentistry*, vol. 20, no. 2, pp. 125–130, 2011.

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Clinical Study

Simultaneous Sinus Lifting and Alveolar Distraction of a Severely Atrophic Posterior Maxilla for Oral Rehabilitation with Dental Implants

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We retrospectively reviewed a new preimplantation regenerative augmentation technique for a severely atrophic posterior maxilla using sinus lifting with simultaneous alveolar distraction, together with long-term oral rehabilitation with implants. We also analyzed the regenerated bone histomorphologically. This study included 25 maxillary sinus sites in 17 patients. The technique consisted of alveolar osteotomy combined with simultaneous sinus lifting. After sufficient sinus lifting, a track-type vertical alveolar distractor was placed. Following a latent period, patient self-distraction was started. After the required augmentation was achieved, the distractor was left in place to allow consolidation. The distractor was then removed, and osseointegrated implants (average of 3.2 implants per sinus site, 80 implants) were placed. Bone for histomorphometric analysis was sampled from six patients and compared with samples collected after sinus lifting alone as controls ($n = 4$). A sufficient alveolus was regenerated, and all patients achieved stable oral rehabilitation. The implant survival rate was 96.3% (77/80) after an average postloading followup of 47.5 months. Good bone regeneration was observed in a morphological study, with no significant difference in the rate of bone formation compared with control samples. This new regenerative technique could be a useful option for a severely atrophic maxilla requiring implant rehabilitation.

1. Introduction

Treatment with dental implants has become a new paradigm in oral and maxillofacial reconstruction and rehabilitation after teeth loss with maxillary alveolar resorption. However, appropriate implant positioning can be compromised by insufficient bone volume and the surrounding soft tissue condition of the residual alveolus. Severe atrophy (Class >IV, according to the classification of Cawood and Howell) of a totally or partially edentulous maxilla can pose a major challenge for implant-supported fixed oral rehabilitation [1, 2]. The three-dimensional (3D) centripetal bone resorption pattern of the maxilla, especially when associated with centrifugal resorption of the mandible, can create a relatively unfavorable vertical, transverse, and sagittal intermaxillary relationship, which can further hinder maxillary implants and make implant functional rehabilitation difficult [2, 3]. Thus, the volume of healthy maxillary bone and intermaxillary positioning must be increased and improved, the condition of the bone and surrounding soft tissue must be

improved, and the interarch situation must be corrected [1–3].

As maxillary bone resorption with alveolar atrophy varies among patients, different reconstructive surgical techniques, including saddle or veneer onlay bone grafting, maxillary sinus floor elevation with grafting, and various guided bone regeneration techniques, alone or in combination, have been introduced [4, 5]. These augmentation methods can effectively create adequate bone volume for implant sites and lead to successful long-term implant treatment [4–6]. However, most fail to recreate the optimal intermaxillary three-dimensional relationship for correct prosthetic rehabilitation, and there may be a limited amount of bone available for augmentation because of soft tissue coverage and donor site issues [4, 6]. Furthermore, careful attention must be taken to avoid an incorrect crown-to-implant ratio in a prosthesis, a flawed intermaxillary relationship, undesirable peri-implant conditions, and bone resorption due to difficult maintenance [4, 7].

For the severely atrophic maxillary alveolus, the advent of Le Fort 1 osteotomy with autogenous interposition

nal bone grafting, typically using iliac bone, allows forward and/or downward repositioning of the maxilla. It also provides sufficient bone volume for the insertion of appropriately sized implants in an ideal position, and a better crown-to-implant ratio in the prosthesis. This technique, used with simultaneous implant placement for bone graft stabilization, was first described by Sailer [8]. Various modifications of the technique include horseshoe sandwich osteotomy, unilateral segmental osteotomy with interpositional bone grafting, and procedures designed for mucosal sinus preservation in bone grafting [4, 9, 10].

Alveolar distraction has recently gained acceptance as a predictable preimplant augmentation method for simultaneously regenerating bone and surrounding soft tissue [11, 12]. For an extremely atrophic posterior maxillary region, we have developed a modified technique that combines sinus lifting with simultaneous alveolar distraction, instead of the interpositional bone grafting of the Le Fort 1 osteotomy [12]. This technique compensates for the conventional sinus lifting approach used for implant treatment and is less surgically invasive. It allows the regeneration of native bone and soft tissue and provides a controllable distracted alveolar segment for the implant prosthesis, regenerating the augmented vertical dimension. As described in our preliminary technical notes published in 2005 [12] and 2009 [13], the mid-term clinical results for a partially or totally edentulous atrophic maxillary alveolus showed optimal implant rehabilitation. Consequently, we have widened the indications for this technique to include severe atrophy (Class >IV, according to the classification of Cawood and Howell [1]) of a totally or partially edentulous maxilla in patients needing implant-supported fixed oral rehabilitation.

This study retrospectively evaluated the efficacy of our new pre-implant reconstruction technique using sinus lifting with simultaneous alveolar distraction for regenerating a severely atrophic maxilla, with long-term oral rehabilitation with implants, and analyzed the regenerated bone histologically.

2. Patients and Methods

This study included 25 maxillary sinus sites in 17 systemically healthy patients (9 females, 8 males; average age 49.3 years; Tables 1 and 2). All patients had a partially or totally edentulous severely atrophied posterior maxilla, Class IV, V, or VI according to the Cawood/Howell classification [1], with relevant maxillary retrusion, interarch distance with incorrect crown-to-implant ratio, or difficulty in wearing an ordinary dental implant-anchored fixed prosthesis. Thus, these patients were possible candidates for our pre-implant surgical method of sinus lifting with simultaneous alveolar distraction, to accomplish oral implant-anchored prosthetic functional rehabilitation (Figure 1).

All patients gave informed consent before participating in this study.

The patients were evaluated using radiography, plaster modeling, and computed tomography (CT; Somatom AR SP; Siemens, Erlangen, Germany). An accurate 3D analysis of the planned surgery was performed using SimPlant OMS (Materialise, Leuven, Belgium), which allows precise 3D simulation of the morphologically complex severely atrophic maxillary alveolar ridge with the maxillary sinus. The original residual alveolar bone height was analyzed based on preoperative CT data for the simulated dental implant positions, measuring from the alveolar crest to the floor of the maxillary sinus. The average data for all of the measured simulated implant positions in the atrophic posterior maxilla for each patient were summarized as the preoperative residual bone height (Tables 1 and 2). It also simulates the 3D changes with gradual repositioning following alveolar distraction, considering the intermaxillary relationship with occlusion, as reported previously [14].

Patient exclusion criteria were (1) tobacco abuse (>20 cigarettes/day), (2) renal or liver disease, (3) history of radiography of the head and neck region, (4) history of chemotherapy for a malignant tumor, (5) uncontrolled diabetes, (6) history of bisphosphonate administration, (7) oral mucosal disease such as lichen planus, (8) poor oral hygiene, and (9) noncompliance.

2.1. Reconstructive Surgical Procedure. For patients with a totally edentulous bilateral severely atrophied posterior maxilla needing bilateral sinus lifting with simultaneous total maxillary alveolar distraction, surgery was performed under general anesthesia with nasal endotracheal intubation (Table 1). On the other hand, for patients with a partially edentulous severely atrophic posterior maxilla needing unilateral simultaneous sinus lifting and alveolar distraction, surgery was performed under local anesthesia and intravenous sedation (Table 2). At the start of the operation, patients were given 1 g of cefazolin sodium and 4 mg of betamethasone. Local anesthesia with a vasoconstrictor was used to minimize bleeding in the soft tissue.

A vestibular incision was made extending from the second molar area on one side to the other. A mucoperiosteal flap was reflected, and the alveolar crest and entire lateral maxillary sinus wall and piriform aperture were deflected to perform the alveolar osteotomy. A horizontal alveolar

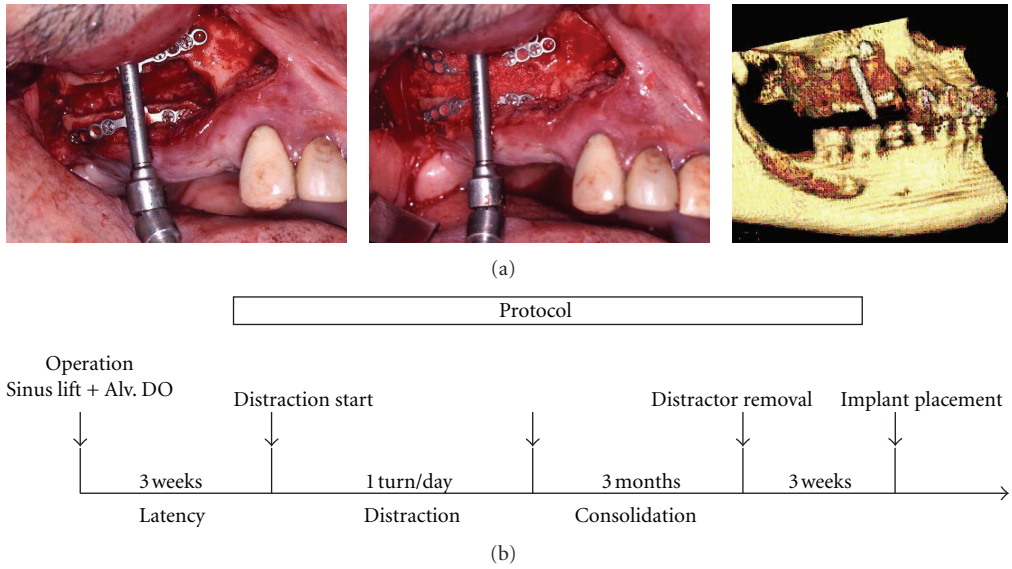


Figure 1: Surgical technique and treatment protocol for simultaneous sinus lifting and alveolar distraction. (a) Intraoperative views and 3D computed tomography of the result; (b) treatment protocol for simultaneous sinus lifting with alveolar distraction and implant placement.

Table 1: Patient profiles and review ($n = 8$) of bilateral sinus lifting and simultaneous total alveolar distraction for the edentulous severely atrophic maxilla. Bilateral sinus lifting + Total Alv. DO for edentulous patients.

Case	Age (year)	Sex	Alveolar distractor	Donor site	Preoperative residual bone height (mm)	Alveolar bone height at implant placement (mm)	Biopsy	Implant	Postloading (months)
1	43	F	Martin Track 1.5 10 mm	Chin	3.2	14.2	−	6	59
2	69	F	Martin Track 1.5 10 mm	Chin	2.6	13.6	+	8	50
3	50	F	Medartis V2 10 mm	Tibia	3.8	14.5	−	6	48
4	34	M	Medartis V2 15 mm	Tibia	2.9	13.1	−	6	47
5	55	F	Martin Track 1.5 10 mm	Tibia	3.2	11.7	+	8	47
6	54	M	Medartis V2 10 mm	Tibia	2.6	13.9	+	5	48
7	50	F	Medartis V2 10 mm	Tibia	3.5	15.3	−	6	38
8	40	M	Medartis V2 10 mm	Tibia	2.4	12.9	−	6	37
	49.4				3.0	13.7		6.4	46.8

Table 2: Patient profiles and review ($n = 9$) for unilateral sinus lifting and simultaneous unilateral alveolar distraction for the unilateral partially edentulous severely atrophic posterior maxilla. Unilateral sinus lifting + Alv. DO for partially edentulous patients.

Case	Age (year)	Sex	Alveolar distractor	Donor site	Preoperative residual bone height (mm)	Alveolar bone height at implant placement (mm)	Biopsy	Implant	Postloading (months)
1	16	M	Martin Track 1.0 9 mm	Ramus	3.8	12.5	−	3	68
2	52	F	Martin Track 1.0 12 mm	Chin	3.7	14.1	−	4	64
3	62	M	Martin Track 1.0 15 mm	Ramus	2.4	12.2	−	4	62
4	48	F	Medartis V2 10 mm	Ramus	2.5	13.9	+	4	48
5	52	M	Medartis V2 10 mm	Ramus	3.5	11.9	−	2	40
6	51	M	Medartis V2 10 mm	Ramus	2.8	11.7	−	3	39
7	58	F	Medartis V2 10 mm	Tibia	2.6	13.1	+	3	38
8	55	M	Martin Track 1.0 15 mm	Ramus	3.6	13.1	−	3	38
9	49	F	Martin Track 1.0 12 mm	Tibia	3.7	13.9	+	3	37
	49.2				3.2	12.9		3.2	48.2

osteotomy for unilateral simultaneous sinus lifting and alveolar distraction was carefully made 3–5 mm from the alveolar crest, which was planned and simulated preoperatively, as described previously [12]. This left ample alveolar bone to fix the plate of the distractor, usually done using a small round bur or Piezosurgery to protect the intact sinus membrane. The sinus membrane was then lifted, taking care to avoid perforating the maxillary sinus. A total alveolar osteotomy for bilateral sinus lifting with simultaneous total maxillary alveolar distraction was completed with a bone saw for bilateral distraction in edentulous cases (Figure 2) [13]. For unilateral cases, a box-shaped window osteotomy of the alveolar bone was made, after the maxillary sinus membrane was carefully lifted (Figure 3) [12]. Confirmation of the reflection and upward lifting was performed, and the palatal side of the alveolus was then completely osteotomized with a bone saw or Piezosurgery to make the transport segment, checking the osteotomy line with a forefinger touching the palatal mucosa. After the transport segment, either a total alveolar osteotomized segment in bilateral cases or a unilateral bow-shaped alveolar osteotomized segment in unilateral cases was prepared, lifting the sinus membrane. An alveolar distractor (KLS Martin, Tuttlingen, Germany; Medartis AG, Basel, Switzerland) (Tables 1 and 2) was positioned with fixation at bilateral molar sites for most total alveolar distraction cases, or a single alveolar distractor was positioned at the central maxilla when sufficient bone remained for distractor setting at the anterior maxillary alveolus (Figure 2). Alternatively, a single distractor adjusted for unilateral distraction cases was set at the sinus-lifted unilateral molar site (Figure 3). After confirming its rigid fixation, the distractor was activated once to widen the window for sufficient maxillary sinus lifting with an equal-volume mixture of particulate autogenous cancellous bone/β-TCP particle grafting material (Olympus, Tokyo, Japan; Pentax, Tokyo, Japan) for sinus floor elevation. The distractor was then returned to its initial position. The alveolar bone and maxillary sinus membrane were protected from injury during the operation. The surgical wounds were sutured without tension by relaxing the soft tissue flaps.

Surgery was performed simultaneously on the donor and recipient sites. Bone donor sites were chosen intraorally from the mandibular chin or ramus, or extraorally from the medial portion of tibia cancellous bone, based on the patient's choice (Tables 1 and 2). The cases for bilateral sinus lifting with total alveolar distraction tended to need more bone, and thus the tibia was chosen as the autogenous bone donor site. Patients were hospitalized for 1–3 days after surgery. Intraoperative and postoperative clinical courses were uneventful.

Following a latent period of 3 weeks, patient self-distraction was started at a slow rate of one turn (0.5 mm) per day (Figure 1). Next, the activation rate was accelerated to two turns (1.0 mm) per day, considering the soft tissue condition. When the required augmentation was achieved, the distractor was left in place for 3 months to ensure bony consolidation. Then, it was removed to allow implant insertion. For some bilateral distraction cases with total maxillary distraction with bilateral alveolar distractors, the bilateral maxillary alveolar segments were distracted palatally due to the directions of the distractors, together with the tight tension of the palatal mucosa (Figure 2). After sufficient vertical distraction, bilateral alveolar segmental widening was performed with an orthodontic palatal expansion device (Hyrax device), so that the bimaxillary relationship and a suitable maxillary arch were acquired (Figure 2).

2.2. Dental Implant Surgery. After the alveolar distractor was removed, soft tissue was allowed to heal for 3-4 weeks before implant surgery (Figure 1). Further instructions included diet, the use of a 0.12% chlorhexidine mouth rinse, and oral health care. Endosseous osseointegrated dental implants (average of 3.2 implants/maxillary sinus site; 80 implants; Straumann ITI, Institute Straumann AG, Basel, Switzerland; Astra Tech, Astra Tech AB, Göteborg, Sweden; Novel Biocare AB, Göteborg, Switzerland), more than 11 mm in length and 4 mm in platform width, were placed in optimized positions applying a computer-guided surgical template using SimPlant OMS, after consultation with prosthodontists and dental implantologists, who had consulted with us regarding the pre-implant bone augmentation reconstructive surgery. The repeated CT data were further analyzed to measure the regenerated alveoli obtained before implant placement. The implants were supplied with cover screws in a two-stage procedure and left to heal for 4–6 months before secondary abutment connection surgery. All patients had dental implant-anchored fixed prosthetic rehabilitation with the cement-retained prosthetic fixation method.

2.3. Bone Histomorphometric Analysis. Using a 2 mm trephine bur, regenerated bone was sampled with informed consent from six patients who underwent bone graft-sinus lifting and alveolar distraction, from the simulated site of the first molar at the time of implant placement. As a control, bone was sampled from four other patients who underwent sinus lifting only as a pre-implant augmentation procedure for two-stage implant placement using the same sinus lifting materials (equal-volume mixture of particulate autogenous cancellous bone/β-TCP) with the same bone-healing period postoperatively in the same simulated position of the first molar for implant placement with a very similar residual bone volume for the atrophic posterior maxilla. Each cylindrical specimen acquired with the trephine biopsy was 2 mm in diameter and at least 10 mm in length.

Briefly, the bone specimens were fixed in 10% formalin for 24 h and decalcified in Calci-Clear Rapid (National Diagnostics, Atlanta, GA, USA) for 12 h. The tissues were rinsed in flowing water, treated with a Hypercenter XP tissue processor (Shandon, Cheshire, UK), embedded in paraffin, cut into 4 μm sections, and stained with H&E or toluidine blue. The prepared specimens were observed under a light microscope (Olympus) through a 20× objective. The bone samples were evaluated for bone volume and mineralization of woven bone volume at bone histomorphometry institutes (Kyodo Byori, Hyogo, Japan and Ito Bone Histomorphometry Institute).

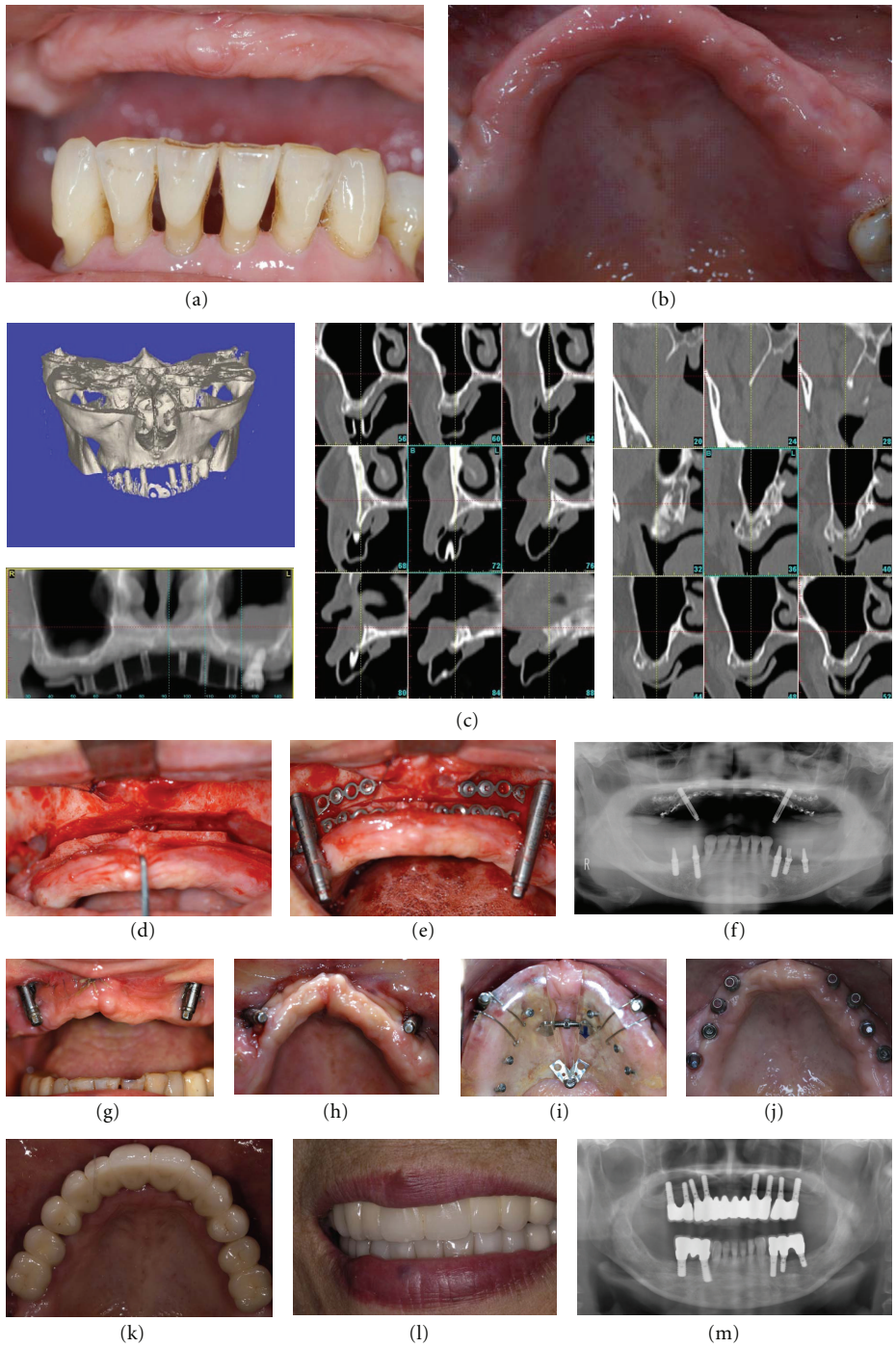


Figure 2: Representative case of bilateral sinus lifting and simultaneous total alveolar distraction for an edentulous severely atrophic maxilla (Case 2, Table 1). (a, b) Preoperative intraoral views; (c) preoperative CT views; (d) intraoperative view. After the end of the bilateral sinus floor elevation and completion of the total alveolar osteotomy: (e) sufficient sinus lifting with an equal-volume mixture of particulate autogenous cancellous bone/β-TCP was observed and the bilateral alveolar distractors were set; (f) postoperative panoramic X-ray; (g) after the end of vertical distraction; (h) good vertical distraction was obtained, but the maxillary alveolar arch was very narrow and V-shaped; (i) bilateral alveolar segmental widening with distraction was followed with use of an orthodontic palatal expansion device (the Hyrax device); (j) implant placement at ideal positioning was obtained for dental implant-anchored fixed prosthetic rehabilitation; (k, l) the definite prosthesis was set after 2 years with a provisional restoration during the postloading period for total oral rehabilitation; (m) panoramic X-ray taken 3 years later.

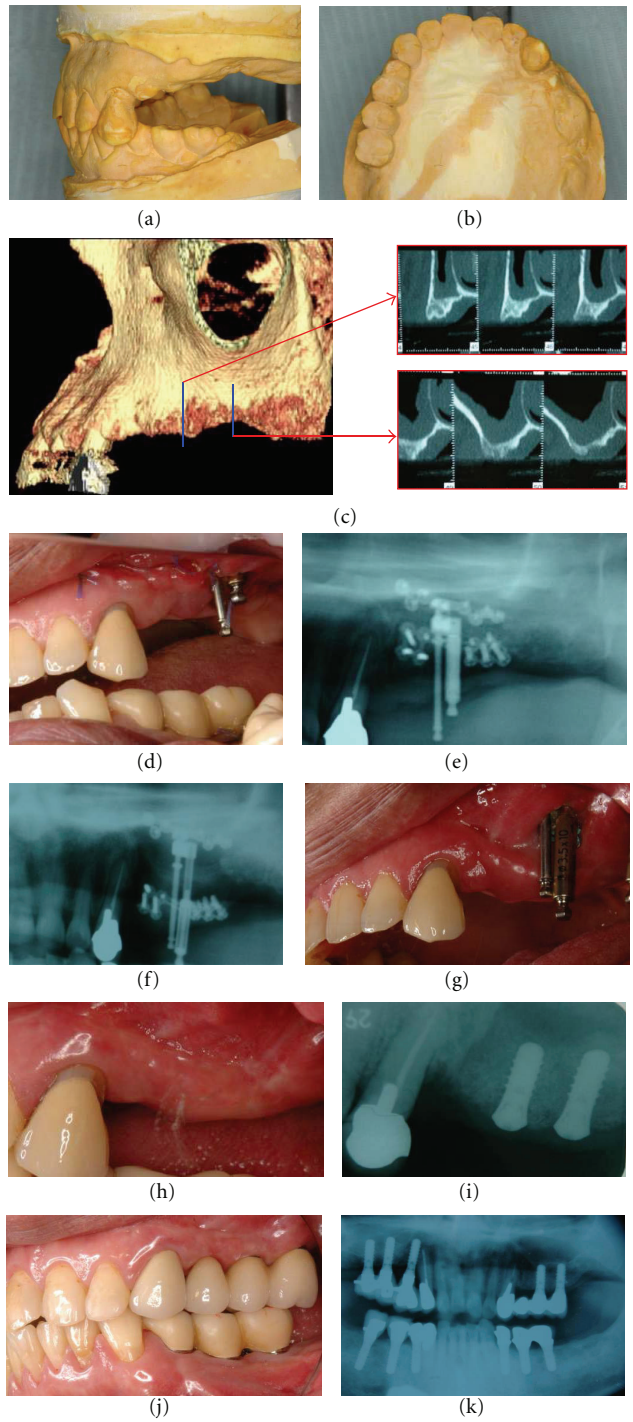


Figure 3: Representative case of unilateral sinus lifting and simultaneous unilateral alveolar distraction for a unilateral partially edentulous, severely atrophic posterior maxilla (Case 5, Table 2). (a, b) Preoperative plaster models of the left posterior maxillary atrophy; (c) preoperative CT views; (d) postoperative intraoral view; (e) postoperative X-ray before activation of distraction with unilateral sinus lifting and simultaneous alveolar distractor setting; (f) postoperative panoramic X-ray after the end of distraction; (g) after the end of vertical distraction; (h) at the time of implant placement and 3 weeks after distractor removal for soft tissue healing; (i) dental X-ray after implant placement; (j) the definite prosthesis was placed after 1 year of provisional restoration as the postloading period; (k) panoramic X-ray taken after 2 years.

2.4. Statistical Analysis. Statistical analyses were performed with StatView 5.0 (SAS Institute, Cary, NC, USA). Student's t-test was used to compare bone regeneration and new bone formation between the study ($n = 6$) and control groups ($n = 4$). Statistical significance was defined as $P < 0.05$ ($^{*}P < 0.05$, $^{**}P < 0.01$).

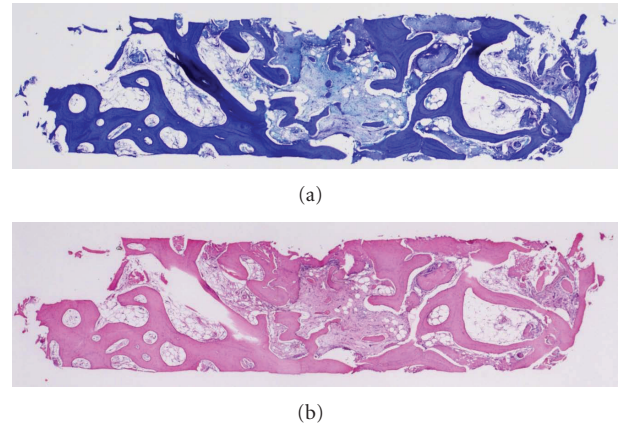
3. Results

The preimplantation augmentation technique using sinus lifting with simultaneous alveolar distraction for regenerating the maxilla was successful after an uneventful postoperative course. No surgical morbidity, infection, dental or gingival injury, or avascular necrosis occurred.

Sufficient sinus floor elevation together with vertical bone augmentation improved the vertical maxilla-mandibular dimension and created an intermaxillary 3D relationship appropriate for correct prosthetic rehabilitation and an improved implant-crown ratio, compared with the preoperative condition. New bone formation with effective vertical and labial-buccal augmentation was observed radiologically after a consolidation period. At the time of implant placement, the regenerated alveoli were analyzed precisely using CT data for the ideal implant positional simulation to quantify the vertical augmentation measuring from the alveolar crest to the floor of the maxillary sinus once again in each patient. The average alveolar bone height augmented for implant placement was 13.7 (range 11.7–15.3) mm for bilateral cases (Table 1) and 12.9 (range 11.7–14.1) mm for unilateral cases (Table 2) from the original severely atrophic posterior maxilla.

Distraction was required for activation to maximum lengths of 10 or 15 mm. A horizontal widening technique was also required in three of eight bilateral distraction cases; bilateral maxillary molar distraction was performed due to the narrowed bilateral alveolus caused after the end of distraction (Figure 2). Soon after the end of distraction, the patients wore palatal expansion orthodontic devices for maxillary arch form correction. The duration of active distraction was approximately 3-4 weeks. By the time of implant placement, the overcorrected distracted alveolus was reduced to some extent, despite maximum overcorrection. After allowing 3 weeks for soft tissue healing, 80 endosseous osseointegrated dental implants (3.2 implants/site), more than 11 mm in length and 4 mm in platform width, were placed in optimized positions using a surgical guide, which was analyzed with SimPlant OMS. All patients achieved stable, functional oral rehabilitation with dental implant placement in the regenerated alveolus.

Regarding the implant survival rate, of the 80 inserted endosseous dental implants (Tables 1 and 2), three failed in three patients (one bilateral and two unilateral distraction cases). They were all early failures, with implant loss within the first year after placement. One bilateral case and one unilateral case with failed implants underwent supplementary insertions; the other failed implant inserted at the most distal molar site in a unilateral case was not reinserted. Consequently, the total implant survival rate was 96.3% (77/80) after an average postloading follow-up period of 47.5 months. The implant-anchored fixed bridge stability rate was 100% because all of the patients were still wearing their definite prosthetic restoration at the time when this clinical study was retrospectively reviewed.



(a)

(b)

Figure 4: Good bone regeneration was observed, with an average mature bone formation rate of 36.3 ± 16.5%. (a) Stained with toluidine blue; (b) stained with H&E.

Table 3: The bone histomorphometric results for new bone formation and maturation were compared between the study group with alveolar distraction and simultaneous sinus lifting with bone grafting and a control group with sinus lifting only with the same bone graft at the time of implant placement in the simulated first molar area. Student's t-test was used to compare bone regeneration and new bone formation between the study group ($n = 6$) and control group ($n = 4$). Statistical significance was defined as $P < 0.05$.

	Age (Year)	TV (μm^2)	BV (μm^2)	BV/TV (%)
Sinus + Alv. DO ($n = 6$)	54.8	2859626.1	995394.1	36.3
Control ($n = 4$) (sinus lift)	55.3	2823053.3	1138133.8	39.3
P (t-test)	0.9228	0.9106	0.6207	0.7789

Regarding the bone biopsy histomorphometric study, good bone regeneration was observed (Figure 4). An average mature bone formation rate (BV/TV) of 36.3 ± 16.5% ($n = 6$) was confirmed in the bone morphological study at the time of implant placement in the six patients who gave informed consent, with no significant difference from the control samples (39.3 ± 10.4%; $n = 4$) at the same simulated site of the first molar area after an equal bone healing period for consolidation ($P > 0.05$) (Table 3). The bone histomorphometric results regarding new bone formation and maturation were essentially the same between the distracted area of the cases and the control areas at the time of implant placement, which were lifted and not distracted, showing that well-formed new bone to promote good initial stability for dental implant placement was present at the distraction sites with sinus lifting.

4. Discussion

The clinical efficacy of our pre-implant reconstruction technique using sinus lifting with simultaneous alveolar distraction changed the contour of the severely atrophic resorbed maxillary alveolus, regenerating sufficient bone on both the alveolar side and inside the maxillary sinus [12, 13].

As mentioned above, 3D computer simulation allows surgeons to perform virtual surgery and create 3D predictions of patient outcomes. We were able to simulate the entire process of alveolar reconstruction with our technique, including alveolar distraction, the shape of the maxillary sinuses for determining the osteotomy line, the amount of sinus lifting, and the subsequent oral implant placement with parameters that included realistic transport segment lengths, angulation, and prosthesis sizes with easy selection from a very wide variety of preset modules [13, 14]. In the future, one may be able to customize prebent plates for the distractor device preoperatively in cases of complicated reconstruction of a severely atrophic maxilla using distractors.

For dental-implant-retained oral rehabilitation of the severely atrophic maxillary alveolus, the advent of the Le Fort 1 osteotomy with autogenous interpositional bone grafting, typically using iliac bone, allows forward and downward repositioning of the maxilla [4, 9, 10]. Bell et al. [15] were the first to describe a Le Fort 1 osteotomy with interpositional bone grafts in edentulous patients to improve the positioning of the resorbed maxilla and restore the intermaxillary relationship. This is because, in the severely atrophic maxilla, creating a dental implant site by merely increasing the bony volume will lead to unfavorable loading of the prosthesis and impaired aesthetic and functional results [4, 15]. The conventional Le Fort 1 osteotomy with interpositioning of bone grafts for dental implants was first described by Sailer [8] as a one-stage operation, and it was later modified by Cawood et al. [16] as a two-stage procedure. The insertion of the endosseous implants was delayed until the bone grafts had been revascularized. The delayed placement of the dental implants resulted in less risk of their loss and made the use of a template possible [16]. Furthermore, this effective interpositional bone graft with a Le Fort 1 level osteotomy was applied to a segmental Le Fort 1 osteotomy with bone grafting in the unilateral severely atrophied maxilla based on the ideal movement of the unilateral posterior maxilla, followed by delayed implant placement for ideal oral rehabilitation by Pelo et al. [9].

Our original pre-implant reconstruction technique using sinus lifting with simultaneous alveolar distraction was based on and drastically modified from conventional pre-implant augmentation Le Fort 1 osteotomy and interpositional bone grafting [13]. Our osteotomy line was not at the Le Fort 1 level, but was an alveolar osteotomy far below this level [11, 12]. This is less invasive and yet sufficient for performing simultaneous sinus lifting with an equal-volume mixture of particulate autogenous cancellous bone/β-TCP and placing the distractor [12]. In addition, the secure protection of the surrounding mucoperiosteum, which promotes osteogenic cell and active bone formation with a broad vascular network, plays a role in ensuring nutrition for the healing surgical wound, bone formation, and bone regeneration for simultaneous sinus lifting with alveolar distraction [11, 14]. The closest strategy to our technique is controlling the osteotomized alveolar segment using vertical alveolar distractors with gradual distraction, while managing the direction and amount of distraction. This is unlike the intraoperative critical determination of the 3D positioning of the Le Fort 1 segment after osteotomy, which was based solely on the surgeon's experience. Moreover, the volume and position of the interpositioned bone graft are usually limited to some extent due to both bone and soft tissue obstacles [8–10].

Nevertheless, although the simulated distraction was less than the maximum amount, all of the patients needed distraction of 10–15 mm, which would allow compensation for distraction loss and bone loss [11, 14]. Furthermore, in several cases using bilateral buccal alveolar distractors with simultaneous sinus lifting, the bilateral segments distracted well, but the distracted arch was narrowed markedly due to the direction of distraction and the atrophic shape of the residual posterior maxillary alveolus [13]. This was attributable to the resistance of the palatal mucosa and lip support of the functional orbicularis oris muscle [13, 14]. Consequently, these patients needed additional maxillary arch widening distraction control using a Hyrax orthodontic device following vertical distraction, following the "floating bone concept" described by Hoffmeister and Wangerin [17]. This 3D distraction method overcame the arch discrepancy problem for ideal implant positioning, which would not be true of the complete controllability of this distraction technique and contrary to the actual preoperative computer simulation [13]. Furthermore, for cases of unilateral distraction, although improvements in distraction systems are still needed, as evidenced by reports describing major complications, including undesirable palatal-lingual inclination of the transport segments, an undesirable inclination leaning palatally was sometimes seen during the activation period. Therefore, a careful check of the distraction vector with manual manipulation for correction is needed to achieve accurate vector control of the transport segments, together with the use of a fixed or removable prosthodontic to guide the direction of distraction for successful preimplant augmentation, as described previously [14, 18]. This tendency toward problematic palatal inclination was improved to some extent by using bidirectional alveolar distraction systems for the latter cases, as described previously as a floating alveolar segmental control, which could eliminate transport segment displacement without the need for burdensome oral rehabilitation appliances [14, 17, 18]. Furthermore, this segmental postoperative controllability should be effective compared to the one-stage determination of Le Fort 1 osteotomy with interpositional bone grafting. We modified the alveolar distraction technique for a severely atrophied posterior maxilla, based on the original idea of Ilizarov [19] that distraction osteogenesis involves the regeneration of bone and surrounding soft tissues through gradual traction between two surgically separated fragments fixed to a mechanical device [20, 21].

The possibility of osteoregeneration using distraction in the posterior maxillary sinus area seemed less likely

compared with the mandible or anterior maxilla because of less recruitment of osteoregenerative osteoblasts from the bone marrow, less cancellous bone volume, and the presence of the pneumatized maxillary sinus and sinus membrane is problematic. In 2004, Boyne and Herford [22] first described new bone formation using alveolar distraction in the posterior maxillary sinus area, in an animal study of three adult baboons (*Papio anubis*). This study reflected the clinical difficulty of implant restoration with a thin margin of crestal maxillary alveolar bone attached to the sinus membrane. After placing the distractor against the antral and nasal floors without bone grafting, and allowing a latency period of 7 days, it was activated at a rate of 1 mm/day to obtain 10 mm of lengthening. Twenty weeks after the completion of distraction, specimens of the atrophic maxilla showed significant bone formation [22]. Consequently, bone regeneration is possible in very small segments of the atrophic posterior maxilla using distraction osteogenesis [22]. However, any clinical protocol should include implant placement after bone formation, and no similar animal study has been reported.

Therefore, we hypothesized that a slightly longer latency period would be needed for sufficient distracted bone regeneration in this difficult situation in the atrophic posterior maxilla [13, 14]. In addition, we performed simultaneous autogenous bone grafting after sufficient careful sinus lifting of the membrane, as we believed that autogenous cortical cancellous bone grafting would not only elevate the maxillary sinus floor to make space, but also reliably induce bone formation, with osteoblast recruitment from marrow stem cells and living osteoblasts [21, 23, 24]. Furthermore, we hypothesized that 2-3 weeks would be needed to retain the grafted materials on the lifted maxillary sinuses [12–14]. Without this retention time for the grafted materials, the lifted sinus material would be distracted with the transport segment using the conventional waiting period of 1 week [12, 13]. Therefore, we waited 3 weeks to allow bony retention of the grafted sinus materials and complete soft tissue healing of the surgical site. With this longer waiting period, we did not experience undesirable bony union making it impossible to activate distraction, breakage of the device, or the loss of fixation screws [14, 21, 23].

Our histomorphometric study showed good bone regeneration with an average mature bone formation rate (BV/TV) of 36.3%. This rate was similar to Szabó et al.'s [25] report of 38.3% with autogenous cancellous bone grafting versus 36.4% with β-TCP particles alone after 6 months. Schwartz et al. [26] reported a 17% bone formation rate using autogenous chin bone with β-TCP particles for sinus floor augmentation after 6 months, and a 21% new bone formation rate with a freeze-dried bone allograft and hyaluronic acid for sinus lifting augmentation after 8 months. As bone maturation with good bone regeneration was observed, with an average mature bone formation rate of 36.3%, which did not differ significantly from the 39.3% in the controls with sinus lifting alone for pre-implant augmentation surgery under similar atrophic conditions, the equal-volume mixture of particulate autogenous cancellous bone/β-TCP seems to be an ideal graft material, accelerating bone formation in sinus augmentation before implant placement [25–28].

Our clinical results were good, with good mature bone formation and an implant survival rate of 96.3% (77/80 implants) after an average postloading followup of 47.5 months. This survival rate is in accord with that of the conventional Le Fort 1 technique with interpositional bone grafting with modifications, as described in many reports [9, 10, 29, 30]. The implants used in our study were from different manufacturers and were more than 11 mm in length and had platforms wider than 4 mm. The implants were chosen by the patients' dentists, implantologists, and prosthodontists, and the choice did not seem to influence the survival with our method.

We performed a buccal osteotomy for both total alveolar osteotomy with bilateral sinus lifting and partial box-shaped osteotomy for unilateral sinus lifting with a round burr [12, 13]. Subsequently, we used Piezosurgery initially for the posterior buccal part, being careful not to damage the sinus membrane. Then, the alveolar osteotomy was made with a bone saw or Piezosurgery. Piezosurgery could be very useful for maxillofacial bone surgery to prevent soft tissue damage. Although we were unable to prevent small tears, no patients developed entrapment cysts of the maxillary epithelium or chronic sinusitis.

The main criticism of our study might be the absence of a control group with only sinus lifting for sinus floor elevation without bone grafting with simultaneous alveolar distraction for both bilateral and unilateral cases, as bone regeneration between the sinus membrane and distracted alveolus might occur, as shown in Boyne's animal study [22]. Another major disadvantage of this idea could be simultaneous autogenous bone grafting for sinus lift [12, 13]. Although we believe that simultaneous autogenous bone grafting could play a great role in bone regeneration because it provides large numbers of osteogenic cells for more efficient bone formation at the site of distraction osteogenesis, it requires patients to undergo a second surgical procedure, with harvesting done intraorally (mandibular chin or ramus) or extraorally (tibia) [23]. Fortunately, we did not experience any complications at the donor site. The amount of autograft required could be minimized by combining it with an equal amount of β-TCP particles. A point reached in this technique could be how much the simultaneous bone grafting for vertical distraction could contribute to the original distraction technique without sinus lifting alone, or a Le Fort 1 internal bone graft at the one-stage surgery exceeding the discomfort of the secondary surgical access for bone harvesting [23, 29, 30].

Recently, many techniques for accelerating bone regeneration during distraction have been introduced, including growth factors and bone morphogenetic proteins [20, 23, 24, 28]. These primarily induce the host tissue to increase the number of osteoblasts, thereby promoting osteogenesis [24, 25]. However, providing viable osteoblasts or preosteoblastic cells via particulate bone grafting might accelerate the osteoregenerative process, as reported here for sinus lifting [13, 23]. Furthermore, the preserved periosteum around the alveolus could play a major role in this alveolar distraction

technique. The periosteum contains sufficient osteochondrogenic progenitor cells, which have two potential roles in regeneration: (1) they proliferate and differentiate to form new bone or cartilage and (2) release osteoinductive factors to recruit and activate osteoprogenitor cells from the host [14, 19, 23, 24, 28]. In addition, the straining force produced in the distraction technique may initiate the differentiation of periosteal cells into osteogenic cells, inducing the process of bone regeneration, as described previously [19, 21, 23, 24]. Consequently, conserving the periosteum during surgery may be very important to obtain a successful result using this pre-implant technique [14, 25]. Additional clinical studies are needed to determine the predictability of the regenerative outcomes associated with alveolar distraction osteogenesis with simultaneous autogenous bone grafting.

In conclusion, alveolar distraction is an attractive treatment option for increasing the amount of bone and surrounding soft tissues. Combining it with simultaneous sinus lifting is a useful technique for patients with a severely atrophic maxilla requiring dental implant rehabilitation. Satisfactory long-term implant survival for oral rehabilitation was realized.

Acknowledgment

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References

[1] J. I. Cawood and R. A. Howell, "A classification of the edentulous jaws," *International Journal of Oral and Maxillofacial Surgery*, vol. 17, no. 4, pp. 232–236, 1988.

[2] J. I. Cawood, P. J. W. Stoelinga, and T. K. Blackburn, "The evolution of preimplant surgery from preprosthetic surgery," *International Journal of Oral and Maxillofacial Surgery*, vol. 36, no. 5, pp. 377–385, 2007.

[3] J. I. Cawood and R. A. Howell, "Reconstructive preprosthetic surgery. I. Anatomical considerations," *International Journal of Oral and Maxillofacial Surgery*, vol. 20, no. 2, pp. 75–82, 1991.

[4] E. L. Van Der Mark, F. Bierenbroodspot, E. M. Baas, and J. De Lange, "Reconstruction of an atrophic maxilla: comparison of two methods," *British Journal of Oral and Maxillofacial Surgery*, vol. 49, no. 3, pp. 198–202, 2011.

[5] P. J. Boyne and R. A. James, "Grafting of the maxillary sinus floor with autogenous marrow and bone," *Journal of Oral Surgery*, vol. 38, no. 8, pp. 613–616, 1980.

[6] E. Nyström, H. Nilson, J. Gunne, and S. Lundgren, "A 9–14 year follow-up of onlay bone grafting in the atrophic maxilla," *International Journal of Oral and Maxillofacial Surgery*, vol. 38, no. 2, pp. 111–116, 2009.

[7] M. Chiapasco, P. Casentini, and M. Zaniboni, "Bone augmentation procedures in implant dentistry.," *The International Journal of Oral & Maxillofacial Implants*, vol. 24, pp. 237–259, 2009.

[8] H. F. Sailer, "A new method of inserting en++dosseous implants in totally atrophic maxillae," *Journal of Cranio-Maxillo-Facial Surgery*, vol. 17, no. 7, pp. 299–305, 1989.

[9] S. Pelo, G. Gasparini, A. Moro, R. Boniello, and P. F. Amoroso, "Segmental Le Fort I osteotomy with bone grafting in unilateral severely atrophied maxilla," *International Journal of Oral and Maxillofacial Surgery*, vol. 38, no. 3, pp. 246–249, 2009.

[10] S. Gössweiner, F. Watzinger, K. L. Ackerman, and R. Ewers, "Horseshoe Le Fort I osteotomy: an augmentation technique for the severely atrophied maxilla—an eight-year follow-up," *Journal of Long-Term Effects of Medical Implants*, vol. 9, no. 3, pp. 193–202, 1999.

[11] T. Kanno, M. Mitsugi, Y. Furuki, M. Hosoe, H. Akamatsu, and T. Takenobu, "Overcorrection in vertical alveolar distraction osteogenesis for dental implants," *International Journal of Oral and Maxillofacial Surgery*, vol. 36, no. 5, pp. 398–402, 2007.

[12] S. G. Kim, M. Mitsugi, and B. O. Kim, "Simultaneous sinus lifting and alveolar distraction of the atrophic maxillary alveolus for implant placement: a preliminary report," *Implant Dentistry*, vol. 14, no. 4, pp. 344–348, 2005.

[13] H. Katsuyama, Y. Kamiura, M. Mitsugi, and T. Kanno, "Maxillary reconstruction using total alveolar distraction with simultaneous sinus lifting prior to implant placement in a severely atrophic maxillary alveolus," *The Journal of the Kanagawa Odontological Society*, vol. 44, no. 1, pp. 68–73, 2009.

[14] T. Kanno, M. Mitsugi, S. Sukegawa, M. Hosoe, and Y. Furuki, "Computer-simulated bi-directional alveolar distraction osteogenesis," *Clinical Oral Implants Research*, vol. 19, no. 12, pp. 1211–1218, 2008.

[15] W. H. Bell, W. A. Buche, J. W. Kennedy, and J. P. Ampil, "Surgical correction of the atrophic alveolar ridge. A preliminary report on a new concept of treatment," *Oral Surgery Oral Medicine and Oral Pathology*, vol. 43, no. 4, pp. 485–498, 1977.

[16] J. I. Cawood, P. J. W. Stoelinga, and J. J. A. Brouns, "Reconstruction of the severely resorbed (Class VI) maxilla A two-step procedure," *International Journal of Oral and Maxillofacial Surgery*, vol. 23, no. 4, pp. 219–225, 1994.

[17] B. Hoffmeister and K. Wangerin, "Callus distraction technique by an intraoral approach: the floating bone concept," *International Journal of Oral and Maxillofacial Surgery*, vol. 26, no. 1, pp. 76–81, 1997.

[18] S. Uckan, S. G. Haydar, and P. Imirzalinodotogbrevelu, "Repositioning of malpositioned segment during alveolar distraction," *Journal of Oral and Maxillofacial Surgery*, vol. 60, no. 8, pp. 963–965, 2002.

[19] G. A. Ilizarov, "Clinical application of the tension-stress effect for limb lengthening," *Clinical Orthopaedics and Related Research*, no. 250, pp. 8–26, 1990.

[20] T. Kanno, T. Takahashi, W. Ariyoshi, T. Tsujisawa, M. Haga, and T. Nishihara, "Tensile mechanical strain up-regulates Runx2 and osteogenic factor expression in human periosteal cells: implications for distraction osteogenesis," *Journal of Oral and Maxillofacial Surgery*, vol. 63, no. 4, pp. 499–504, 2005.

[21] T. Kanno, M. Mitsugi, M. Hosoe, S. Sukegawa, K. Yamauchi, and Y. Furuki, "Long-term skeletal stability after maxillary advancement with distraction osteogenesis in nongrowing patients," *Journal of Oral and Maxillofacial Surgery*, vol. 66, no. 9, pp. 1833–1846, 2008.

[22] P. J. Boyne and A. S. Herford, "Distraction osteogenesis of the nasal and antral osseous floor to enhance alveolar height," *Journal of Oral and Maxillofacial Surgery*, vol. 62, no. 2, pp. 123–130, 2004.

[23] T. Kanno, M. Mitsugi, S. Sukegawa, and Y. Furuki, "Simultaneous particulated bone graft and vertical alveolar distraction for the posttraumatic atrophic alveolar ridge: report of a case,"

Hospital Dentistry and Oral-Maxillofacial Surgery, vol. 19, no. 2, pp. 55–58, 2007.

[24] T. Kanno, T. Takahashi, T. Tsujisawa, W. Ariyoshi, and T. Nishihara, "Mechanical stress-mediated Runx2 activation is dependent on Ras/ERK1/2 MAPK signaling in osteoblasts," *Journal of Cellular Biochemistry*, vol. 101, no. 5, pp. 1266–1277, 2007.

[25] G. Szabó, L. Huys, P. Coulthard et al., "A prospective multicenter randomized clinical trial of autogenous bone versus β-tricalcium phosphate graft alone for bilateral sinus elevation: histologic and histomorphometric evaluation," *International Journal of Oral and Maxillofacial Implants*, vol. 20, no. 3, pp. 371–381, 2005.

[26] Z. Schwartz, M. Goldstein, E. Raviv, A. Hirsch, D. M. Ranly, and B. D. Boyan, "Clinical evaluation of demineralized bone allograft in a hyaluronic acid carrier for sinus lift augmentation in humans: a computed tomography and histomorphometric study," *Clinical Oral Implants Research*, vol. 18, no. 2, pp. 204–211, 2007.

[27] P. K. Moy, S. Lundgren, and R. E. Holmes, "Maxillary sinus augmentation: histomorphometric analysis of graft materials for maxillary sinus floor augmentation," *Journal of Oral and Maxillofacial Surgery*, vol. 51, no. 8, pp. 857–862, 1993.

[28] Y. Zhang, S. Tangl, C. D. Huber, Y. Lin, L. Qiu, and X. Rausch-Fan, "Effects of Choukroun's platelet-rich fibrin on bone regeneration incombination with deproteinized bovine bone mineral in maxillary sinus augmentation: a histological and histomorphometric study," *Journal of Cranio-Maxillofacial Surgery*, vol. 40, no. 4, pp. 321–328, 2011.

[29] P. J. W. Stoelinga, A. P. Slagter, and J. J. A. Brouns, "Rehabilitation of patients with severe (Class VI) maxillary resorption using Le Fort I osteotomy, interposed bone grafts and endosteal implants: 1–8 years follow-up on a two-stage procedure," *International Journal of Oral and Maxillofacial Surgery*, vol. 29, no. 3, pp. 188–193, 2000.

[30] P. F. Nocini, D. Bertossi, M. Albanese, A. D'Agostino, M. Chilosi, and P. Procacci, "Severe maxillary atrophy treatment with Le Fort I, allografts, and implant-supported prosthetic rehabilitation," *Journal of Craniofacial Surgery*, vol. 22, no. 6, pp. 2247–2254, 2011.

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Review Article

The Maxillary Sinus Membrane Elevation Procedure: Augmentation of Bone around Dental Implants without Grafts—A Review of a Surgical Technique

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Background. Long-term edentulism may in many cases result in resorption of the alveolar process. The sinus lift procedure aims to create increased bone volume in the maxillary sinus in order to enable installation of dental implants in the region. The method is over 30 years old, and initially autogenous bone grafts were used and later also different bone substitutes. Since 1997, a limited number of studies have explored the possibility of a graftless procedure where the void under the sinus membrane is filled with a blood clot that enables bone formation. *Aim*. To describe the evolution of the sinus-lift technique and to review the literature related to the technique with a focus on long-term studies related to the graft-less technique. *Methods*. The electronic database PubMed was searched, and a systematic review was conducted regarding relevant articles. *Results*. A relatively few long-term studies using the described technique were found. However, the technique was described as reliable considering the outcome of the existing studies. *Conclusion*. All investigated studies show high implant survival rates for the graftless technique. The technique is considered to be cost-effective, less time-consuming, and related to lower morbidity since no bone harvesting is needed.

1. Introduction

The aim of this paper is to describe the evolution of the sinus membrane elevation technique, from when the concept of sinus lift was first reported in the literature in 1976, to the present, where bone can be formed around implants placed in the sinus floor using only blood and no other augmentation material. The paper describes the proposed mechanisms that make this technique possible. Since the technique can be less time-consuming regarding periods and involves less morbidity for the patient, it is of interest to review the scientific data of this specific procedure.

2. Strategy of Literature Search on the Graftless Sinus Augmentation (Sinus Membrane Elevation Technique)

The PubMed database was searched to locate studies related to sinus lift surgery in general and sinus lift without the use of graft in specific. Articles were searched from 1997 (the first known study of sinus lift surgery without the use of grafts [1]) to November 2011.

2.1. PubMed Search. The free test words *sinus* and *implant* were used. References in relevant publications were also examined. There were no language restrictions.

2.2. Search in Reference List. The reference list of all included articles was searched for relevant clinical trials.

2.3. Inclusion and Exclusion Criteria. Clinical human studies with a minimum followup of one year or more were included. Retrospective and prospective studies were included. Studies were excluded when bone graft or bone substitutes had been used in relation to sinus lift surgery or when the osteotome technique was used. Due to the low number of relevant articles, lack of randomization or control group did not pose a reason for exclusion.

3. Methods and Review

3.1. Study Selection. The authors (CR and AT) who together performed the study selection were not blinded to the publishing journal, the authors, or the institution. Titles and abstracts were assessed to determine whether an article was meeting the predetermined criteria. When this was not enough to make a decision, the full article was retrieved and examined and a decision on inclusion in the paper was finalized.

Data collection from the included studies was done without blinding to the publishing journal, the authors, or the institution.

Articles investigating and discussing sinus lift surgery, however, not directly related to the described sinus elevation technique, found during the literature search or previously known to the authors, were included for the general overview.

3.2. Background on Sinus Lift. During long-term edentulism, resorption of the alveolar process occurs. Since the maxillary sinus also pneumatises during these circumstances [2], the remaining bone volume can become very small and therefore clinicians and researchers have continuously developed techniques to overcome this problem.

The sinus lift is a surgical procedure aiming to create an increased bone volume in the maxillary sinus floor in order to enable installation of fixtures in the region. The graft in the sinus bottom may be left to heal primarily before implants are placed in a second surgery (2-stage procedure), or implants may be placed simultaneously with the graft (1-stage procedure). The grafts are, however, exposed to a rather substantial degree of resorption [3].

The technique of sinus lift was first orally reported in 1976 by Tatum [4] and first published in 1980 by Boyne and James [5] and subsequently also by Tatum [6]. The surgical procedure has undergone development, and variations exist. Autogenous bone, regarded as the preferred option but with an important drawback of an unpredictable rate of resorption, has later been replaced by many surgeons by the use of bone substitutes [7]. The range of different materials installed and explored in the sinus is impressive. Later works have included trials of rhBMP-2 [8] as well as the use of mesenchymal stem cells (MSCs) in combination with inorganic bovine bone [9]. Long-term followup showing satisfying results regarding implant survival using two commonly used techniques, the lateral sinus floor elevation technique and the osteotome technique, was presented in 2010 by Tetsch et al. They followed 983 patients with 2190 implants over a time period of 176 months using Kaplan-Meier analysis and showed an implant survival rate of 97,1% [10].

3.3. Surgical Technique. The basic surgical principle and technique have not significantly changed. Intraoral access to the maxillary sinus is gained through the oral mucosa in the region of the anterior maxillary sinus wall. A bony window is prepared, and the sinus membrane is dissected and lifted from the sinus floor in order to enable insertion of a graft alone, or around installed implants to facilitate bone formation in the created secluded space. The bony window has mostly been kept attached to the membrane and elevated superiorly.

The sinus lift surgical technique has developed over time, and several minor variations now exist. The surgery is commonly performed under local anaesthesia and sedation.

3.4. Sinus Lift Surgery with Simultaneous Installation of Implants without the Use of Grafts. For over 30 years, extensive experimental and clinical research has been undertaken based on the idea of necessity of grafting the maxillary sinus and great industrial investments have been made into developing products for this area [11]. Eventually, the idea of a graftless augmentation of the maxillary sinus has evolved (Figures 1, 2, 3, and 4).

Boyne presented experimental results from a primate study in 1993 in which implants were left without grafts to protrude 5 mm into the sinus floor and experienced bone formation [12].

In 1997, Ellegaard and colleagues described a technique whereby 80 fixtures were installed in the posterior maxilla in 24 periodontally compromised patients, of which 38 involved surgery of the maxillary sinus [1]. A circular fenestration was prepared in the lateral antral wall, at least 5 mm superiorly to the estimated maxillary sinus floor. Thereafter, the sinus membrane was dissected around the fenestration as well as from the floor of the maxillary sinus. The implants were otherwise conventionally installed through the remaining alveolar crest. The sinus membrane was left resting on the installed protruding implants, creating a secluded void filled with blood, forming around and between the implants. The repositioned flap covered the prepared window in the antral wall, and no barrier membrane was placed over the bony defect created for entrance to the sinus. In the study, a note was made of the newly formed bone seen around the upper part of the implants protruding up into the sinus cavity on follow-up radiographs. After 5-6 months of healing, the implants were functionally loaded. Of the 38 implants in the maxillary sinus, 35 were successfully integrated during the follow-up time of 27 months.

In 2001, a report at the yearly convention of the Swedish Dental Association by Lundgren included reference to a patient who was planned to initially have a mucosal cyst of the maxillary sinus removed with subsequent augmentation of the maxillary sinus to facilitate implant placement [13]. The cyst was removed through a prepared bony window in the lateral antral wall, and the ruptured mucosa was sutured. The bony window was then replaced and a space secluded by bony walls, and sinus membrane had been created. After 3 months of healing, clear signs of bone formation were observed.

Inspired by this outcome, Lundgren et al. presented a study in 2004 where 19 implants were installed in 12 maxillary sinuses [14]. The bony window was dissected from the underlying sinus membrane and placed in sterile saline solution. The sinus membrane was then dissected from the floor of the maxillary sinus to create the secluded space for the implants. The implants were installed, the bony window was replaced, and the flap was sutured into position. During

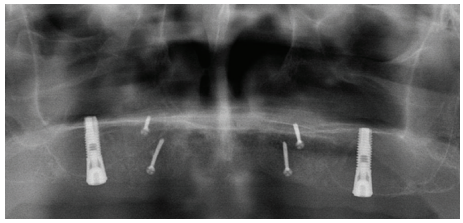

Figure 1: One-week postoperative baseline panoramic view over reconstructed atrophic maxilla. Block bone grafts attached with titanium screws in the anterior and sinus membrane elevation performed in the maxillary sinus floor. Notice the minute amount of bone (1-2 mm) in the sinus floor. The conical shape of the marginal part of the implant represents 5 mm.

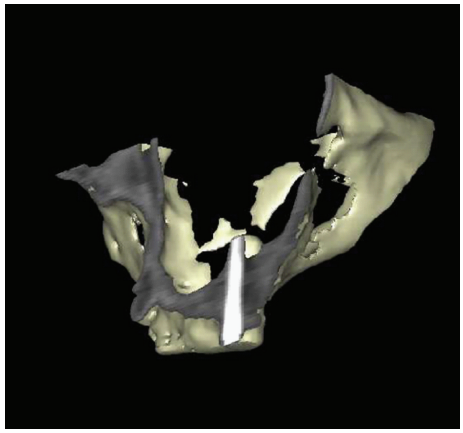

Figure 2: 3 D reconstruction of CT scan from the same patient as in Figure 1 six months postoperatively, left side. Bone is formed around implants in the maxillary sinus floor.

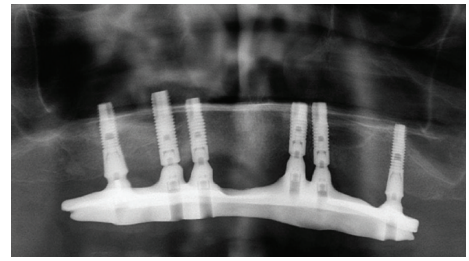

Figure 3: Situation 3 years postoperatively.

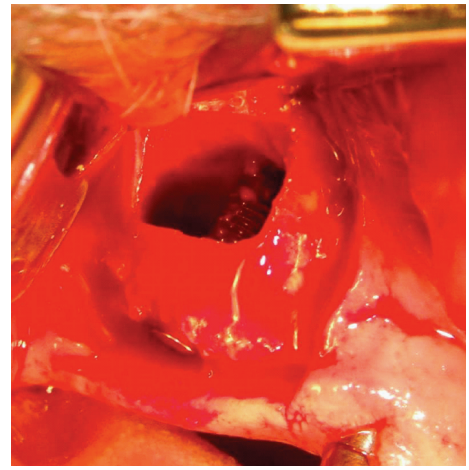

Figure 4: Surgical technique. An osteotomy is performed, and the bony window is temporarily removed. The installed implant is here seen elevating the sinus membrane, and, after blood has filled the created compartment around the implant, the bony window is thereafter replaced.

the follow-up period and at the final evaluation after 12 months, all implants showed stability and bone formation in the maxillary sinus.

Ellegaard et al. presented a followup of the study from 1997 [1] in which all patients treated during 1990–2002 were examined [15]. Of 262 implants, 131(50%) had been placed in the maxillary sinus. The conclusion of the study was that implants in periodontally compromised patients could be installed in the maxillary sinus with success rate similar to that of conventional implants over a long follow-up period. In a study by Thor from 2007, 20 patients who had received 44 Astra Tech implants in the maxillary sinus were followed annually for up to four years (mean 27.5 months and range 14–45 months) [17]. A sinus lift procedure was considered when the subantral bone was 5 mm or less (mean residual bone height 4.6 mm, range 2.0–9.0 mm). The survival rate of implants evaluated after an average time of 27.5 months was 97.7%. The average amount of bone formation in the maxillary sinus was 6.5 mm. It was concluded that greater bone formation was related to longer implants installed and lower preoperative bone height in the subantral region.

Chen et al. published a study in 2007 of 47 implants in 33 patients evaluated after 2 years [16]. Unlike Ellegaard et al. who removed bone tissue in the region to gain access to the maxillary sinus, the sinus mucosal membrane was here elevated with the bony window still attached to the membrane (folded up into the sinus) and the implants served as tentpoles and space holders. No graft except blood was used, and preoperative bone of 7.5 ± 2.1 mm was reported (measured on panoramic X-ray). After 6 months of healing there were no failures and the average bone gain was 4.5 mm.

Hatano et al. presented a case series of 6 patients in whom successful new bone formation was found in all sinuses after a healing period of 6 months for the implants and an observation period of up to 34 months [18]. In addition, blood clot formation in the compartments around the implants was secured via an injection of peripheral blood and medical glue for closure of the potential gap in the bony window of the osteotomy. In a study by Sohn et al. from 2008, 21 implants inserted in 10 patients were evaluated after 6 months [19]. All implants remained stable during the study period, and bone formation was found in both radiographic and histologic evaluations.

Balleri et al. presented a study where 28 Astra Tech implants had been evaluated after one year [20]. The average baseline bone level was 6.2 mm. No implants were, lost and the average bone gain was 5.5 mm. It was concluded that the bone gain was less than the average lift of the membrane lift

(8.2 mm) and that the length of the implants was not related to the amount of gained bone. Also, the bone regeneration was less at the distal aspect of the most posterior-placed implant which could be explained by the theory that this surface was more exposed for the pneumatisation of the sinus.

Jensen and Terheyden recently reviewed bone augmentation techniques related to implant treatment as described by the 4:th ITI Consensus Conference from 2009 [23] and identified 179 sinus augmentation studies using the lateral window technique. Of the 47 studies that fulfilled the inclusion criteria, only three presented data on the graftless technique considered in this paper [14, 16, 17]. All three studies report survival rates (evaluation period of 12–27.5 months) within the range of 97.7% to 100% (110 implants in 63 patients). In their concluding remarks and despite the low number of extant studies, Jensen and Terheyden considered this technique to be a well-documented procedure for maxillary sinus floor elevation.

Recently in 2011, Lin et al. presented a study where 44 patients with 80 implants in the maxillary sinus were followed for five years after delivery of the prosthesis [21]. The survival rate was 100% after five years. The average residual bone height was 5.1 mm before treatment and at least 3 mm was required for inclusion. The average gained bone height after five years was 7.4 mm in the sinus. Also, in 2011, Cricchio et al. presented a study where 189 implants had been installed in the maxillary sinus in 84 patients [22]. A two-stage technique was used in the majority of the cases, 78. The range of the followup was 1–6 years. The survival rate was 98,7%, and the average new bone formation was 5.3 mm after 6 months of healing. Resonance Frequency Analyses showed adequate primary stability and small changes over time.

A summary of studies of sinus lift with blood only is presented in Table 1.

3.5. Studies Where the Reported Bone Height Is Low under the Maxillary Sinus. Lundgren et al. [14] reported results from patients with mean bone levels of 7 mm (range 4–10 mm) and the use of Brånemark type implants (19 implants, Ø 3.75 mm, TiUnite, Nobel Biocare, Gothenburg, Sweden). Ellegaard et al. reported on patients with as little as 3 mm [1], and Sohn et al. reported on cases in their paper where pretreatment bone levels varied from 1–9 mm [19]. The paper by Chen et al. included patients with at least 5 mm (mean of 7.5 mm ± 2.1 mm). Primary stability was easily achieved in the remaining bone [16]. Hatano et al. reported on 6 patients in whom the thickness of the basal bone ranged from 2 to 10 mm preoperatively, and Brånemark type implants were used in a standard implant drilling protocol [24].

Thor et al. [17] included patients with a minimum of 2 mm of remaining bone. The implant installation protocol was therefore altered to achieve primary stability. By using a conical implant with microthreads over the superior 5 mm, sufficient primary stability was achieved in the remaining bone (44 implants, Ø 4.5 mm and 5.0 mm, Fixture Microthread ST, Astra Tech AB, Mölndal, Sweden). In order to optimize the primary stability of the implant, a "press-fit" effect was achieved due to a modified drilling protocol. The implant site was thus less widened with the burr than the standard recommended size of the site. The implant was allowed to engage enough in even minimal amounts of remaining subantral bone. The length of the implant was also important as a longer implant may be able to engage the medial part of the sinus wall for apical support for the implant [17]. The relation between primary stability and the conical shape and design of this type of implant had also been pointed out earlier by Norton [25].

3.6. Bone Formation. After the sinus-lift surgery as described above, there are several local factors that may be important to the anticipated bone formation. Anatomical, prosthetic, surgical/technical, and patient-related variations and difficulties have to be evaluated in every case and may influence the outcome.

The newly formed bone around an implant installed with this technique is repeatedly seen on panoramic radiographs and resembles the bone seen around natural teeth in the maxillary sinus region. The first histological evidence to describe this special bone formation was published in 2006 by Palma et al. [26], where blood alone or autogenous bone graft in a sinus lift study in four primates were compared. Both test and control sides revealed no differences in bone formation, but the importance of the implant surface characteristics became evident as well as the bone forming capacity of the Schneiderian mucous membrane. More bone was formed on the oxidized modified surface than the control turned surface. In a similar way, more bone was also observed forming in the nonaugmented sides with blood only, along the top of the implants where the sinus mucosa was resting. One very important point may be that the grafted autogenous bone had to be replaced before new bone formation could occur in comparison with direct formation of bone from the blood clot. This event perhaps gives rise to "blocking" of the bone formation by the inflammation and removal that needs to take place in replacing old bone with new.

Recently, Kim et al. used a dog model to study the bone formation around implants under the sinus membrane protruding 8 mm into the maxillary sinus. The authors found extensive collapse of the clot and membrane resulting in rather minimal formation of new bone. They recommended that this method be used in cases when only a small amount of new bone was needed around implants placed simultaneously in the maxillary sinus floor [27].

The tenting of the sinus mucous membrane by the implants in the sinus floor is, of course, important for the clot formation and subsequent bone formation. The tissue formed by the clot under the elevated membrane is an unstable stage in the bone formation process, as also discussed by Xu et al. 2005 [28]. In their rabbit study, the sinus membranes were elevated and a clot was allowed to form; the newly formed clot decreased in volume significantly during the first weeks of healing, indicating the importance of a space holder such as an implant or other device. Sul et al. [29] evaluated different lengths of installed implants into the

Table 1: Summary of published studies (1997–2011) of sinus lift with blood only with a follow-up of one year or more.

Study	number of patients	number of implants	Implant type	One-stage/ two-stage	Implant surface	Followup (mo)	Baseline bonelevel (mm)	Bone gain (mm)	Perforation of sinus (%)	Survival (%)
Ellegaard et al. [1]	24	26	Astra	Two-stage	TiO2-blasted	29,9 (average)	≥3	"Bone gain in most of the implants"	"In a few cases away from the implant site"	95%
		12	ITI	Two-stage	Solid screw	25,3 (average)				86%
Lundgren et al. [14]	10	19	TiUnite	Two-stage	Anodic oxidized	12	7 (range 4–10)	"In all patients bone formation was seen"	Perforation is described but ND	100%
Ellegaard et al. [15]	68	59	Astra	Two-stage	TiO2-blasted	64.2 (0–128)	≥3	ND	ND	10 yrs 85.4%
		72	ITI	One-stage	Solid screw	57.5 (0–143)				10 yrs 79.9%
Chen et al. [16]	33	18	ITI and Swissplus	One-stage	ND	24	7.5 ± 2.1	4.5 (range 3–9)	0	100%
		29	Frialit-2	Two-stage	ND					
Thor et al. [17]	20	44	Astra	Two-stage	TiO2-blasted	14–45	range 2–9	6.51 (range 4–10)	41	97.7%
Hatano et al. [18]	6	14	TiUnite	Two-stage	Anodic oxidized	12–34	range 2–10	ND	0	92,9%
Sohn et al. [19]	10	21	Seven	Two-stage	Sand-blasted and acid-etched	8.5 (range 6–12)	5 (range 1–9)	"All cases revealed bone formation"	Perforation is described but ND	100%
Balleri et al. [20]	15	28	Astra	Two-stage	TiO2-blasted	12	6.2 (range 4–10)	5.5 (range 3–8.2)	3 cases unknown number of sinuses	100%
Lin et al. [21]	44	80	ITI, Swissplus and Frialit-2	Mixed	ND	60	5.1 (range 4.6–6.6)	7.4 (range 5.7–9.1)	ND	100%
Cricchio et al. [22]	84	179	TiUnite	Two-stage	Anodic oxidized	12–72	5,7 (range 3.4–8)	5,2 (range 3–7.4)	11	99%

ND: no data.

sinus cavity. They could see no difference on bone formation using 4 and 8 mm implants.

These studies question the bone forming capability of the technique. The new bone formed with this technique is seen in the marginal part around the implants. This resembles the situation in the human anatomy of the sinus floor with protruding roots of the teeth, often covered only by a thin layer of bone.

Cricchio et al. explored this problem in placing a resorbable space-making device in the sinus floor in six primates for a two-stage procedure, aiming at later implants installation. Even though the device had shortcomings regarding stability, the device was found histologically not to trigger any inflammation and succeeded in enabling formation of bone seen after 6 months [30]. Johansson et al. recently reported on the use of a hollow hydroxyapatite space-maintaining device in three patients for preventing the clot collapsing and enabling bone regeneration and subsequent implant installation [31].

Lundgren suggests that the sinus membrane should be sutured to the superior part of the bony window after elevation to prevent collapse of the membrane and to enable stable clot formation [14]. Other workers did not perform this manipulation in their studies, and the question remains to be solved whether this is significantly important or not [1, 24, 32].

There is also a difference in technique between studies, as some remove and replace the bony window and some keep it attached to the sinus mucosa elevating it up- and inwards into the maxillary sinus. In the study by Sohn et al. the bony window was replaced on one side by a resorbable membrane in 5 patients. In the other 5 patients, the bony window was used to seal the lateral wall of the sinus. No differences in outcome were reported. The technique using the bony window was shown to take less time and was also a less expensive solution for sealing the lateral wall [19].

Srouji and coauthors recently attempted to explain the formation of bone beneath the sinus membrane on the maxillary sinus floor by exploring the osteogenic potential of the Schneiderian maxillary sinus membrane as an explanation for the clinically observed induction of bone formation. In their first paper from 2009, human samples of the membrane were cultured and studied histologically [33]. Flow cytometry analysis proved the cells capable of inducing and expressing different osteogenic markers including alkaline phosphatase, bone morphogenic protein-2, osteopontin, osteonectin, and osteocalcin and of further mineralizing their extracellular matrix. Cultured cells and a ceramic mix (HA/β-TCP) were combined into a fibrin clot and subcutaneously implanted in a thymic nude mice. Bone of human origin was seen being formed over the surface of the carrier particles after 8 weeks of healing. The paper left the remaining question of where exactly in the cellular compartments of the Schneiderian membrane the osteogenic progenitor cells were located. The deeper layers of the membrane, with periosteum-like structure, and microvascular cells within the membrane may both serve as sources for the osteogenic capacity of the membrane and subsequent bone formation. In the second paper, human Schneiderian membrane was folded around a fibrin clot, which was then transplanted into mice [34]. As a result, ectopic bone formation was seen in the pocket. Dispase digestion was used to eliminate the epithelial layer, leaving the lamina propria to be transplanted subcutaneously with the periosteal layers facing each other. The scaffold, in this case a fibrin clot, was shown to be important for bone formation together with the osteogenic cells, as the absence of a fibrin clot resulted in significantly less formation (as did fibrin only as control with minimal or no formation of new ectopic bone).

The technique described requires a more invasive surgical approach than the transalveolar osteotome technique originally presented by Summers [35, 36]. In the paper by Jensen and Terheyden, 16 studies of transalveolar sinus floor elevation were identified. Of these studies, three reported data on the technique performed without the introduction of grafting material [37–39] using only blood around the implants elevating the sinus mucosa**.** After up to 25 months of loading, the median survival rate was 96% (186 implants in 110 patients). It could be argued that the transalveolar technique would be the method of choice due to its relative simplicity and low morbidity. On the other hand, the technique with the lateral window approach offers the possibility of controlling the sinus membrane and allows a wide dissection of the sinus membrane, hence minimizing the risk of sinus membrane perforations. Long implants are also able to be installed with a good overview and control through the bony window, eventually resulting in higher bone formation along these implants [17]. Additionally, the lateral window technique combined with use of a favourable implant design offers the possibility of treating cases with bone levels as low as 1-2 millimetres [16, 17]. Complete edentulous cases may therefore be treated with multiple sinus implants for a fixed restoration without the use of previous grafting. No studies comparing these two techniques could be identified in the literature so far, neither experimental nor clinical.

3.7. Potential Difficulties and Complications. The membrane elevation technique without the use of grafting materials, as described in this paper, is not initially an easy technique as it may require adaptation from the more common technique using grafts and where the bony window is prepared with a burr [1, 40]. The bony window needs to be removed from the sinus membrane, and piezosurgery may be advantageous when performing this stage in the procedure. However, with results comparable with routine sinus lift techniques, the membrane elevation technique displays possible advantages. The problems encountered, such as sinus septae and membrane perforations, are still factors that need to be taken in consideration.

The maxillary sinus is often divided into compartments by complete, or incomplete, bony septae. These must be accounted for in the surgical planning of the procedure and are best visualised by preoperative CT scanning [41]. The premolar region is also the location of most septae in atrophic edentulous ridges, and it has been shown that septae in dentate maxillas are of greater height than in edentulous

patients [42]. When planning surgery, these septae may not only be a problem during the procedure but may also be helpful in achieving satisfactory primary stability for the implant when placed in these septae of the basal bone of the maxillary atrophied crest. The use of a wide bony window for access to the sinus mucosa is important. These anatomical features, septae and a fragile mucosa, may develop into lacerations of the sinus mucosa during the dissection, which needs to be addressed to complete the procedure. Suturing of the mucosa to the superior part of the bony window after extensive dissection has been recommended but not yet evaluated in controlled studies [14, 17].

Jung et al. evaluated the significance of perforation of the Schneiderian membrane during implant installation in the sinus floor [43]. Implants were allowed to penetrate up into the maxillary sinuses of eight dogs. The implants were placed so that 2, 4, or 8 mm of the implant surface was uncovered by bone in the bottom of the sinus, as observed through the bone window and the intentionally made laceration of the membrane. The dogs were killed after 6 months of healing. No signs of sinus disorder were seen in the dogs, also verified with CT scans after six months.

Implants penetrating with 2 mm into the sinus showed overgrowth with a new membrane. This new covering membrane (called a functional barrier) was not seen in the 4 and 8 mm groups, but the membrane was there found, without inflammatory signs, more to the base of the well-osseointegrated implants with direct attachment to the titanium implant surface.

In a retrospective study on humans, Jung et al. reported a similar lack of complications as seen in dogs. Nine patients with 23 implants inserted in the maxillary sinus were evaluated for sinus complications 6–10 months after insertion. No clinical signs of sinusitis were found although CT scans showed postoperative mucous thickening around 14 of the 23 implants [44]. If a perforation occurs, it might not be devastating to the operation.

In a prospective study of 100 cases, Wallace et al. found that the complication of perforations during surgery could be significantly reduced with the piezotechnique compared to the use of rotating instruments. The authors also pointed out that the perforations occurred during the hand instrumentation phase and not during the use of piezosurgery performed osteotomies [45].

The time needed for adequate maturation of new bone prior to loading of implants placed in low initial bone height is not well understood and needs further study.

4. Conclusion

The technique presented offers a method of augmenting the posterior maxilla when remaining bone levels in the edentulous region are low. The technique is now recognized as reliable and established [23, 46, 47]. The innate osteogenic potential of the Schneiderian membrane may be a main reason for the successful formation of bone with this augmentation technique. It is cost-effective as it is graftless, less time-consuming, and comparatively inexpensive. Morbidity is lower than autogenous bone grafting since no extra graft material is needed.

Conflict of Interests

The authors claim to have no financial interest, directly or indirectly, in any entity that is commercially related to the products mentioned in this paper. The authors report that no conflict of interest exists.

References

[1] B. Ellegaard, J. Kølsen-Petersen, and V. Baelum, "Implant therapy involving maxillary sinus lift in periodontally compromised patients," *Clinical Oral Implants Research*, vol. 8, no. 4, pp. 305–315, 1997.

[2] S. Asai, Y. Shimizu, and K. Ooya, "Maxillary sinus augmentation model in rabbits: effect of occluded nasal ostium on new bone formation," *Clinical Oral Implants Research*, vol. 13, no. 4, pp. 405–409, 2002.

[3] B. Johansson, A. Grepe, K. Wannfors, and J. M. Hirsch, "A clinical study of changes in the volume of bone grafts in the atrophic maxilla," *Dentomaxillofacial Radiology*, vol. 30, no. 3, pp. 157–161, 2001.

[4] O. H. Tatum, "Lecture presented to the Alabama Implant Congress," 1976.

[5] P. J. Boyne and R. A. James, "Grafting of the maxillary sinus floor with autogenous marrow and bone," *Journal of Oral Surgery*, vol. 38, no. 8, pp. 613–616, 1980.

[6] H. Tatum Jr., "Maxillary and sinus implant reconstructions," *Dental clinics of North America*, vol. 30, no. 2, pp. 207–229, 1986.

[7] M. Hallman and A. Thor, "Bone substitutes and growth factors as an alternative/complement to autogenous bone for grafting in implant dentistry," *Periodontology 2000*, vol. 47, no. 1, pp. 172–192, 2008.

[8] R. G. Triplett, M. Nevins, R. E. Marx et al., "Pivotal, randomized, parallel evaluation of recombinant human bone morphogenetic protein-2/absorbable collagen sponge and autogenous bone graft for maxillary sinus floor augmentation," *Journal of Oral and Maxillofacial Surgery*, vol. 67, no. 9, pp. 1947–1960, 2009.

[9] P. Voss, S. Sauerbier, M. Wiedmann-Al-Ahmad et al., "Bone regeneration in sinus lifts: comparing tissue-engineered bone and iliac bone," *British Journal of Oral and Maxillofacial Surgery*, vol. 48, no. 2, pp. 121–126, 2010.

[10] J. Tetsch, P. Tetsch, and D. A. Lysek, "Long-term results after lateral and osteotome technique sinus floor elevation: a retrospective analysis of 2190 implants over a time period of 15 years," *Clinical oral implants research*, vol. 21, no. 5, pp. 497–503, 2010.

[11] R. E. Marx, E. R. Carlson, R. M. Eichstaedt, S. R. Schimmele, J. E. Strauss, and K. R. Georgeff, "Platelet-rich plasma: growth factor enhancement for bone grafts," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 85, no. 6, pp. 638–646, 1998.

[12] P. J. Boyne, "Analysis of performance of root-form endosseous implants placed in the maxillary sinus," *Journal of Long-Term Effects of Medical Implants*, vol. 3, no. 2, pp. 143–159, 1993.

[13] S. Lundgren, S. Andersson, and L. Sennerby, "Spontaneous bone formation in the maxillary sinus after removal of a cyst:

coincidence or consequence?" *Clinical Implant Dentistry and Related Research*, vol. 5, no. 2, pp. 78–81, 2003.

[14] S. Lundgren, S. Andersson, F. Gualini, and L. Sennerby, "Bone reformation with sinus membrane elevation: a new surgical technique for maxillary sinus floor augmentation," *Clinical Implant Dentistry and Related Research*, vol. 6, no. 3, pp. 165–173, 2004.

[15] B. Ellegaard, V. Baelum, and J. Kølsen-Petersen, "Non-grafted sinus implants in periodontally compromised patients: a time-to-event analysis," *Clinical Oral Implants Research*, vol. 17, no. 2, pp. 156–164, 2006.

[16] T. W. Chen, H. S. Chang, K. W. Leung, Y. L. Lai, and S. Y. Kao, "Implant placement immediately after the lateral approach of the trap door window procedure to create a maxillary sinus lift without bone grafting: a 2-year retrospective evaluation of 47 implants in 33 patients," *Journal of Oral and Maxillofacial Surgery*, vol. 65, no. 11, pp. 2324–2328, 2007.

[17] A. Thor, L. Sennerby, J. M. Hirsch, and L. Rasmusson, "Bone formation at the maxillary sinus floor following simultaneous elevation of the mucosal lining and implant installation without graft material: an evaluation of 20 patients treated with 44 Astra Tech implants," *Journal of Oral and Maxillofacial Surgery*, vol. 65, no. 7, pp. 64–72, 2007.

[18] N. Hatano, L. Sennerby, and S. Lundgren, "Maxillary sinus augmentation using sinus membrane elevation and peripheral Venous blood for implant-supported rehabilitation of the atrophic posterior maxilla: case series," *Clinical Implant Dentistry and Related Research*, vol. 9, no. 3, pp. 150–155, 2007.

[19] D. S. Sohn, J. S. Lee, M. R. Ahn, and H. I. Shin, "New bone formation in the maxillary sinus without bone grafts," *Implant Dentistry*, vol. 17, no. 3, pp. 321–331, 2008.

[20] P. Balleri, M. Veltri, N. Nuti, and M. Ferrari, "Implant placement in combination with sinus membrane elevation without biomaterials: a 1-year study on 15 patients," *Clinical Implant Dentistry and Related Research*. In press.

[21] I. C. Lin, A. M. Gonzalez, H. J. Chang, S. Y. Kao, and T. W. Chen, "A 5-year follow-up of 80 implants in 44 patients placed immediately after the lateral trap-door window procedure to accomplish maxillary sinus elevation without bone grafting.," *The International Journal of Oral & Maxillofacial Implants*, vol. 26, no. 5, pp. 1079–1086, 2011.

[22] G. Cricchio, L. Sennerby, and S. Lundgren, "Sinus bone formation and implant survival after sinus membrane elevation and implant placement: a 1- to 6-year follow-up study," *Clinical Oral Implants Research*, vol. 22, no. 10, pp. 1200–1212, 2011.

[23] S. S. Jensen and H. Terheyden, "Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials," *The International Journal of Oral & Maxillofacial Implants*, vol. 24, pp. 218–236, 2009.

[24] N. Hatano, L. Sennerby, and S. Lundgren, "Maxillary sinus augmentation using sinus membrane elevation and peripheral Venous blood for implant-supported rehabilitation of the atrophic posterior maxilla: case series," *Clinical Implant Dentistry and Related Research*, vol. 9, no. 3, pp. 150–155, 2007.

[25] M. R. Norton, "Marginal bone levels at single tooth implants with a conical fixture design. The influence of surface macro- and microstructure," *Clinical Oral Implants Research*, vol. 9, no. 2, pp. 91–99, 1998.

[26] V. C. Palma, O. Magro-Filho, J. A. De Oliveira, S. Lundgren, L. A. Salata, and L. Sennerby, "Bone reformation and implant integration following maxillary sinus membrane elevation: an experimental study in primates," *Clinical Implant Dentistry and Related Research*, vol. 8, no. 1, pp. 11–24, 2006.

[27] H. R. Kim, B. H. Choi, F. Xuan, and S. M. Jeong, "The use of autologous venous blood for maxillary sinus floor augmentation in conjunction with sinus membrane elevation: an experimental study," *Clinical Oral Implants Research*, vol. 21, no. 3, pp. 346–349, 2010.

[28] H. Xu, Y. Shimizu, and K. Ooya, "Histomorphometric study of the stability of newly formed bone after elevation of the floor of the maxillary sinus," *British Journal of Oral and Maxillofacial Surgery*, vol. 43, no. 6, pp. 493–499, 2005.

[29] S. H. Sul, B. H. Choi, J. Li, S. M. Jeong, and F. Xuan, "Effects of sinus membrane elevation on bone formation around implants placed in the maxillary sinus cavity: an experimental study," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 105, no. 6, pp. 684–687, 2008.

[30] G. Cricchio, V. C. Palma, P. E. Faria et al., "Histological outcomes on the development of new space-making devices for maxillary sinus floor augmentation," *Clinical Implant Dentistry and Related Research*, vol. 13, no. 3, pp. 224–230, 2011.

[31] L. Johansson, S. Isaksson, E. Adolfsson et al., "Bone regeneration using a hollow hydroxyapatite space-maintaining device for maxillary sinus floor augmentation—a clinical pilot study," *Clinical Implant Dentistry and Related Research*. In press.

[32] A. Thor, V. Franke-Stenport, C. B. Johansson, and L. Rasmusson, "Early bone formation in human bone grafts treated with platelet-rich plasma: preliminary histomorphometric results," *International Journal of Oral and Maxillofacial Surgery*, vol. 36, no. 12, pp. 1164–1171, 2007.

[33] S. Srouji, T. Kizhner, D. Ben David, M. Riminucci, P. Bianco, and E. Livne, "The schneiderian membrane contains osteoprogenitor cells: In vivo and in vitro study," *Calcified Tissue International*, vol. 84, no. 2, pp. 138–145, 2009.

[34] S. Srouji, D. Ben-David, R. Lotan, M. Riminucci, E. Livne, and P. Bianco, "The innate osteogenic potential of the maxillary sinus (Schneiderian) membrane: an ectopic tissue transplant model simulating sinus lifting," *International Journal of Oral and Maxillofacial Surgery*, vol. 39, no. 8, pp. 793–801, 2010.

[35] R. B. Summers, "A new concept in maxillary implant surgery: the osteotome technique," *Compendium*, vol. 15, no. 2, pp. 152–162, 1994.

[36] R. Nedir, N. Nurdin, S. Szmukler-Moncler, and M. Bischof, "Placement of tapered implants using an osteotome sinus floor elevation technique without bone grafting: 1-year results," *The International Journal of Oral & Maxillofacial Implants*, vol. 24, no. 4, pp. 727–733, 2009.

[37] A. A. Winter, A. S. Pollack, and R. B. Odrich, "Placement of implants in the severely atrophic posterior maxilla using localized management of the sinus floor: a preliminary study," *International Journal of Oral and Maxillofacial Implants*, vol. 17, no. 5, pp. 687–695, 2002.

[38] B. Leblebicioglu, S. Ersanli, C. Karabuda, T. Tosun, and H. Gokdeniz, "Radiographic evaluation of dental implants placed using an osteotome technique," *Journal of Periodontology*, vol. 76, no. 3, pp. 385–390, 2005.

[39] R. Fermergård and P. Åstrand, "Osteotome sinus floor elevation and simultaneous placement of implants—a 1-year retrospective study with astra tech implants," *Clinical Implant Dentistry and Related Research*, vol. 10, no. 1, pp. 62–69, 2008.

[40] A. Thor, "TiOblast and OsseoSpeed implants in sinus lift surgery," *Applied Osseointegration Research*, vol. 7, pp. 17–25, 2008.

[41] M. J. Kim, U. W. Jung, C. S. Kim et al., "Maxillary sinus septa: prevalence, height, location, and morphology. A reformatted

computed tomography scan analysis," *Journal of Periodontology*, vol. 77, no. 5, pp. 903–908, 2006.

[42] G. Krennmair, C. W. Ulm, H. Lugmayr, and P. Solar, "The incidence, location, and height of maxillary sinus septa in the edentulous and dentate maxilla," *Journal of Oral and Maxillofacial Surgery*, vol. 57, no. 6, pp. 667–672, 1999.

[43] J. H. Jung, B. H. Choi, S. J. Zhu et al., "The effects of exposing dental implants to the maxillary sinus cavity on sinus complications," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 102, no. 5, pp. 602–605, 2006.

[44] J. H. Jung, B. H. Choi, S. M. Jeong, J. Li, S. H. Lee, and H. J. Lee, "A retrospective study of the effects on sinus complications of exposing dental implants to the maxillary sinus cavity," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 103, no. 5, pp. 623–625, 2007.

[45] S. S. Wallace, Z. Mazor, S. J. Froum, S. O. Cho, and D. P. Tarnow, "Schneiderian membrane perforation rate during sinus elevation using piezosurgery: clinical results of 100 consecutive cases," *International Journal of Periodontics and Restorative Dentistry*, vol. 27, no. 5, pp. 413–419, 2007.

[46] M. Esposito, M. G. Grusovin, J. Rees et al., "Effectiveness of sinus lift procedures for dental implant rehabilitation: a cochrane systematic review," *European journal of oral implantology*, vol. 3, no. 1, pp. 7–26, 2010.

[47] M. Esposito, M. G. Grusovin, J. Rees et al., "Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus," *Cochrane Database of Systematic Reviews*, vol. 3, Article ID CD008397, 2010.

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Review Article

Postextraction Alveolar Ridge Preservation: Biological Basis and Treatments

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Following tooth extraction, the alveolar ridge undergoes an inevitable remodeling process that influences implant therapy of the edentulous area. Socket grafting is a commonly adopted therapy for the preservation of alveolar bone structures in combination or not with immediate implant placement although the biological bases lying behind this treatment modality are not fully understood and often misinterpreted. This review is intended to clarify the literature support to socket grafting in order to provide practitioners with valid tools to make a conscious decision of when and why to recommend this therapy.

1. Introduction

Anatomical changes and physiological processes taking over tooth extraction were studied in the past [1–3]; however, since the introduction of dental implants in modern odontology, these issues and the prevention of edentulous jaw atrophy have become very hot topics. The survival of implants and their ability to provide adequate function and esthetic are strictly correlated with their proper positioning in relation to the alveolar housing, the neighboring teeth and the occluding dentition. It is thus easily understood the tremendous effort that has been used by many researchers and practitioners in reducing this unavoidable modeling and remodeling process. This article goes through the biological basis for socket augmentation procedure and the available treatment options to prevent edentulous ridge atrophy.

2. Alveolar Ridge Remodeling

Maxillary and mandibular bony complexes are composed by several anatomical structures with a proper function, composition, and physiology: (i) basal bone that develops together with the overall skeleton, and forms the body of mandible and maxilla; (ii) alveolar process that develops following tooth eruption and contains the tooth alveolus; (iii) the bundle bone that lines the alveolar socket, extends coronally forming the crest of the buccal bone, and makes part of the periodontal structure as it encloses the external terminations of periodontal fibres (Sharpey's fibers).

After tooth extraction, bundle bone appears to be the first bone to be absorbed [4–6] whereas alveolar bone is gradually absorbed throughout life [7, 8]. The remodeling process results in a ridge morphology reduced in vertical height and more palatal in relation to the original tooth position [1–3, 9].

Studies from another research group suggest bone resorption to occur in 2 phases (see Figure 1). During the first phase, bundle bone is rapidly resorbed and replaced with woven bone leading to a great reduction in bone height especially in the buccal aspect of the socket, as its crestal portion is comprised solely of bundle bone [10]. The buccal plate experiences more resorption even because it is generally thinner, averaging 0.8 mm in anterior teeth and 1.1 mm in premolar sites [11]. *In-vitro* animal studies have demonstrated the osteogenic potential of PDL-derived cells [12, 13] although the role of bundle bone in providing cells for the regeneration of new bone has been more recently challenged [14] as new bone formation appears to initiate from

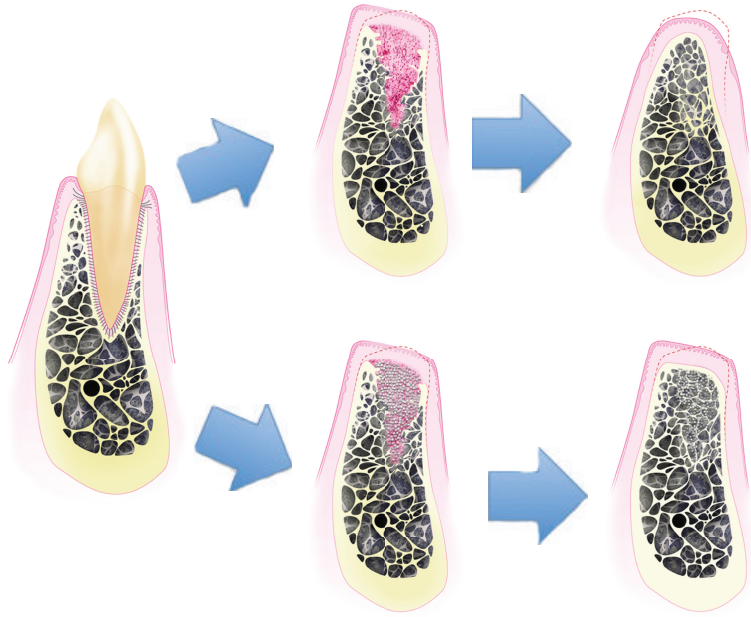

Figure 1: Healing of the extraction socket with and without socket grafting. When socket grafting is not adopted, major alveolar ridge resorption occurs. In a first phase, initially the blood clot, subsequently the granulation tissue and later the provisional matrix and the woven bone fill up the alveolus. The bundle bone is completely resorbed causing a reduction in the vertical ridge. In a second phase, the buccal wall and the woven bone are remodeled causing the horizontal and further vertical ridge reduction. When socket grafting is adopted, the first phase and vertical bone reduction still occur, however, the second phase and the horizontal contraction are reduced.

the surrounding alveolar bone cells [4–6]. This group reported that the presence or absence of PDL in the extraction socket does not influence the features of healing after 3 months [15]. During the second phase, the outer surface of the alveolar bone is remodeled causing an overall horizontal and vertical tissue contraction. The reason for this remodeling process is still not well understood. Disuse atrophy, decreased blood supply, and localized inflammation might play important roles in bone resorption. However, it is now apparent that bone remodeling is a complex process involving structural, functional, and physiologic factors and that surgical trauma from extraction induces microtrauma to surrounding bone, which accelerates bone remodeling [16].

Resorption rate of the alveolar ridges is faster during the first six months following the extraction [9, 17] and proceeds at an average of 0.5–1.0% per year for the entire life [7, 8]. The height of a healed socket never reaches the coronal level of bone attached to the extracted tooth, and horizontal resorption seems to be greater in the molar region compared to the premolar area [18, 19]. Schropp et al. estimated two thirds of the hard and soft tissue changes occur in the first 3 months. The authors reported 50% of crestal width to be lost in a 12-month period (corresponding to 6.1 mm; range 2.7 to 12.2 mm), 2/3 of which (3.8 mm; 30%) occurred in the first 12 weeks. When examining the premolar area only, a loss of alveolar ridge width of 4.9 mm (45%) was reported, of which 3.1 mm (28.4%) occurred in the first 12 weeks [20]. A recently published systematic review [21] reported a greater horizontal alveolar ridge reduction (29–63%; 3.79 mm) than vertical bone loss (11–22%; 1.24 mm on the buccal, 0.84 mm on mesial, and 0.80 on distal sites) at 6 months. In a long-term study, Ashman reported an alveolar bone shrinkage of 40–60% in height and width within the first 2-3 years [8, 22].

3. Socket Healing

Immediately after tooth extraction, the alveolar socket is filled by blood clot that is replaced by granulation tissue within 1 week (see Figure 1) [23]. In the healing of a skin wound, epithelial cells migrate underneath and are protected by the blood clot. In socket healing instead, the epithelium migrates over the granulation tissue to cover the healing socket [24]. This happens because this inflammatory tissue is recognized as a connective tissue by the epithelial cells, therefore, cellular migration occurs over its surface. This is important when we examine guided bone regeneration applied to socket grafting. Starting from the apical and lateral residual bony walls, the granulation tissue is rapidly remodeled to provisional matrix. Mineralizing processes occur leading to the formation of woven bone that eventually is replaced by mature lamellar bone [25]. For more information on socket healing stages, please refer to Table 1.

Early human histological investigations reported that extraction sockets are filled with delicate cancellous bone in their apical two thirds at 10 weeks, and they are completely filled with bone at 15 weeks [24]. Increased radiopacity is demonstrated as soon as 38 days and radiopacity similar to that of the surrounding bone at 105 days [24]. These figures might be partially biased as specimens were harvested from cadavers; therefore their late age and their systemic condition

Table 1: Healing of the extraction socket. Articles reporting timing and histological evidence of extraction socket healing events are reported.

Reference	Model	Healing
Clafin, 1936 [26]	Experimental extraction in a dog model.	Day 1. Blood clot filled the socket, fibrin network covered the clot. Day 3. Epithelium starts to proliferate. Osteoclasts are present on the bone crest. Fibroblasts started invading the clot. Day 5. Bone formation at the fundus of the socket. Day 11. New bone along the alveolar socket walls. Day 19. New bone reached the crest. The clot is present in the center of the socket. Day 28. The alveolus is filled with new bone.
Weinmann and Sicher, 1955 [27]	Animal model.	Blood clot. Organization of the blood clot by proliferating connective tissue. Replacement of the connective tissue with fibrillar bone. Reconstruction of the coarse fibrillar bone and replacement by mature bone matrix.
Amler et al., 1960 [28]	Human biopsies of the content of extraction wounds scooped out with small curets. 3 days intervals.	Clot formation. Replacement with granulation tissue (7th day). Replacement of granulation tissue with connective tissue (20th day). Osteoid is present at the base of the socket at the 7th day and fills 2/3 of the socket at the 28th day. Epithelialization starts on the 4th day and is complete after day 24. Epithelial migration proceeds from the margins of the socket with the organization of the clot.
Boyne, 1966 [4]	12 patients (20–45 yo). Extraction of 1st maxillary premolar. Flaps were not elevated. 2 doses of IM Oxytetracyclines at different postoperative days for each patient. 1 week after administration of the antibiotic all the remaining maxillary teeth were extracted and a block section of the whole socket of the 1st premolar is harvested and grafted with FDBA.	Specimens tagged at day 5-6. No fluorescent new matrix. Day 7-8. Fluorescent new bone in the marrow vascular spaces adjacent to and along the entire length of the lamina dura. No bone in the socket. Day 9-10. New bone appears also on the lateral aspects of the socket walls. Day 12. New bone along the lateral walls and in adjacent bone areas. Day 13-14. New bone fills approximately 1/3 of the alveolus. Day 15-16. Similar to previous 13-14 days specimens. Day 19. Bone matrix had filled a large portion of the socket.

Table 1: Continued.

Reference	Model	Healing
Evian et al., 1982 [29]	10 patients. Extractions at different timepoints prior to periodontal surgery. Bone cores harvested at the time of periodontal surgery. Conclusions: 8–12 weeks is the best timeframe in which to harvest a graft.	4 weeks: Abundance of fibrous connective tissue. Rows of osteoblasts in the osteoid layer. 6 weeks: Osteoblasts are actively laying down new bone. 8 weeks: Trabeculae of new bone occupy the majority of the socket. Fewer osteoblasts and less osteoid are present. 10 weeks: Trabeculae interconnected with a minimum of osteoid. 12 weeks: Similar to 10 weeks. 16 weeks: Dense bone trabeculae with fewer cellular elements. Very little bone formation and few osteoblasts.
Hsieh et al., 1994 [5]	Rat teeth are extracted and fluorochrome is administered at different intervals. Conclusions: mineral formation is greatest at the gingivopalatal aspect and least at the gingivobuccal.	5 days: osteogenesis mainly in the apical region. Subperiosteal bone formation on the external surface of the buccal bone. 10 days: epithelium covered the socket. Woven bone filled 1/3 to 1/2 of the socket height. Margins of the socket are rounded by resorption of buccal and palatal crests and the apposition of buccal subperiosteal woven bone. Day 14: thick trabeculae fill the socket. Numerous osteoblasts and few osteoclasts.
Devlin and Sloan, 2002 [6]	Extraction socket of patients requiring mandibular squamous cell carcinoma resection. Extractions were performed 2 weeks prior to resection.	2 weeks postextraction the PDL ligament was present in the center of the socket. Osteocytes and osteoblasts in the marrow spaces and on the socket margins strongly expressed Runx2, pre-osteoblasts on the socket surfaces, osteoprogenitor cells in the center of the socket also expressed Runx2. SB-10 and SB-20 antibodies were expressed in osteoprogenitor cells, pre-osteoblasts and osteoblasts surrounding trabeculae.
Cardaropoli et al., 2003 [30]	9 mongrel dogs (1 for each timepoint). Distal roots of the 4th mandibular premolars are extracted. *B* and *L* soft tissue is stabilized by sutures. Sections in the *M*-*D* direction.	Day 1: Coagulum fills most of the socket, inflammatory cells in the connective tissue. Day 3: Small areas of the coagulum are replaced by richly vascularized granulation tissue. Day 7: The clot is partially replaced by a provisional matrix. Day 14: The socket margins are covered by connective tissue. The socket contained a provisional matrix and woven bone. PDL and bundle bone are absent. Woven bone extends from the socket walls to the center of the wound. Day 30: Osteoclasts are resorbing woven bone and are also observed on the surface of the old lamellar bone of the crestal region. Soft tissue is organized and keratinized. Day 60 and 90: A woven bone hard tissue bridges the defect. Woven bone is being replaced by lamellar bone. Day 120 and 180: Bridging bone is remodeled to lamellar bone. A new periosteum is established.

might have led to delayed wound healing capabilities. On the other side, animal studies demonstrate accelerated healing as 3 weeks old extraction sockets in humans compare with 9-10 days old sockets in dogs and a 3.5 months sockets in humans compares with 8 weeks sockets in dogs [26].

4. Rationale for Extraction Socket Preservation

Bone formation in the alveolar socket is a naturally occurring event as long as surrounding alveolar walls remain intact; however, the alveolar ridge volumetric contraction may impair implant placement.

To reduce loss of alveolar bone to acceptable levels, several surgical techniques have been proposed. Reducing the extraction trauma and limiting flap elevation [31] are essential for obtaining success in each of these procedures. Animal studies show mixed results when evaluating differences in ridge remodeling between flapped and nonflapped extraction sockets [31–36] although it has been hypothesized that by disrupting the thin layer of cells that comprises the osteogenic layer of the adult periosteum, the elevation of a flap might diminish the ability of periosteal cells to regenerate bone, while an undisturbed periosteum maintains its osteogenic potential [10, 37–39]. It is possible that flap elevation affects alveolar dimensional alterations only in the short-term [21], while in the long term no appreciable differences are found [36]. In guided bone regeneration 4, methods can be used to increase the rate of bone formation and to augment bone volume: osteoinduction by the use of appropriate growth factors; osteoconduction, where a grafting material serves as a scaffold for new bone growth; distraction osteogenesis, by which a fracture is surgically induced and bone fragments are then slowly pulled apart; finally, guided tissue regeneration, which allows spaces maintained by barrier membranes to be filled with new bone [40]. Utilizing these concepts, it has been proposed guided bone regeneration with nonresorbable and absorbable membranes, several types of bone grafts with or without use of barrier membranes or the addition of mucogingival treatments, and more recently the use of bioactive molecules for the generation of bone in the extraction socket. When analyzing the results of the following described studies, it should be kept in mind the goal of the additional service that is provided to the patient, which include the following:

(i) to enable installation and stability of a dental implant,

(ii) to reduce loss of alveolar bone volume,

(iii) to reduce need for additional bone grafting procedures,

(iv) to enable the generated tissues to provide implant osseointegration,

(v) to improve the esthetic outcome of the final prosthesis,

(vi) to regenerate bone faster allowing earlier implantation and restoration.

In the following sections, several articles attempting to obtain these purposes by means of alveolar ridge preservation will be reviewed and briefly summarized.

4.1. Ridge Preservation with Membranes. Guided bone regeneration (GBR) techniques utilize barrier membranes to refrain gingival cells from penetrating into the defect to be regenerated. The concept of compartmentalization was introduced by Melcher [39] to explain periodontal wound healing, but it may not be applicable to socket healing. If it were, one would expect the socket to be filled with soft tissue in all instances. On the other side, even early observations in humans and animals demonstrated that the alveolar socket tends to heal by regeneration of bone up to the alveolar crest. As in periodontal wound healing [41–43], the stability of the blood clot previously described explains why the compartmentalization concept does not result in a socket filled by epithelium and how epithelial cells migrate over the granulation tissue to close the healing socket. Questions remain as to whether barrier membranes have an effect in maintaining alveolar ridge morphology.

In 1997, Lekovic and coworkers adopted nonabsorbable ePTFE membranes for the preservation of the alveolar ridge following tooth extraction. No changes in clinical measures were noted in the test sites that remained protected for 6 months while significant volumetric changes were observed in control sites and in test sites experiencing membrane exposure [44]. Pinho and coworkers evaluated the use of a titanium membrane with or without autologous bone graft. They found no significant differences between groups and, therefore, concluded that space maintenance is more important than the use of grafting materials in the treatment of extraction sockets [45].

Barrier membranes seem to minimize alveolar bone resorption when compared to nonintact (released) periosteum regardless of the use of additional grafting material. Titanium membranes certainly would have a distinctly different mechanism of action when compared to resorbable membranes that on the other side reduce the potential of exposure and do not require a second surgical intervention for their removal. In 1998, Lekovic et al. examined the effect of glycolide and lactide polymer membranes demonstrating reduced loss of alveolar height, more internal bone socket bone fill and less horizontal resorption than controls [46]. Luczyszyn et al. evaluated the effect of acellular dermal matrix with or without a resorbable hydroxylapatite graft. Both groups preserved ridge thickness, although, better results were achieved in the combined treatment group suggesting that bone grafts might benefit bone regeneration when using a resorbable membranes [47].

A recent study performed a detailed evaluation of the healing of extraction sockets covered with a resorbable collagen membrane. Through the use of histological evaluation, subtraction radiography, and of μ-CT analysis, this study demonstrated that adequate bone formation for implant placement occurs as early as 12 weeks following tooth extraction, with insignificant changes in alveolar ridge dimensions [48].

4.2. Ridge Preservation with Bone Grafts and Bone Substitutes. The clinical advantages of bone fillers in alveolar ridge volume preservation and prevention of additional bone grafting procedure are largely supported by the available literature

[47, 49–51]. Minimal ridge remodeling has been observed when using nonresorbable hydroxyapatite crystals covered by a rotated pediculated split thickness palatal flap [52], DFDBA covered with an ePTFE membrane [53], or even allogenic or xenogenic bone grafts covered with nothing but a collagen plug [51, 54] (Figure 1). Histological evidence demonstrates that bone formation occurs over the surface of the implanted osteoconductive graft particles [55, 56]. At 3 months or later, grafted sockets generally demonstrate higher mineralized tissue figures, when considering both new vital bone and remaining graft particles, but the formation of new bone appears to be similar in grafted and nongrafted sites. It can be extrapolated that residual particles occupy part of the volume that would have been occupied by bone marrow if bone grafting were not adopted [57].

At earlier healing stages (2 weeks) instead, grafted sockets demonstrate xenograft particles enclosed in connective tissue and coated by multinucleated cells when nongrafted sites already show newly formed woven bone occupying most of the socket [58]. This response is typical of a foreign body reaction which can be elicited by the xenograft and though it is clinically non-immunogenic, non-toxic and chemically inert [59], it results in a delayed healing response during the earliest stages of socket healing. Many articles reported only a partial resorption of the grafted particles at short and long timepoints [49, 53, 58, 60–63] arising doubts on the achievement of the osteointegration of implants inserted in augmented sites and on the success of the restorative therapy. Histological animal studies [64, 65] evaluated the osteointegration of dental implants following bone regeneration performed with different bone fillers and observed a bone-to-implant contact similar to that of implants placed in pristine bone (40% to 65%). Furthermore, clinical studies observed that good primary stability can be reached at implant insertion, that the grafting procedure does not impair early osteointegration [66, 67], and that implants placed in bone regenerated using mineralized grafts are able to sustain loading and provide similar long-term results as those placed in pristine bone [68].

Mineralized grafting materials may interfere with the earliest stages of socket healing and their elimination may require several years [57] or they may in fact be nonresorbable even in the long term [62]. On the other side, their ability to prevent crestal ridge resorption and sustain long-term implant success has been clearly demonstrated [66–68].

Other advantages in the use of osteoconductive grafting material were reported by a clinical and histological human study of postextractive defects in posterior maxillary area treated with a xenogenic graft. In this study, Rasperini et al. confirmed the space-maintaining activity of the implanted material and reported a decreased demand for sinus lift augmentation procedure when the socket preservation procedure was performed [63]. Through a computed tomography analysis of maxillary anterior postextractive defects, Nevins et al. reported that 79% of grafted sites underwent less than 20% buccal plate loss, while 71% of nongrafted sites demonstrated more than 20% buccal plate loss. An interesting finding of this investigation was that even the experienced surgeons participating to this study were not able to predict the fate of the buccal plate, therefore, the authors suggested socket grafting to be performed at the time of extraction [69].

4.2.1. Buccal Bone Overbuilding. Another technique that may be adopted is to augment the buccal bone by implanting graft materials on its buccal surface. Simon et al. used DFDBA covered by a bioabsorbable membrane for the augmentation procedure. The dimensions on the ridge were augmented compared to the original volume but the invasiveness and technical demand of this procedure may refrain the clinician from its use in everyday practice [70]. In another study, 2 different grafting techniques were adopted according to whether the buccal bone was intact or dehiscence. Sockets with an intact buccal bone were grafted to the level of the alveolar crest, a membrane was used to protect the defect, and the flap was closed by primary intention while sockets with deficient buccal bone were augmented. Their results showed complete loss of the horizontally augmented bone in augmented sites, but grafted sited experienced bone loss in a greater extent than augmented sites [71].

An histological animal study found that buccal bone augmentation with a xenograft failed to prevent the physiological bone modeling and remodeling taking part in the buccal and lingual bony walls; however, the insertion of grafting material seemed to promote *de novo* hard tissue formation, thus limiting the total bone volume contraction [57]. Xenograft particles positioned on the buccal surface of the extraction alveolus were found to be encapsulated in collagen fibers after 3 months of healing. They were always located lateral to the periosteum of the buccal wall and, therefore, did not participate to ridge augmentation [57]. Fickl and coworkers also proposed the overbuilding of the buccal bone with a xenograft and a membrane. Data from their studies indicates that extrasocket grafting does not seem to compensate for ridge alteration after extraction possibly because of the additional trauma to buccal tissues [72, 73].

4.2.2. Free Soft-Tissue Grafts over Grafted Sockets. The placement of free soft-tissue graft to cover the augmented alveolar socket was introduced to minimize the soft tissue shrinkage, optimize aesthetical results of implant restoration, and obtain a primary closure that may preserve the graft from bacterial infections and secondary graft failure [74, 75]. The first attempt to cover the socket graft with an autogenous soft tissue implant was described by Landsberg and Bichacho in 1994 [76]. Nevins and Mellonig suggested the use of soft tissue grafts to improve ridge topography after tooth extraction [77] and in combination with immediate implant placement [78].

In 1999, Tal described the survival of circular connective tissue grafts placed over extraction sockets treated either with DFDBA or Bio-Oss. They found that the survival was not dependent on the adopted graft and that at 1 week 18/42 grafts were vital, 13/42 were partially vital, and 11/42 were nonvital. Complete closure of all sockets occurred 4 weeks postextraction. The authors noted that more often partially vital grafts maintained their vitality over the socket area more than on the graft margins; they concluded that

the nourishment could be originated from plasmatic elements in the socket blood clot more than from vessels originating from the periphery of the graft [79].

4.3. Immediate Implant Placement and the "Jumping Distance." The first report of implant placement immediately after tooth extraction dates back to 1978 when the Tübingen immediate implant was described [80–82]. In 1991, Barzilay et al. suggested that immediate implant placement might reduce or eliminate alveolar ridge resorption during the initial healing of the alveolar extraction socket [83]. In two subsequent papers in a monkey model, he demonstrated that substantially less ridge remodeling was induced in the immediate implant group [84] and that histologically bone to implant contact was similar within the different anatomic regions of the oral cavity [85].

Other authors challenged the results of the Canadian reporting that the placement of an implant in the fresh extraction site failed to prevent the remodeling that occurred in the walls of the socket. The height of the buccal and lingual walls at 3 months was similar compared to extraction only sites [86–90]. Vertical bone loss was more pronounced at the buccal aspect even with some marginal loss of osseointegration [87]. Histologically, the gap between the implant and the socket walls filled in at 4 weeks with woven bone, while, the buccal and lingual walls underwent marked surface resorption. After 12 weeks, the buccal crest was located >2 mm apical of the implant margin [88] (Figure 2). Evaluating immediately placed implants, Schropp et al. reported 70% of the 3-wall infrabony defects with a parallel width of up to 5 mm, a depth of maximum 4 mm, and a perpendicular width of maximum 2 mm had a capacity of spontaneous healing within a period of 3 months [18]. Botticelli et al. found that 1–1.25 mm wide and 5 mm deep defects around implants healed uneventfully with or without membrane [91]. Defects up to 2.25 mm wide were found to heal using barrier membranes, although when the buccal bone was intentionally removed, less regeneration at the buccal aspects was observed [92]. These studies adopted an animal model with surgically created defects, which typically exhibit lesser resorption than extraction sockets [90].

When immediate implant placement is adopted, many clinicians feel the need of "filling" the buccal gap (i) by placing a larger diameter implant, (ii) by placing the implant in a more buccal position, or (iii) by grafting the buccal defect with some kind of bone substitutes. Given the available literature, the first two strategies do not seem to be recommendable. It seems instead that the presence of a large gap between the buccal wall and the implant apparently promotes new bone formation and enhances the level of bone-to-implant contact [88].

An implant position 0.8 mm deeper and more lingual in relation to the center of the socket results in a lesser degree of buccal bone dehiscence [93]. Other studies demonstrated that the closer the implant is to the buccal bony plate, the more the buccal bone resorbs [94, 95]. Bone resorption of the buccal crest is more pronounced when placing large size (5 mm) root-formed implants when compared to cylindrical implants with a smaller diameter (3.3 mm) demonstrating that implants placed immediately after tooth extraction fail to preserve the alveolar crest of the socket irrespective of their design or configuration [96]. Moreover, soft tissues followed bone levels and also they were located more apical on large size implants compared to smaller size implants [97].

Caneva et al. evaluated the use of a collagen membrane over the buccal gap of immediately placed implants and found that the alveolar crest outline was better maintained at the test sites compared with the control sites even if the buccal gap was relatively small [98]. Interestingly, enhanced bone preservation was found when using deproteinized bovine bone mineral particles and a collagen membrane compared to controls whereas no such benefit was noted when using magnesium-enriched hydroxyapatite [99–101]. Recently Araújo and coworkers have evaluated the use of Bio-Oss Collagen in the volume between the buccal wall and the implant in cases treated with immediate implant placement in an experimental animal model. The authors found that this treatment modified the process of hard tissue healing, provided additional amounts of hard tissue at the entrance of the previous socket, improved the level of marginal bone-to-implant contact, and prevented soft tissue recession [102] (Figure 2).

Implants immediately placed into fresh extraction sockets are classified as Type 1 implants, early placed implants (4–8 weeks) following tooth extraction are Type 2 implants, Type 3 implants represent implants early placed (12–16 weeks) in a socket with partial bone healing, and Type 4 implants are delayed implants placed in a fully healed edentulous site (>6 month) [103]. Timing of implant placement is not a topic to be treated in this review but it might be of interest to the reader that bone grafting in early placed implants (Type 2-3) seems to provide better hard tissue dimensions and with less postoperative complications than bone grafting in delayed implants (Type 4) [104].

When evaluating the expression of osteogenesis-related growth factors, Lin et al. demonstrated apparent tissue maturation delayed during osseointegration, compared to extraction socket bone repair. The two healing models developed distinct features and triggered a characteristic coordinated expression and orchestration of transcription factors, growth factors, extracellular matrix molecules, and chemokines. These groundbreaking findings open new horizons to researchers, which might lead to a better understanding of the cooperative molecular dynamics in alveolar bone healing [105].

4.4. Ridge Preservation with Nonmineralized Grafts. Serino et al. evaluated the use of a bioabsorbable polylactide-polyglycolide acid sponge as a ridge preservation grafting material. The grafting material was placed with no attempt to achieve primary intention wound closure. 6 months following the extractions, biopsies were harvested. Both test and control extraction sockets showed mature and well-structured bone with no residual particles of the grafted material. Clinical measures seemed to favor the test group [106]. In a following study, both the regenerated sites and controls resulted in the formation of a highly mineralized and well-structured bone with the control group showing a "slightly minor percentage

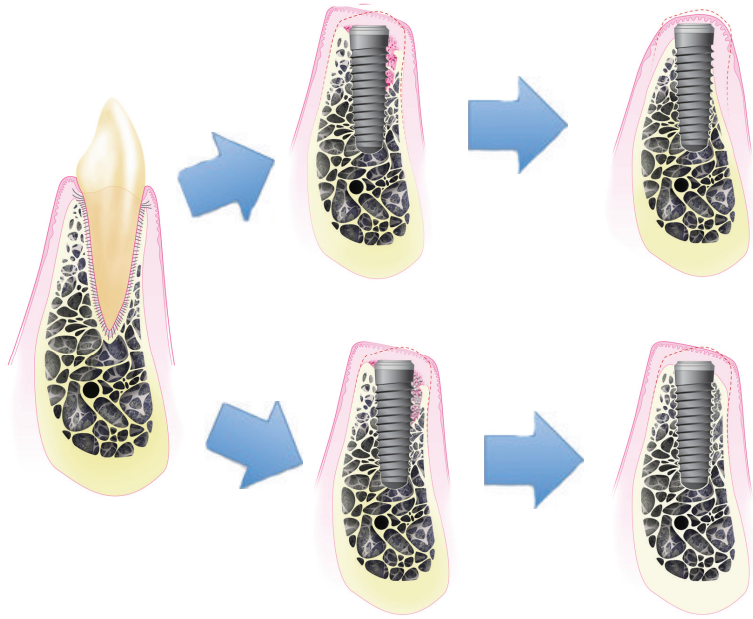

Figure 2: Healing of the extraction socket, with postextractive implant placement, with and without socket grafting. After tooth extraction and immediate implant placement, the blood clot fills the remaining space and the bundle bone undergoes the physiological changes. When grafting material is placed around the implant surface, filling the remaining socket area, the buccal bone wall remodeling process is corrupted, thus leading the maintenance of the horizontal ridge volume.

of mineralized bone" and a higher presence of connective tissue in the coronal portion of the biopsies. Particles of the grafted material could not be identified in any of the biopsies [107].

Grafting materials with high resorption rates allow for the formation of bone with no residual graft particles at the time of implant placement and loading but their ability to sustain alveolar ridge volume in the long term might be inferior to that of mineralized grafts.

4.5. Novel Tissue Engineering Approaches. In order to overcome the limitations of routinely adopted biomaterials as allografts, xenografts, and alloplasts in terms of predictability and quality of bone formation and ability to sustain alveolar ridge morphology over long periods of time, novel tissue engineering therapies have been developed including the delivery of growth factors incorporated in carriers, the stimulation of the selective production of growth factors using gene therapy, and the delivery of expanded cellular constructs.

Bone morphogenic proteins (BMPs) are an example of growth factors; they have the ability of inducing the differentiation of the host stem cells into bone forming cells in a process known as *osteoinduction* [108]. A feasibility study introducing the use of rhBMP-2 absorbed in a collagen sponge for alveolar ridge preservation after tooth extraction was published in 1997. Howell et al. demonstrated the safety of this grafting material. Patients receiving socket grafting demonstrated increase in bone height while patients receiving a ridge augmentation procedure showed no evidence of augmented ridge width or height [109]. Implants placed in the regenerated bone were stable and presented healthy periimplant tissues [110]. After this pilot study, Fiorelini and coworkers performed a randomized clinical trial testing the regenerative potential of the recombinant BMP-2 in the collagen sponge compared to the use of the collagen sponge alone. Anterior maxillary postextraction alveolar defects in which more than 50% of the alveolar buccal bone had been lost prior to extraction were treated with either of the two grafting material. Two different rhBMP-2 concentrations were used (0.75 mg/mL and 1.50 mg/mL). Significantly greater augmentation was noted in the 1.50 mg/mL group and both rhBMP-2 groups outperformed the control groups. Histological findings showed generation of bone no different from native bone [111].

PDGF-BB in a β-TCP carrier is a material accepted from the FDA for regeneration of bone and PDL elements in guided tissue regeneration procedures. Nevins et al. evaluated the use of the recombinant protein in socket grafting. In this case, series 8 extraction sockets received Bio-Oss Collagen hydrated with 0.3 mg/mL PDGF-BB, and flaps were released for closure by primary intention. Then 4 or 6 months after grafting bone core, biopsies revealed "robust bone formation". Also $23.2 \pm 3.2\%$ new bone and 9.5 ± 9.1 residual grafting material were noted at 4 months. However, $18.2 \pm 2.1\%$ new bone and $17.1 \pm 7.0\%$ residual grafting material were noted at 6 months in the hystomorphometrical evaluation [112]. More recently, tissue repair cells (TRC), a cell construct derived from each patient's bone marrow and cultivated using automated bioreactors to concentrations not achievable through a simple bone marrow aspiration, were evaluated in socket healing. This study showed that this

cell construct is able to produce significant concentrations of cytokines and maintains the cells' ability to differentiate toward both the mesenchymal and endothelial pathway and produce angiogenic factors. TRC therapy enhanced formation of highly vascular mature bone as early as 6 weeks after implantation when compared to guided bone regeneration with no serious study-related adverse event reported and lower degrees of alveolar ridge resorption were noted [113, 114]. Please refer to our recent review for further information on cell therapy applications in craniofacial regeneration [115].

5. Conclusions

Postextraction alveolar ridge resorption is an inevitable process and the molar area is not an exception. Molar ridges present higher degrees of resorption than premolar areas do. Socket grafting techniques have been readily adopted by dentists throughout the world. A great amount of research has been conducted to examine the effectiveness of several materials or membranes.

The use of invasive techniques is hardly recommended at this treatment timepoint as any procedure requiring primary intention healing with the advancement of flaps may result in increased inflammatory response, in a decrease in vestibular depth, and in the creation of unaesthetic scars. Even expert practitioners might not be able to accurately determine when these techniques might be indicated [69]. For the very same reason, less invasive grafting techniques should be adopted when indicated especially when treating defects in the esthetic or molar areas. It should be understood that the use of osteoconductive-mineralized grafts does not accelerate bone healing, but may allow for a better preservation of the ridge volume that is highly desirable for both esthetic and function of the future implant restoration. Moreover, invasive procedures as guided bone regeneration and sinus floor elevation are less frequently needed when socket grafting is adopted [63]. For more predictable results, it is recommended to allow proper time for bone healing prior to proceed with implant placement. Anyway, when immediate implant placement is adopted, the use of mineralized grafts on the buccal gap helps reducing the resorption of the buccal crest bone [102] and may lessen the chances for undesirable hard and soft tissue recessions. Clinicians should escape the temptation of placing larger diameter implants or placing the implant in a more buccal position in order to fill the buccal gap. Instead, a larger gap should be preserved and the buccal defect should be filled with bone substitutes.

The rationale for a frankly palatal/lingual positioning of immediately placed implants is also supported by the knowledge that significantly more facial recessions are correlated with implants placed too buccal [116, 117].

Advances in tissue engineering techniques might soon provide practitioners with biomaterials for a more predictable and enhanced bone formation that will definitely improve our clinical results. These novel biomaterials are currently evaluated worldwide and will soon be introduced in everyday practice.

Practitioners should be well informed of the biological characteristics of new biomaterials and on which stages of wound healing may they take an action.

This paper attempted to summarize the concepts on socket grafting resulting from the available literature. Current knowledge may still be insufficient to fully justify the use of certain techniques in everyday practice, and more studies evaluating basic biological concepts should be performed.

In socket grafting as in other medical divisions, proper diagnosis is often more important than the rendered treatment.

References

[1] M. H. Cryer, *The Internal Anatomy of the Face*, Lea & Febiger, Philadelphia , Pa, USA, 2nd edition, 1916.

[2] W. Rogers and E. Applebaum, "Changes in the mandible following closure of the bite with particular reference to edentulous patients," *Journal of the American Dental Association*, vol. 28, p. 1573, 1941.

[3] J. Pietrokovski and M. Massler, "Ridge remodeling after tooth extraction in rats," *Journal of Dental Research*, vol. 46, no. 1, pp. 222–231, 1967.

[4] P. J. Boyne, "Osseous repair of the postextraction alveolus in man," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 21, no. 6, pp. 805–813, 1966.

[5] Y. D. Hsieh, H. Devlin, and C. Roberts, "Early alveolar ridge osteogenesis following tooth extraction in the rat," *Archives of Oral Biology*, vol. 39, no. 5, pp. 425–428, 1994.

[6] H. Devlin and P. Sloan, "Early bone healing events in the human extraction socket," *International Journal of Oral and Maxillofacial Surgery*, vol. 31, no. 6, pp. 641–645, 2002.

[7] G. E. Carlsson and G. Persson, "Morphologic changes of the mandible after extraction and wearing of dentures. A longitudinal, clinical, and x-ray cephalometric study covering 5 years," *Odontologisk Revy*, vol. 18, no. 1, pp. 27–54, 1967.

[8] A. Ashman, "Postextraction ridge preservation using a synthetic alloplast," *Implant Dentistry*, vol. 9, no. 2, pp. 168–176, 2000.

[9] J. Pietrokovski and M. Massler, "Alveolar ridge resorption following tooth extraction," *The Journal of Prosthetic Dentistry*, vol. 17, no. 1, pp. 21–27, 1967.

[10] M. G. Araujo and J. Lindhe, "Dimensional ridge alterations following tooth extraction. An experimental study in the dog," *Journal of Clinical Periodontology*, vol. 32, no. 2, pp. 212–218, 2005.

[11] G. Huynh-Ba, B. E. Pjetursson, M. Sanz et al., "Analysis of the socket bone wall dimensions in the upper maxilla in relation to immediate implant placement," *Clinical Oral Implants Research*, vol. 21, no. 1, pp. 37–42, 2010.

[12] P. R. Ramakrishnan, W. L. Lin, J. Sodek, and M. I. Cho, "Synthesis of noncollagenous extracellular matrix proteins during development of mineralized nodules by rat periodontal ligament cells in vitro," *Calcified Tissue International*, vol. 57, no. 1, pp. 52–59, 1995.

[13] M. I. Cho, N. Matsuda, W. L. Lin, A. Moshier, and P. R. Ramakrishnan, "In vitro formation of mineralized nodules by periodontal ligament cells from the rat," *Calcified Tissue International*, vol. 50, no. 5, pp. 459–467, 1992.

[14] G. G. Steiner, W. Francis, R. Burrell, M. P. Kallet, D. M. Steiner, and R. Macias, "The healing socket and socket

regeneration," *Compendium of Continuing Education in Dentistry*, vol. 29, no. 2, pp. 114–124, 2008.

[15] G. Cardaropoli, M. Araújo, R. Hayacibara, F. Sukekava, and J. Lindhe, "Healing of extraction sockets and surgically produced—augmented and non-augmented—defects in the alveolar ridge. An experimental study in the dog," *Journal of Clinical Periodontology*, vol. 32, no. 5, pp. 435–440, 2005.

[16] L. P. Garetto, J. Chen, J. A. Parr, and W. E. Roberts, "Remodeling dynamics of bone supporting rigidly fixed titanium implants: a histomorphometric comparison in four species including humans," *Implant dentistry*, vol. 4, no. 4, pp. 235–243, 1995.

[17] K. Johnson, "A study of the dimensional changes occurring in the maxilla following tooth extraction," *Australian Dental Journal*, vol. 14, no. 4, pp. 241–244, 1969.

[18] L. Schropp, L. Kostopoulos, and A. Wenzel, "Bone healing following immediate versus delayed placement of titanium implants into extraction sockets: a prospective clinical study," *International Journal of Oral and Maxillofacial Implants*, vol. 18, no. 2, pp. 189–199, 2003.

[19] C. H. Hammerle, M. G. Araujo, and M. Simion, "Evidence-based knowledge on the biology and treatment of extraction sockets," *Clinical Oral Implants Research*, vol. 23, supplement 5, pp. 80–82, 2012.

[20] L. Schropp, A. Wenzel, L. Kostopoulos, and T. Karring, "Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12-month prospective study," *International Journal of Periodontics and Restorative Dentistry*, vol. 23, no. 4, pp. 313–323, 2003.

[21] W. L. Tan, T. L. T. Wong, M. C. M. Wong, and N. P. Lang, "A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in humans," *Clinical Oral Implants Research*, vol. 23, supplement 5, pp. 1–21, 2012.

[22] A. Ashman, "Ridge preservation: important buzzwords in dentistry," *General Dentistry*, vol. 48, no. 3, pp. 304–312, 2000.

[23] M. H. Amler, "The time sequence of tissue regeneration in human extraction wounds," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 27, no. 3, pp. 309–318, 1969.

[24] J. G. Mangos, "The healing of extraction wounds: a microscopic and ridographic investigation," *New Zeeland Dental Journal*, vol. 37, pp. 4–23, 1941.

[25] L. Trombelli, R. Farina, A. Marzola, L. Bozzi, B. Liljenberg, and J. Lindhe, "Modeling and remodeling of human extraction sockets," *Journal of Clinical Periodontology*, vol. 35, no. 7, pp. 630–639, 2008.

[26] R. S. Clafin, "Healing of disturbed and undisturbed extraction wounds," *Journal of the American Dental Association*, vol. 23, pp. 945–959, 1936.

[27] J. P. Weinmann and H. Sicher, *Bone and Bones*, 2nd edition, 1955.

[28] M. H. Amler, P. L. Johnson, and I. Salman, "Histological and histochemical investigation of human alveolar socket healing in undisturbed extraction wounds," *Journal of the American Dental Association*, vol. 61, pp. 32–44, 1960.

[29] C. I. Evian, E. S. Rosenberg, J. G. Coslet, and H. Corn, "The osteogenic activity of bone removed from healing extraction sockets in humans," *Journal of Periodontology*, vol. 53, no. 2, pp. 81–85, 1982.

[30] G. Cardaropoli, M. Araújo, and J. Lindhe, "Dynamics of bone tissue formation in tooth extraction sites: an experimental study in dogs," *Journal of Clinical Periodontology*, vol. 30, no. 9, pp. 809–818, 2003.

[31] S. Fickl, O. Zuhr, H. Wachtel, W. Bolz, and M. Huerzeler, "Tissue alterations after tooth extraction with and without surgical trauma: a volumetric study in the beagle dog," *Journal of Clinical Periodontology*, vol. 35, no. 4, pp. 356–363, 2008.

[32] S. Fickl, O. Zuhr, H. Wachtel, W. Bolz, and M. B. Huerzeler, "Hard tissue alterations after socket preservation: an experimental study in the beagle dog," *Clinical Oral Implants Research*, vol. 19, no. 11, pp. 1111–1118, 2008.

[33] J. Blanco, V. Nuñez, L. Aracil, F. Muñoz, and I. Ramos, "Ridge alterations following immediate implant placement in the dog: flap versus flapless surgery," *Journal of Clinical Periodontology*, vol. 35, no. 7, pp. 640–648, 2008.

[34] M. G. Araújo and J. Lindhe, "Ridge alterations following tooth extraction with and without flap elevation: an experimental study in the dog," *Clinical Oral Implants Research*, vol. 20, no. 6, pp. 545–549, 2009.

[35] F. Vignoletti, P. Matesanz, D. Rodrigo, E. Figuero, C. Martin, and M. Sanz, "Surgical protocols for ridge preservation after tooth extraction. A systematic review," *Clinical Oral Implants Research*, vol. 23, supplement 5, pp. 22–38, 2012.

[36] M. Caneva, D. Botticelli, L. A. Salata, S. L. S. Souza, E. Bressan, and N. P. Lang, "Flap vs. 'flapless' surgical approach at immediate implants: a histomorphometric study in dogs," *Clinical Oral Implants Research*, vol. 21, no. 12, pp. 1314–1319, 2010.

[37] A. H. Melcher, "Wound healing in monkey (Macaca irus) mandible: effect of elevating periosteum on formation of subperiosteal callus," *Archives of Oral Biology*, vol. 16, no. 4, pp. 461–IN19, 1971.

[38] A. H. Melcher, "Role of the periosteum in repair of wounds of the parietal bone of the rat," *Archives of Oral Biology*, vol. 14, no. 9, pp. 1101–IN23, 1969.

[39] A. H. Melcher, "On the repair potential of periodontal tissues," *Journal of Periodontology*, vol. 47, no. 5, pp. 256–260, 1976.

[40] C. H. F. Hämmerle and T. Karring, "Guided bone regeneration at oral implant sites," *Periodontology 2000*, vol. 17, no. 1, pp. 151–175, 1998.

[41] U. M. Wikesjö, R. E. Nilvéus, and K. A. Selvig, "Significance of early healing events on periodontal repair: a review," *Journal of Periodontology*, vol. 63, no. 3, pp. 158–165, 1992.

[42] U. M. Wikesjö, G. C. Bogle, and R. E. Nilvéus, "Periodontal repair in dogs: effect of a composite graft protocol on healing in supraalveolar periodontal defects," *Journal of Periodontology*, vol. 63, no. 2, pp. 107–113, 1992.

[43] J. M. Haney, K. N. Leknes, T. Lie, K. A. Selvig, and U. M. Wikesjö, "Cemental tear related to rapid periodontal breakdown: a case report," *Journal of Periodontology*, vol. 63, no. 3, pp. 220–224, 1992.

[44] V. Lekovic, E. B. Kenney, M. Weinlaender et al., "A bone regenerative approach to alveolar ridge maintenance following tooth extraction. Report of 10 cases," *Journal of Periodontology*, vol. 68, no. 6, pp. 563–570, 1997.

[45] M. N. Pinho, V. M. Roriz, A. B. Novaes et al., "Titanium membranes in prevention of alveolar collapse after tooth extraction," *Implant Dentistry*, vol. 15, no. 1, pp. 53–61, 2006.

[46] V. Lekovic, P. M. Camargo, P. R. Klokkevold et al., "Preservation of alveolar bone in extraction sockets using bioabsorbable membranes," *Journal of Periodontology*, vol. 69, no. 9, pp. 1044–1049, 1998.

[47] S. M. Luczyszyn, V. Papalexiou, A. B. Novaes, M. F. M. Grisi, S. L. S. Souza, and M. Taba, "Acellular dermal matrix and hydroxyapatite in prevention of ridge deformities after tooth

extraction," *Implant Dentistry*, vol. 14, no. 2, pp. 176–184, 2005.

[48] R. Neiva, G. Pagni, F. Duarte et al., "Analysis of tissue neogenesis in extraction sockets treated with guided bone regeneration: clinical, histologic, and micro-CT results," *The International Journal of Periodontics & Restorative Dentistry*, vol. 31, no. 5, pp. 457–469, 2011.

[49] J. M. Lasella, H. Greenwell, R. L. Miller et al., "Ridge preservation with freeze-dried bone allograft and a collagen membrane compared to extraction alone for implant site development: a clinical and histologic study in humans," *Journal of Periodontology*, vol. 74, no. 7, pp. 990–999, 2003.

[50] S. Fickl, O. Zuhr, H. Wachtel, C. F. J. Stappert, J. M. Stein, and M. B. Hürzeler, "Dimensional changes of the alveolar ridge contour after different socket preservation techniques," *Journal of Clinical Periodontology*, vol. 35, no. 10, pp. 906–913, 2008.

[51] A. G. Sclar, "Preserving alveolar ridge anatomy following tooth removal in conjunction with immediate implant placement. The Bio-Col technique," *Atlas of the Oral and Maxillofacial Surgery Clinics of North America*, vol. 7, no. 2, pp. 39–59, 1999.

[52] C. E. Nemcovsky and V. Serfaty, "Alveolar ridge preservation following extraction of maxillary anterior teeth. Report on 23 consecutive cases," *Journal of Periodontology*, vol. 67, no. 4, pp. 390–395, 1996.

[53] F. Brugnami, P. R. Then, H. Moroi, and C. W. Leone, "Histologic evaluation of human extraction sockets treated with demineralized freeze-dried bone allograft (DFDBA) and cell occlusive membrane," *Journal of Periodontology*, vol. 67, no. 8, pp. 821–825, 1996.

[54] H. L. Wang and Y. P. Tsao, "Mineralized bone allograft-plug socket augmentation: rationale and technique," *Implant Dentistry*, vol. 16, no. 1, pp. 33–41, 2007.

[55] Z. Artzi, H. Tal, and D. Dayan, "Porous bovine bone mineral in healing of human extraction sockets. Part 1: histomorphometric evaluations at 9 months," *Journal of Periodontology*, vol. 71, no. 6, pp. 1015–1023, 2000.

[56] Z. Artzi, H. Tal, and D. Dayan, "Porous bovine bone mineral in healing of human extraction sockets: 2. Histochemical observations at 9 months," *Journal of Periodontology*, vol. 72, no. 2, pp. 152–159, 2001.

[57] M. Araújo, E. Linder, J. Wennström, and J. Lindhe, "The influence of Bio-Oss collagen on healing of an extraction socket: an experimental study in the dog," *International Journal of Periodontics and Restorative Dentistry*, vol. 28, no. 2, pp. 123–135, 2008.

[58] M. Araújo, E. Linder, and J. Lindhe, "Effect of a xenograft on early bone formation in extraction sockets: an experimental study in dog," *Clinical Oral Implants Research*, vol. 20, no. 1, pp. 1–6, 2009.

[59] D. T. Luttikhuizen, M. C. Harmsen, and M. J. A. Van Luyn, "Cellular and molecular dynamics in the foreign body reaction," *Tissue Engineering*, vol. 12, no. 7, pp. 1955–1970, 2006.

[60] W. Becker, C. Clokie, L. Sennerby, M. R. Urist, and B. E. Becker, "Histologic findings after implantation and evaluation of different grafting materials and titanium micro screws into extraction sockets: case reports," *Journal of Periodontology*, vol. 69, no. 4, pp. 414–421, 1998.

[61] H. L. Wang and Y. P. Tsao, "Histologic evaluation of socket augmentation with mineralized human allograft," *International Journal of Periodontics and Restorative Dentistry*, vol. 28, no. 3, pp. 231–237, 2008.

[62] A. Mordenfeld, M. Hallman, C. B. Johansson, and T. Albrektsson, "Histological and histomorphometrical analyses of biopsies harvested 11 years after maxillary sinus floor augmentation with deproteinized bovine and autogenous bone," *Clinical Oral Implants Research*, vol. 21, no. 9, pp. 961–970, 2010.

[63] G. Rasperini, L. Canullo, C. Dellavia, G. Pellegrini, and M. Simion, "Socket grafting in the posterior maxilla reduces the need for sinus augmentation," *The International Journal of Periodontics & Restorative Dentistry*, vol. 30, no. 3, pp. 265–273, 2010.

[64] E. De Santis, D. Botticelli, F. Pantani, F. P. Pereira, M. Beolchini, and N. P. Lang, "Bone regeneration at implants placed into extraction sockets of maxillary incisors in dogs," *Clinical Oral Implants Research*, vol. 22, no. 4, pp. 430–437, 2011.

[65] J. P. Fiorellini, D. M. Kim, Y. Nakajima, and H. P. Weber, "Osseointegration of titanium implants following guided bone regeneration using expanded polytetrafluoroethylene membrane and various bone fillers," *International Journal of Periodontics and Restorative Dentistry*, vol. 27, no. 3, pp. 287–294, 2007.

[66] D. Carmagnola, P. Adriaens, and T. Berglundh, "Healing of human extraction sockets filled with Bio-Oss®," *Clinical Oral Implants Research*, vol. 14, no. 2, pp. 137–143, 2003.

[67] L. Molly, H. Vandromme, M. Quirynen, E. Schepers, J. L. Adams, and D. Van Steenberghe, "Bone formation following implantation of bone biomaterials into extraction sites," *Journal of Periodontology*, vol. 79, no. 6, pp. 1108–1115, 2008.

[68] J. P. Fiorellini and M. L. Nevins, "Localized ridge augmentation/preservation. A systematic review," *Annals of Periodontology*, vol. 8, no. 1, pp. 321–327, 2003.

[69] M. Nevins, M. Camelo, S. De Paoli et al., "A study of the fate of the buccal wall of extraction sockets of teeth with prominent roots," *International Journal of Periodontics and Restorative Dentistry*, vol. 26, no. 1, pp. 19–29, 2006.

[70] B. I. Simon, S. Von Hagen, M. J. Deasy, M. Faldu, and D. Resnansky, "Changes in alveolar bone height and width following ridge augmentation using bone graft and membranes," *Journal of Periodontology*, vol. 71, no. 11, pp. 1774–1791, 2000.

[71] G. Zubillaga, S. Von Hagen, B. I. Simon, and M. J. Deasy, "Changes in alveolar bone height and width following post-extraction ridge augmentation using a fixed bioabsorbable membrane and demineralized freeze-dried bone osteoinductive graft," *Journal of Periodontology*, vol. 74, no. 7, pp. 965–975, 2003.

[72] S. Fickl, O. Zuhr, H. Wachtel, M. Kebschull, and M. B. Hürzeler, "Hard tissue alterations after socket preservation with additional buccal overbuilding: a study in the beagle dog," *Journal of Clinical Periodontology*, vol. 36, no. 10, pp. 898–904, 2009.

[73] S. Fickl, D. Schneider, O. Zuhr et al., "Dimensional changes of the ridge contour after socket preservation and buccal overbuilding: an animal study," *Journal of Clinical Periodontology*, vol. 36, no. 5, pp. 442–448, 2009.

[74] M. Stimmelmayer, E. P. Allen, T. E. Reichert, and G. Iglhaut, "Use of a combination epithelized-subepithelial connective tissue graft for closure and soft tissue augmentation of an extraction site following ridge preservation or implant placement: description of a technique," *The International Journal of Periodontics & Restorative Dentistry*, vol. 30, no. 4, pp. 375–381, 2010.

[75] T. Thalmair, M. Hinze, W. Bolz, and H. Wachtel, "The healing of free gingival autografts for socket-seal surgery: a case

report," *The European Journal of Esthetic Dentistry*, vol. 5, no. 4, pp. 358–368, 2010.

[76] C. J. Landsberg and N. Bichacho, "A modified surgical/prosthetic approach for optimal single implant supported crown. Part I—the socket seal surgery," *Practical Periodontics and Aesthetic Dentistry*, vol. 6, no. 2, pp. 11–19, 1994.

[77] M. Nevins and J. T. Mellonig, "The advantages of localized ridge augmentation prior to implant placement: a staged event," *The International Journal of Periodontics & Restorative Dentistry*, vol. 14, no. 2, pp. 96–111, 1994.

[78] C. J. Landsberg, "Socket seal surgery combined with immediate implant placement: a novel approach for single-tooth replacement," *International Journal of Periodontics and Restorative Dentistry*, vol. 17, no. 2, pp. 141–149, 1997.

[79] H. Tal, "Autogenous masticatory mucosal grafts in extraction socket seal procedures: a comparison between sockets grafted with demineralized freeze-dried bone and deproteinized bovine bone mineral," *Clinical Oral Implants Research*, vol. 10, no. 4, pp. 289–296, 1999.

[80] W. Schulte, H. Kleineikenscheidt, K. Lindner, and R. Schareyka, "The Tubingen immediate implant in clinical studies," *Deutsche zahnarztliche Zeitschrift*, vol. 33, no. 5, pp. 348–859, 1978.

[81] W. Schulte, H. Kleineikenscheidt, R. Schareyka, and G. Heimke, "Concept and testing of the Tubingen immediate implant," *Deutsche zahnarztliche Zeitschrift*, vol. 33, no. 5, pp. 319–325, 1978.

[82] W. Schulte, H. Kleineikenscheidt, K. Lindner et al., "Animal experiments on the question of healing around the Tübingen immediate implant," *Deutsche zahnarztliche Zeitschrift*, vol. 33, no. 5, pp. 326–331, 1978.

[83] I. Barzilay, G. N. Graser, B. Iranpour, and J. R. Natiella, "Immediate implantation of a pure titanium implant into an extraction socket: report of a pilot procedure," *The International Journal of Oral & Maxillofacial Implants*, vol. 6, no. 3, pp. 277–284, 1991.

[84] I. Barzilay, G. N. Graser, B. Iranpour, and H. M. Proskin, "Immediate implantation of pure titanium implants into extraction sockets of Macaca fascicularis part I: clinical and radiographic assessment," *International Journal of Oral and Maxillofacial Implants*, vol. 11, no. 3, pp. 299–310, 1996.

[85] I. Barzilay, G. N. Graser, B. Iranpour, J. R. Natiella, and H. M. Proskin, "Immediate implantation of pure titanium implants into extraction sockets of Macaca fascicularis. Part II: histologic observations," *International Journal of Oral and Maxillofacial Implants*, vol. 11, no. 4, pp. 489–497, 1996.

[86] D. Botticelli, T. Berglundh, and J. Lindhe, "Hard-tissue alterations following immediate implant placement in extraction sites," *Journal of Clinical Periodontology*, vol. 31, no. 10, pp. 820–828, 2004.

[87] M. G. Araújo, F. Sukekava, J. L. Wennström, and J. Lindhe, "Ridge alterations following implant placement in fresh extraction sockets: an experimental study in the dog," *Journal of Clinical Periodontology*, vol. 32, no. 6, pp. 645–652, 2005.

[88] M. G. Araújo, F. Sukekava, J. L. Wennström, and J. Lindhe, "Tissue modeling following implant placement in fresh extraction sockets," *Clinical Oral Implants Research*, vol. 17, no. 6, pp. 615–624, 2006.

[89] M. G. Araújo, J. L. Wennström, and J. Lindhe, "Modeling of the buccal and lingual bone walls of fresh extraction sites following implant installation," *Clinical Oral Implants Research*, vol. 17, no. 6, pp. 606–614, 2006.

[90] D. Botticelli, L. G. Persson, J. Lindhe, and T. Berglundh, "Bone tissue formation adjacent to implants placed in fresh extraction sockets: an experimental study in dogs," *Clinical Oral Implants Research*, vol. 17, no. 4, pp. 351–358, 2006.

[91] D. Botticelli, T. Berglundh, D. Buser, and J. Lindhe, "The jumping distance revisited: an experimental study in the dog," *Clinical Oral Implants Research*, vol. 14, no. 1, pp. 35–42, 2003.

[92] D. Botticelli, T. Berglundh, and J. Lindhe, "Resolution of bone defects of varying dimension and configuration in the marginal portion of the peri-implant bone: an experimental study in the dog," *Journal of Clinical Periodontology*, vol. 31, no. 4, pp. 309–317, 2004.

[93] M. Caneva, L. A. Salata, S. S. De Souza, G. Baffone, N. P. Lang, and D. Botticelli, "Influence of implant positioning in extraction sockets on osseointegration: histomorphometric analyses in dogs," *Clinical Oral Implants Research*, vol. 21, no. 1, pp. 43–49, 2010.

[94] M. Sanz, D. Cecchinato, J. Ferrus, E. B. Pjetursson, N. P. Lang, and J. Lindhe, "A prospective, randomized-controlled clinical trial to evaluate bone preservation using implants with different geometry placed into extraction sockets in the maxilla," *Clinical Oral Implants Research*, vol. 21, no. 1, pp. 13–21, 2010.

[95] C. Tomasi, M. Sanz, D. Cecchinato et al., "Bone dimensional variations at implants placed in fresh extraction sockets: a multilevel multivariate analysis," *Clinical Oral Implants Research*, vol. 21, no. 1, pp. 30–36, 2010.

[96] M. Caneva, L. A. Salata, S. S. de Souza, E. Bressan, D. Botticelli, and N. P. Lang, "Hard tissue formation adjacent to implants of various size and configuration immediately placed into extraction sockets: an experimental study in dogs," *Clinical Oral Implants Research*, vol. 21, no. 9, pp. 885–890, 2010.

[97] M. Caneva, D. Botticelli, F. Rossi, L.C. Cardoso, F. Pantani, and N.P. Lang, "Influence of implants with different sizes and configurations installed immediately into extraction sockets on peri-implant hard and soft tissues: an experimental study in dogs," *Clinical Oral Implants Research*, vol. 23, no. 4, pp. 396–401, 2012.

[98] M. Caneva, D. Botticelli, L. A. Salata, S. L. Scombatti Souza, L. Carvalho Cardoso, and N. P. Lang, "Collagen membranes at immediate implants: a histomorphometric study in dogs," *Clinical Oral Implants Research*, vol. 21, no. 9, pp. 891–897, 2010.

[99] M. Caneva, D. Botticelli, E. Stellini, S. L. S. Souza, L. A. Salata, and N. P. Lang, "Magnesium-enriched hydroxyapatite at immediate implants: a histomorphometric study in dogs," *Clinical Oral Implants Research*, vol. 22, no. 5, pp. 512–517, 2011.

[100] M. Caneva, D. Botticelli, F. Morelli, G. Cesaretti, M. Beolchini, and N.P. Lang, "Alveolar process preservation at implants installed immediately into extraction sockets using deproteinized bovine bonemineral-an experimental study in dogs," *Clinical Oral Implants Research*. In press.

[101] M. Caneva, D. Botticelli, F. Pantani, G. M. Baffone, I. G. Rangel, and N. P. Lang, "Deproteinized bovine bone mineral in marginal defects at implants installed immediately into extraction sockets: an experimental study in dogs," *Clinical Oral Implants Research*, 2011.

[102] M. G. Araújo, E. Linder, and J. Lindhe, "Bio-Oss Collagen in the buccal gap at immediate implants: a 6-month study in the dog," *Clinical Oral Implants Research*, vol. 22, no. 1, pp. 1–8, 2011.

[103] C. H. F. Hämmerle, S. T. Chen, and T. G. Wilson Jr, "Consensus statements and recommended clinical procedures

regarding the placement of implants in extraction sockets," *International Journal of Oral and Maxillofacial Implants*, vol. 19, pp. 26–28, 2004.

[104] I. Sanz, M. Garcia-Gargallo, D. Herrera, C. Martin, E. Figuero, and M. Sanz, "Surgical protocols for early implant placement in post-extraction sockets: a systematic review," *Clinical Oral Implants Research*, vol. 23, supplement 5, pp. 67–79, 2012.

[105] Z. Lin, H. F. Rios, S. L. Volk, J. V. Sugai, Q. Jin, and W. V. Giannobile, "Gene expression dynamics during bone healing and osseointegration," *Journal of Periodontology*, vol. 82, no. 7, pp. 1007–1017, 2011.

[106] G. Serino, S. Biancu, G. Iezzi, and A. Piattelli, "Ridge preservation following tooth extraction using a polylactide and polyglycolide sponge as space filler: a clinical and histological study in humans," *Clinical Oral Implants Research*, vol. 14, no. 5, pp. 651–658, 2003.

[107] G. Serino, W. Rao, G. Iezzi, and A. Piattelli, "Polylactide and polyglycolide sponge used in human extraction sockets: bone formation following 3 months after its application," *Clinical Oral Implants Research*, vol. 19, no. 1, pp. 26–31, 2008.

[108] S. E. Lynch, *Tissue Engineering: Applications in Oral and Maxillofacial Surgery and Periodontics*, 2nd edition, 2008.

[109] T. H. Howell, J. Fiorellini, A. Jones et al., "A feasibility study evaluating rhBMP-2/absorbable collagen sponge device for local alveolar ridge preservation or augmentation," *International Journal of Periodontics and Restorative Dentistry*, vol. 17, no. 2, pp. 125–139, 1997.

[110] D. L. Cochran, A. A. Jones, L. C. Lilly, J. P. Fiorellini, and H. Howell, "Evaluation of recombinant human bone morphogenetic protein-2 in oral applications including the use of endosseous implants: 3-year results of a pilot study in humans," *Journal of Periodontology*, vol. 71, no. 8, pp. 1241–1257, 2000.

[111] J. P. Fiorellini, T. Howard Howell, D. Cochran et al., "Randomized study evaluating recombinant human bone morphogenetic protein-2 for extraction socket augmentation," *Journal of Periodontology*, vol. 76, no. 4, pp. 605–613, 2005.

[112] M. L. Nevins, M. Camelo, P. Schupbach, D. M. Kim, J. M. B. Camelo, and M. Nevins, "Human histologic evaluation of mineralized collagen bone substitute and recombinant platelet-derived growth factor-bb to create bone for implant placement in extraction socket defects at 4 and 6 months: a case series," *International Journal of Periodontics and Restorative Dentistry*, vol. 29, no. 2, pp. 129–139, 2009.

[113] D. Kaigler, G. Pagni, A. Galloro et al., "Acceleration of human oral osseous regeneration using bone repair cells," in *Proceedings of the 39th AADR Annual Meeting*, Washington, DC, USA, 2010.

[114] D. Kaigler, G. Pagni, C. H. Park, S. A. Tarle, R. L. Bartel, and W. V. Giannobile, "Angiogenic and osteogenic potential of bone repair cells for craniofacial regeneration," *Tissue Engineering A*, vol. 16, no. 9, pp. 2809–2820, 2010.

[115] G. Pagni, D. Kaigler, G. Rasperini, G. Avila-Ortiz, R. Bartel, and W. V. Giannobile, "Bone repair cells for craniofacial regeneration," *Advanced Drug Delivery Reviews*. In press.

[116] S. T. Chen, I. B. Darby, and E. C. Reynolds, "A prospective clinical study of non-submerged immediate implants: clinical outcomes and esthetic results," *Clinical Oral Implants Research*, vol. 18, no. 5, pp. 552–562, 2007.

[117] N. P. Lang, L. Pun, K. Y. Lau, K. Y. Li, and M. C. Wong, "A systematic review on survival and success rates of implants placed immediately into fresh extraction sockets after at least 1 year," *Clinical Oral Implants Research*, vol. 23, supplement 5, pp. 39–66, 2012.

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Research Article

How Precise Is Dental Volumetric Tomography in the Prediction of Bone Density?

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Objectives. The aim of this study was to review the bone density assessment techniques and evaluate the macroscopic structure of bone specimens scored by Hounsfield Units (HUs) and decide if they are always in congruence. *Methods*. The mandible of a formalin-fixed human cadaver was scanned by dental volumetric tomography (DVT) for planning of the specimen positions and fabrication of a surgical guide and a surgical stent was fabricated afterwards. Bone cylinders of 3.5 mm diameter and 5 mm length, were excised from the mandible using the surgical stent with a slow speed trephine drill. After removal of the cylinders two more scans were performed and the images of the first scan were used for the determination of the HU values. The removed bone cylinder was inspected macroscopically as well by micro-CT scan. *Results*. The highest HU values were recorded in the interforaminal region, especially in the midline (408–742). Posterior regions showed lower HU values, especially the first molar regions (22–61 for the right; 14–66 for the left first molar regions). *Conclusion*. Within the limitations of this pilot study, it can be concluded that HU values alone could be a misleading diagnostic tool for the determination of bone density.

1. Introduction

Dental implants play an important role in the treatment of partial or complete edentulism. Although the success is very high, posterior maxilla can withstand lower mechanical forces because of its thinner cortical layer, and the lower density of the maxillary spongiosa [1] thus is more critical than other sites. Furthermore, the maxillary sinus restrict the available bone volume, necessitating shorter implants and/or grafting procedures [2].

Bone density plays an important role in planning of implant dentistry in terms of timing of loading as well as number of implants to be used for denture support especially in critical locations such as posterior maxillae. Bone mass, structural properties (macro- and microarchitecture), and material properties (modulus of elasticity, mineral density, etc.) constitute mechanical competence of bone, which is commonly referred to as bone quality in implant dentistry [3]. Substantial variations in bone quality in corresponding anatomical sites and direct correlation between bone quality and implant success rates exist [4]. Since mechanical behavior of bone is a critical factor in the attainment and maintenance of osseointegration, several classification systems and procedures were advocated for assessing bone quality and predicting prognosis [5, 6].

These assessment methods have various limitations in addressing cortical and cancellous bones in a subjective and quantitative manner. There are several radiological methods for bone mineral density (BMD) measurements yielding close relationships such as dual-X-ray absorptiometry (DXA) scanning [7] and Hounsfield unit (HUs) from computed tomography imaging [7]. Texture analysis has been applied in micro-CT [8], while Hounsfield units (HU) have been used in spiral CT as a measure, related to jaw BMD [9]. Cone beam computed tomography (CBCT) is a more recent development than spiral CT. Its clinical application in the field of dentomaxillofacial radiology is gaining importance and spreading widely [10–12], but the available research on CBCT-based bone quality assessment is scarce. Low dose CBCT is often advised for implant planning, considering the possibility to gather clinically relevant 3D data at a low dose, but CBCT does not necessarily allow

reliable and accurate bone quality assessment when focusing on the inherent radiographic density information that is otherwise expressed by HU [13]. On the other hand, a very recent study reported of a strong positive correlation of radiographic bone density assessed by CBCT with bone volumetric fraction assessed by micro-CT at the site of dental implants in the maxillary bones [14].

Although strong correlations exist, still a 30–50% of unaccounted variance in mechanical properties from bone density measurement has been reported [15, 16]. Osteoporotic cancellous bone is characterized by low bone mass as well as a deterioration of the microarchitecture. Whether a patient is diagnosed osteoporotic depends only on his/her BMD and how this BMD value compares to a population average [17]. Clinical results have shown that BMD of patients with osteoporotic bone fractures and patients without such fractures can have a substantial overlap [18], causing variance similar to that in density—mechanical property relationship studies. The microarchitecture of cancellous bone has been largely attributed to this variance; density approximates the amount of bone tissue within a cancellous bone specimen but it does not quantify the microarchitecture that is inherent. Together with bone density readings, a quantitative measurement of microarchitectural parameters may improve our ability to better estimate bone strength [19]. Microcomputed tomography (micro-CT) is a relatively new method to image and quantify bone with very high resolution [14, 20]. Microcomputed tomography (micro-CT) scanners, with similar working principle as conventional clinical CT scanners, have been used to study microstructure of materials in three dimensions and to study the relationship between microarchitectural parameters [21] and mechanical properties of cancellous bone [22]. Micro-CT may not be applicable routinely in clinical practice for now, although as a reliable method for bone mass and structure evaluation, it might offer much needed insight into bone quality assessment by providing objective and quantitative microstructural data. Image datasets of human cancellous bone specimens at micron resolution were acquired and from these datasets, microarchitectural parameters have been determined and converted into microfinite element (FE) models [23]. It was shown that the predictive power of bone strength and stiffness was improved with the combination of bone density and microarchitecture information and this work supported the prediction of microarchitecture using current clinical computed tomography imaging technology [23].

While clinical CT scanners typically produce images composed of 1 mm^3 volume elements (voxels), X-ray microcomputed tomography (micro-CT or μCT) systems developed in the early 1980s had much better spatial resolution, producing voxels in the range of 5–50 μm, or approximately 1,000,000 times smaller in volume than CT voxels [24, 25]. Early micro-CT scanners were custom-built and not widely available. Compact commercial systems are now available and are rapidly becoming essential components of many academic and industrial research laboratories. A wide range of specimens may be examined directly using Micro-CT including mineralized tissues such as teeth, bone, and materials such as ceramics, polymers, or biomaterial scaffolds [26].

Micro-CT systems are now widely used in many academic fields, several recent reviews have presented the current state of micro-CT imaging and analysis of them [14, 27–30].

Emphasis has traditionally been placed on the cortical bone as quality predictor due to its stiffness for achieving primary stabilization [31, 32]. However, a dental implant is mainly in contact with cancellous part of bone, and mechanical characteristics of cancellous bone also influence the load bearing capacity of implant-bone union. In fact, the presurgical determination of bone density plays an important role in planning of the surgical procedure as well as prosthetic treatment. In another study human cadaveric maxillary and mandibular trabecular bone with 3D morphometric data acquired through micro-CT were analyzed and correlated with bone density measurements in Hounsfield scale and Lekholm-Zarb bone classification [3, 5].

Micro-CT is a nondestructive, fast, and precise technique that allows measurements of trabecular and cortical bone [26]. It can provide a spatial representation of bone formation at the implant surface and the peri-implant region up to a few microns or even better, and can evaluate both qualitative and quantitative morphometry of bone integration about dental implants [33].

The aim of this pilot study was to review the current literature about bone density assessment and evaluate the macroscopic structure of bone specimens having been scored by Hounsfield units afore.

2. Material and Methods

2.1. Experimental Protocol

2.1.1. Preoperative CBCT Imaging. The mandible of a formalin-fixed human cadaver was involved in this study. After removal of the mandible from the cadaver, the obtained mandible was scanned by dental volumetric tomography (DVT) for planning of the specimen positions and fabrication of a surgical guide. The scan of the mandible was performed with a Newtom (Newtom Cone Beam 3D Imaging, AFP Imaging Corporation, New York, USA; Figure 1). A surgical guide was fabricated on the cast obtained from an impression of the alveolar process of the mandible (Figure 2).

2.1.2. Specimen Preparation. Bone cylinders of 3.5 mm diameter and 5 mm length, were excised from a cadaver mandible using the surgical stent (Figure 3). Excising of bone cylinders from the mandibular body was done using a slow speed trephine drill (Trephine Drill 3.5 mm × 22 mm, Salvin Dental Specialties, Inc, Charlotte, NC, USA) under constant irrigation by the use of the prepared stent (Figure 4). Nine bone cylinders in total were extracted for the experiment; cylinders were stored in consequently numerated 0.9% saline solution containing little vessels. However, since 2 of the cylinders were damaged during removal, these were excluded from the study. The 5 mm cylinder length was chosen to

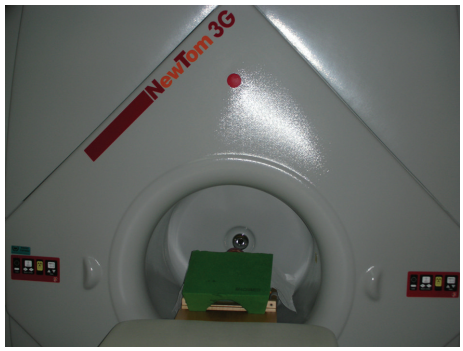

Figure 1: Newtom cone beam 3D imaging equipment.

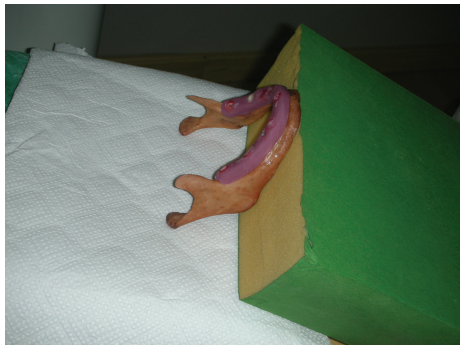

Figure 2: The surgical guide which was fabricated on the cast obtained from an impression of the alveolar process of the mandible.

Figure 3: Excised bone cylinders using the surgical stent.

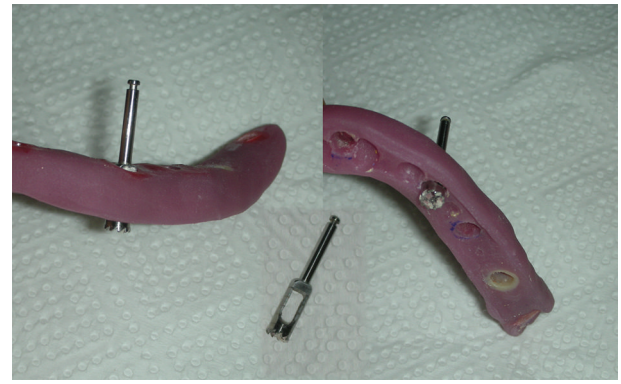

Figure 4: Excision of bone cylinders from the mandibular body using a slow speed trephine drill.

satisfy continuum assumption, so that mechanical properties derived for each cylinder was representative of the whole bone [34].

2.1.3. Postoperative CBCT Imaging and Determination of the Hounsfield Units. After removal of the cylinders two more scans were performed, with the surgical stent and without surgical the stent, respectively. The images of the first scan were used for the determination of the Hounsfield Unit values. The cavities of the removed bone specimens were localized by viewing the second and third scan images and the Hounsfield Unit values of the missing bone cylinders was determined by taking the mean of five values: coronal, apical, buccal, lingual, and the center. The software (Newtom Imaging Software, AFP Imaging Corporation, New York, USA) is capable of giving graphically the HU values of the marked zone. For each bone cylinder, the raw CT values were converted into HU by means of the following formula [35]: $HU = 1000(CT - CT_w)/(CT_w - CT_a)$ where CT, CT_w, and CT_a are the values of bone, saline, and air, respectively.

2.1.4. Micro-CT Imaging. As a part of the pilot study, the bone cylinder on the left first premolar molar region of human cadaver bone was randomly chosen for micro-CT scanning. The bone cylinder was placed in a custom vessel wrapped in paper soaked with saline solution to prevent any desiccation, and isotropically scanned at 14 μm resolution with a model 1172 micro-CT scanner (Skyscan, Kontich, Belgium) using a CBCT scanning technique (Figure 5). CBCT is a novel CT image acquisition technique in which up to a several hundred CT images (as opposed to 1–3 images in normal CT) are reconstructed by one data acquisition as the data on the fluoroscopic image is handled as plane data. The total time required for scanning and reconstruction was approximately 30 minutes per sample, thus deterioration of the bone cylinder as a result of being exposed to ambient conditions was significantly reduced. To ensure a consistent CT image resolution among all the datasets, the scanner turntable location was fixed at a specific SOD and SID distance of 19.03 mm and 356.90 mm, respectively. The X-ray parameters were set at 51 kV and 200 μA and the CT images were processed at a scaling coefficient of 50 and averaged three times. With these parameters, together with a 0.5 mm aluminum plate placed at the X-ray detector, a good contrast was achieved in the resultant CT images between trabeculae. Resultant dataset had an isotropic resolution of 14.836 μm. Resultant CT images for each bone cylinder was evaluated for microarchitectural parameters

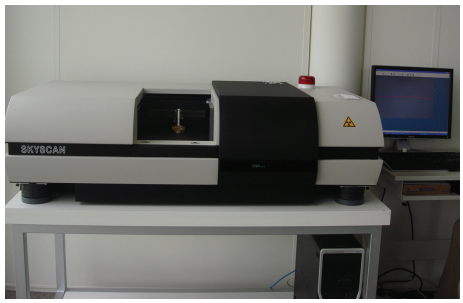

Figure 5: The photograph of the micro-CT scanner.

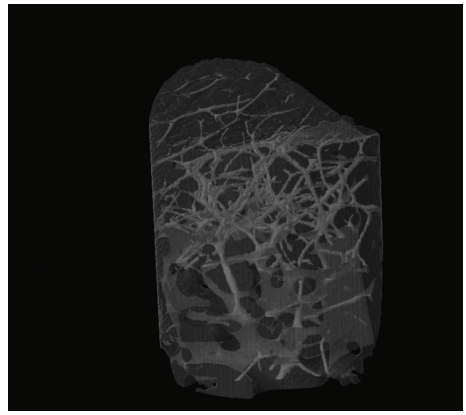

Figure 6: The micro-CT image of the cylinder-shaped bone specimen.

[19] such as tissue volume, bone volume, percent bone volume, tissue surface, bone surface, intersection surface, bone specific surface, bone surface density, trabecular bone pattern factor, structure model index, trabecular thickness, trabecular number and trabecular separation (CT Analyzer, Skyscan, Belgium) (Figure 6).

3. Results

3.1. Relationship between Microarchitectural Parameters and Hounsfield Unit and Interrelationship between Microarchitectural Parameters. The main objective of this study was to study the possibility of inferring of microarchitectural parameters from clinical CT images.

The rate of cancellous bone volume in the total volume of core is the bone volume density (BV/TV), which was in the range of 0.12–0.29 for the sample.

All the measured HU values, means, and ranges are shown in Table 1. The highest HU values were encountered in the interforaminal region, especially in the midline (408–742). Posterior regions showed lower HU values, especially the first molar regions (22–61 for the right; 14–66 for the left first molar regions). The bone cylinder which was scanned by micro-CT showed an incongruous structure when HU of the donor site was considered. The HU values indicated a higher density bone, whereas the Micro CT image revealed rather a spongious bone (Figure 6).

4. Discussion

Our primary objective of studying the relationship between HU from CT images and microarchitectural parameters, density given in objective values (mg/cm^3) and HU, was the evaluation of a diagnostic tool for in vivo assessment of bone quality.

A formalin-fixed cadaver mandible was harvested and used in the present study for several reasons. The main reason was the ease to obtain in comparison to a fresh cadaver as recommended in a few studies [36, 37]. Another reason was the protection from communicable diseases. Tissue fixation with 10% formalin (4% formaldehyde) is widely used to preserve specimens without refrigeration, offering researchers the added benefit of protection from specimens with communicable diseases [38–42]. Although it is assumed that formalin fixation alters the mechanical properties of bone, studies failed to deduce quantitative data [43, 44]. Chemical fixation through the use of aldehydes has been shown to cause a direct effect on bone mechanical properties by forming an increased number of inter- and intrafibrillar cross-links of primary amine groups of polypeptide collagen chains [38, 44] have shown that while formalin fixation has no effect on the mineral composition of bone, it causes the collagen fibrils to be more closely packed. However, in a recent study it was reported that formalin fixation and freezing would not adversely affect the viscoelastic and elastic mechanical properties of murine bone [45]. The use of embalmed bone is known to be used in studies testing the mechanical behavior and efficacy of fracture fixation devices, joint prostheses, and other reconstructive orthopedic devices [46].

Accuracy of micro-CT was qualitatively evaluated by comparing to standard histomorphometric data with the corresponding CT slices for the same specimen. The results showed that, in general there was a good correlation between histomorphometric data and microtomographic data. One author obtained a correlation coefficient of 0.855 [33].

The result from this pilot study has raised doubt that in addition to bone density, bone microarchitectural parameters can also be predicted from clinical-CT imaging. We chose to use the CBCT, as it is a three-dimensional measurement often used in dentistry. In similar studies [47, 48], it was reported that to reasonably evaluate cancellous bone architecture, image datasets of resolutions not more than 100 μm should be used. Microarchitectural parameters from both clinical-CT imaging and histological sections were also compared and it was shown that high-resolution clinical-CT resulted in an overestimation of microarchitectural parameters. In a recent study [3], the scan was initially utilized to assess bone quality subjectively in Lekholm and Zarb classification [5] at incisor and molar edentulous sites by rating the distribution of cortical and cancellous bones

Table 1: HU values of the specified regions.

Region	HU values					HU range	HU mean
1	84	40	50	74	66	40–84	62,8
2	32	61	44	30	22	22–61	37,8
3	164	92	74	129	155	74–164	122,8
4	234	285	378	354	308	234–378	311,8
5	742	614	534	586	408	408–742	576,8
6	384	425	331	285	456	285–456	376,2
7	124	185	98	82	155	82–185	128,8
8	24	66	62	14	26	14–66	38,4
9	84	107	42	34	26	26–107	58,6

Region 1: right retromolar pad region of human cadaver bone.
Region 2: right first molar region of human cadaver bone.
Region 3: right first premolar molar region of human cadaver bone.
Region 4: right lateral region of human cadaver bone.
Region 5: midline (symphysis).
Region 6: left lateral region of human cadaver bone.
Region 7: left first premolar molar region of human cadaver bone.
Region 8: left first molar region of human cadaver bone.
Region 9: left retromolar pad region of human cadaver bone.

and density of cancellous bone in HU was determined through a function of the CT equipment by averaging the readings of multiple slices within respective sites. Similarly, in our study, the Hounsfield units were determined by taking the average of five values of the removed cylinders: coronal, apical, buccal, center, and lingual, additionally stating the range of HU values of each cylinder.

For harvesting the cylinders a trephine drill was used as described in another study [3]. There is great difficulty in accurately excising bone specimens that correspond to the exact CT volume of interest, if the bone specimens are to be excised after clinical imaging, as pointed out in a previous study [23]. In the previously mentioned study, the specimens were scanned after removal from the bone for this reason. However in the present study we preferred to use the whole mandible in the CBCT to mimic the clinical application.

In a study by Fanuscu and Chang [3], the anterior sites in both arches were noted to be volumetrically denser than the posterior sites, indicating varying bone mass. It was noted that volume density remained depthwise stable in the maxilla, whereas in the mandible it decreased with depth in the corono-apical direction, as being seen in our study too.

Current classifications and procedures for evaluating bone have certain shortcomings as mechanical competence in terms of mass, structure and material is not well addressed for trabecular bone. There have been unsuccessful attempts to quantify bone density in consideration of mechanical strength. Friberg et al. [49] proposed an objective cutting resistance procedure that might provide a composite value for mechanical characteristics in predicting bone quality for initial stability. However, mechanics of drilling with a bur and withstanding occlusal forces by an implant has to be further investigated and correlated. Trisi and Rao [50] compared histomorphometrics and hand-felt cutting resistance and demonstrated that subjective tactile sensation was proved to be poor in discerning finer differences.

About ten years ago an image-based bone density classification that utilizes gray-scale values through CT was suggested [51]. The method of preoperative bone density measurement was advocated as a prognostic indicator in which site-specific, objective and quantitative results on the Hounsfield scale would provide bone-quality information. Following this perspective, the reliability of Hounsfield units in predicting bone density was evaluated in this preliminary study. The proposed classification evaluates bone mass; however, its mechanical value is limited without structural and material properties. Riggs et al. [52] reported on bone mass increase in osteoporotic patients by medications and found that bone strength was not increased and fracture risk was not lowered as much as expected by the gain in bone density. This suggests that there is an important influence of the complex microarchitecture on the mechanical competence of bone.

It should be underlined that CBCT data have a larger amount of scattered X-rays than conventional spiral CT. This may enhance the noise in reconstructed images, and thus affect the low contrast detectability [53]. Because of scatter and artifacts, HU values in CBCT are not valid, and therefore the method of correlating BMD to HU values from CBCT is not ideal. Moreover, the scatter and artifacts in CBCT get worse around inhomogeneous tissues with reduced HU values up to 200 HU [54], which confirms that the HU in CBCT is not a valid method for bone quality assessment. Since up till now CBCT-based bone quality assessment is neither accurate nor reliable, there is a need to find methods to circumvent the shortcomings of this particular development, so as to have a reliable way to assess bone quality or there is a need for methods, other

than density measurements, for bone quality assessment. In a bone density assessment study it was concluded that mandibular cortical bone was denser than cortical bone of the upper maxilla, whereas cancellous bone has similar densities in both mandible and the upper maxilla. The main problem appears to lie in the differentiation of tissues of similar density [14]. Texture analysis may thus come into play, which is strengthened by the fact that bone quality may be expressed by its microarchitectural composition. May be for this reason a very recent study concluded that correlation of micro-CT and conventional histomorphometry should be subject of future research [14]. In contrast to classic histomorphometry architectural metric parameters such as bone volume (BV), total volume (TV), and bone surface can be directly determined from the 3D images acquired by micro-CTs, without assuming the geometric model [55].

The increased failure rate of implants that are placed in posterior regions was attributed to differences in bone quality and quantity and elevated occlusal stress in the molar areas [56, 57]. Therefore it is very important to analyze the bone density in posterior maxillae before implant surgery.

Within the limitations of this pilot study, it can be concluded that HU values alone could be a misleading diagnostic tool for the determination of bone density. It is advisable to concentrate future research on density quantification from clinical CT images and relate those to various bone types with different mechanical properties to be able to make predictions concerning the bone quality.

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References

[1] J. Roos, L. Sennerby, U. Lekholm, T. Jemt, K. Gröndahl, and T. Albrektsson, "A qualitative and quantitative method for evaluating implant success: a 5-year retrospective analysis of the Brånemark implant," *International Journal of Oral and Maxillofacial Implants*, vol. 12, no. 4, pp. 504–514, 1997.

[2] I. Naert, G. Koutsikakis, M. Quirynen, J. Duyck, D. van Steenberghe, and R. Jacobs, "Biologic outcome of implant-supported restorations in the treatment of partial edentulism part 2: a longitudinal radiographic evaluation," *Clinical Oral Implants Research*, vol. 13, no. 4, pp. 390–395, 2002.

[3] M. I. Fanuscu and T. L. Chang, "Three-dimensional morphometric analysis of human cadaver bone: microstructural data from maxilla and mandible," *Clinical Oral Implants Research*, vol. 15, pp. 213–218, 2004.

[4] T. Jemt and U. Lekholm, "Oral implant treatment in posterior partially edentulous jaws: a 5-year follow-up report," *International Journal of Oral and Maxillofacial Implants*, vol. 8, no. 6, pp. 635–640, 1993.

[5] U. Lekholm and G. A. Zarb, "Patient selection and preparation," in *Tissue Integrated Prostheses: Osseointegration in Clinical Dentistry*, P. I. Branemark, G. A. Zarb, and T. Albrektsson, Eds., pp. 199–209, Quintessence Publishing, Chicago, Ill, USA, 1985.

[6] C. E. Misch, "Density of bone: effect on treatment planning, surgical approach, and healing," in *Contemporary Implant Dentistry*, C. E. Misch, Ed., pp. 469–485, Mosby-Year Book, St. Louis, Mo, USA, 1993.

[7] G. Dougherty, "Quantitative CT in the measurement of bone quantity and bone quality for assessing osteoporosis," *Medical Engineering and Physics*, vol. 18, no. 7, pp. 557–568, 1996.

[8] L. Apostol, V. Boudousq, O. Basset et al., "Relevance of 2D radiographic texture analysis for the assessment of 3D bone micro-architecture," *Medical Physics*, vol. 33, no. 9, pp. 3546–3556, 2006.

[9] N. Stoppie, V. Pattijn, T. van Cleynenbreugel, M. Wevers, J. V. Sloten, and N. Ignace, "Structural and radiological parameters for the characterization of jawbone," *Clinical Oral Implants Research*, vol. 17, no. 2, pp. 124–133, 2006.

[10] M. E. Guerrero, R. Jacobs, M. Loubele, F. Schutyser, P. Suetens, and D. van Steenberghe, "State-of-the-art on cone beam CT imaging for preoperative planning of implant placement," *Clinical Oral Investigations*, vol. 10, no. 1, pp. 1–7, 2006.

[11] M. Loubele, F. Maes, F. Schutyser, G. Marchal, R. Jacobs, and P. Suetens, "Assessment of bone segmentation quality of cone-beam CT versus multislice spiral CT: a pilot study," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 102, no. 2, pp. 225–234, 2006.

[12] W. C. Scarfe, A. G. Farman, and P. Sukovic, "Clinical applications of cone-beam computed tomography in dental practice," *Journal of the Canadian Dental Association*, vol. 72, no. 1, pp. 75–80, 2006.

[13] A. Yamashina, K. Tanimoto, P. Sutthiprapaporn, and Y. Hayakawa, "The reliability of computed tomography (CT) values and dimensional measurements of the oropharyngeal region using cone beam CT: comparison with multidetector CT," *Dentomaxillofacial Radiology*, vol. 37, no. 5, pp. 245–251, 2008.

[14] R. González-García and F. Monje, "The reliability of cone-beam computed tomography to assess bone density at dental implant recipientsites: a histomorphometric analysis by micro-CT," *Clinical Oral Implants Research*. In press.

[15] T. M. Keaveny and O. C. Yeh, "Architecture and trabecular bone—toward an improved understanding of the biomechanical effects of age, sex and osteoporosis," *Journal of Musculoskeletal Neuronal Interactions*, vol. 2, no. 3, pp. 205–208, 2002.

[16] G. H. van Lenthe, J. P. W. van den Bergh, A. R. M. M. Hermus, and R. Huiskes, "The prospects of estimating trabecular bone tissue properties from the combination of ultrasound, dual-energy X-ray absorptiometry, microcomputed tomography, and microfinite element analysis," *Journal of Bone and Mineral Research*, vol. 16, no. 3, pp. 550–555, 2001.

[17] J. A. Kanis, "Osteoporosis III: diagnosis of osteoporosis and assessment of fracture risk," *The Lancet*, vol. 359, no. 9321, pp. 1929–1936, 2002.

[18] S. Majumdar, H. K. Genant, S. Grampp et al., "Correlation of trabecular bone structure with age, bone mineral density, and osteoporotic status: in vivo studies in the distal radius using high resolution magnetic resonance imaging," *Journal of Bone and Mineral Research*, vol. 12, no. 1, pp. 111–118, 1997.

[19] H. K. Genant, C. Gordon, Y. Jiang, T. F. Lang, T. M. Link, and S. Majumdar, "Advanced imaging of bone macro and micro structure," *Bone*, vol. 25, no. 1, pp. 149–152, 1999.

[20] P. Rüegsegger, B. Koller, and R. Müller, "A microtomographic system for the nondestructive evaluation of bone architecture," *Calcified Tissue International*, vol. 58, no. 1, pp. 24–29, 1996.

[21] A. M. Parfitt, "Bone histomorphometry: standardization of nomenclature, symbols and units," *Bone*, vol. 9, no. 1, pp. 67–69, 1988.

[22] D. Ulrich, B. van Rietbergen, A. Laib, and P. Rüegsegger, "The ability of three-dimensional structural indices to reflect mechanical aspects of trabecular bone," *Bone*, vol. 25, pp. 55–60, 1999.

[23] J. C. Teo, K. M. Si-Hoe, J. E. Keh, and S. H. Teoh, "Relationship between CT intensity, micro-architecture and mechanical properties of porcine vertebral cancellous bone," *Clinical Biomechanics*, vol. 21, pp. 235–244, 2006.

[24] L. A. Feldkamp, S. A. Goldstein, A. M. Parfitt, G. Jesion, and M. Kleerekoper, "The direct examination of three-dimensional bone architecture in vitro by computed tomography," *Journal of Bone and Mineral Research*, vol. 4, pp. 3–11, 1989.

[25] J. L. Kuhn, S. A. Goldstein, L. A. Feldkamp, R. W. Goulet, and G. Jesion, "Evaluation of a microcomputed tomography system to study trabecular bone structure," *Journal of Orthopaedic Research*, vol. 8, pp. 833–842, 1990.

[26] M. V. Swain and J. Xue, "State of the art of micro-CT applications in dental research," *International Journal of Oral Science*, vol. 1, no. 4, pp. 177–188, 2009.

[27] M. J. Paulus, S. S. Gleason, S. J. Kennel, P. R. Hunsicker, and D. K. Johnson, "High resolution X-ray computed tomography: an emerging tool for small animal cancer research," *Neoplasia*, vol. 2, no. 1-2, pp. 62–70, 2000.

[28] M. D. Bentley, M. C. Ortiz, E. L. Ritman, and J. Carlos Romero, "The use of microcomputed tomography to study microvasculature in small rodents," *American Journal of Physiology*, vol. 282, no. 5, pp. R1267–R1279, 2002.

[29] D. W. Holdsworth and M. M. Thornton, "Micro-CT in small animal and specimen imaging," *Trends in Biotechnology*, vol. 20, no. 8, pp. S34–S39, 2002.

[30] R. E. Guldberg, A. S. P. Lin, R. Coleman, G. Robertson, and C. Duvall, "Microcomputed tomography imaging of skeletal development and growth," *Birth Defects Research Part C*, vol. 72, no. 3, pp. 250–259, 2004.

[31] O. Geckili, H. Bilhan, and T. Bilgin, "A 24-week prospective study comparing the stability of titanium dioxide grit-blasted dental implants with and without fluoride treatment," *The International Journal of Oral & Maxillofacial Implants*, vol. 24, no. 4, pp. 684–688, 2009.

[32] N. Meredith, "Assessment of implant stability as a prognostic determinant," *The International Journal of Prosthodontics*, vol. 11, pp. 491–501, 1998.

[33] Y. S. Park, K. Y. Yi, I. S. Lee, and Y. C. Jung, "Correlation between microtomography and histomorphometry for assessment of implant osseointegration," *Clinical Oral Implants Research*, vol. 16, no. 2, pp. 156–160, 2005.

[34] T. P. Harrigan, M. Jasty, R. W. Mann, and W. H. Harris, "Limitations of the continuum assumption in cancellous bone," *Journal of Biomechanics*, vol. 21, no. 4, pp. 269–275, 1988.

[35] J. Y. Rho, J. E. Zerwekh, and R. B. Ashman, "Examination of several techniques for predicting trabecular elastic modulus and ultimate strength in the human lumbar spine," *Clinical Biomechanics*, vol. 9, no. 2, pp. 67–71, 1994.

[36] I. Turkyilmaz, L. Sennerby, B. Yilmaz, B. Bilecenoglu, and E. N. Ozbek, "Influence of defect depth on resonance frequency analysis and insertion torque values for implants placed in fresh extraction sockets: a human cadaver study," *Clinical Implant Dentistry and Related Research*, vol. 11, no. 1, pp. 52–58, 2009.

[37] W. J. Seong, U. K. Kim, J. Q. Swift, Y. C. Heo, J. S. Hodges, and C. C. Ko, "Elastic properties and apparent density of human edentulous maxilla and mandible," *International Journal of Oral and Maxillofacial Surgery*, vol. 38, no. 10, pp. 1088–1093, 2009.

[38] A. L. Boskey, M. L. Cohen, and P. G. Bullough, "Hard tissue biochemistry: a comparison of fresh-frozen and formalin-fixed tissue samples," *Calcified Tissue International*, vol. 34, no. 4, pp. 328–331, 1982.

[39] M. E. Nimni, D. Cheung, B. Strates, M. Kodama, and K. Sheikh, "Chemically modified collagen: a natural biomaterial for tissue replacement," *Journal of Biomedical Materials Research*, vol. 21, no. 6, pp. 741–771, 1987.

[40] S. L. Nuccion, N. Y. Otsuka, and J. R. Davey, "The effect of freezing and intraosseous fluid on the stiffness behavior of canine trabecular bone," *Orthopedics*, vol. 24, no. 4, pp. 375–380, 2001.

[41] S. Wingerter, G. Calvert, M. Tucci, H. Benghuzzi, G. Russell, and A. Puckett, "Mechanical strength repercussions of various fixative storage methods on bone," *Biomedical Sciences Instrumentation*, vol. 42, pp. 290–295, 2006.

[42] A. Cömert, A. M. Kökat, M. Akkocaòlu, I. Tekdemir, K. Akça, and M. C. Çehreli, "Fresh-frozen vs. embalmed bone: is it possible to use formalin-fixed human bone for biomechanical experiments on implants?" *Clinical Oral Implants Research*, vol. 20, no. 5, pp. 521–525, 2009.

[43] E. D. Sedlin and C. Hirsch, "Factors affecting the determination of the physical properties of femoral cortical bone," *Acta Orthopaedica Scandinavica*, vol. 37, no. 1, pp. 29–48, 1966.

[44] J. D. Currey, K. Brear, P. Zioupos, and G. C. Reilly, "Effect of formaldehyde fixation on some mechanical properties of bovine bone," *Biomaterials*, vol. 16, no. 16, pp. 1267–1271, 1995.

[45] A. Nazarian, B. J. Hermannsson, J. Müller, D. Zurakowski, and B. D. Snyder, "Effects of tissue preservation on murine bone mechanical properties," *Journal of Biomechanics*, vol. 42, no. 1, pp. 82–86, 2009.

[46] G. E. Chacon, F. Dillard, N. Clelland, and R. Rashid, "Comparison of strains produced by titanium and poly D, L-lactide acid plating systems to in vitro forces," *Journal of Oral and Maxillofacial Surgery*, vol. 63, no. 7, pp. 968–972, 2005.

[47] R. Müller and P. Rüegsegger, "Micro-tomographic imaging for the nondestructive evaluation of trabecular bone architecture," *Studies in Health Technology and Informatics*, vol. 40, pp. 61–79, 1997.

[48] E. Cendre, D. Mitton, J. P. Roux et al., "High-resolution computed tomography for architectural characterization of human lumbar cancellous bone: relationships with histomorphometry and biomechanics," *Osteoporosis International*, vol. 10, no. 5, pp. 353–360, 1999.

[49] B. Friberg, L. Sennerby, J. Roos, P. Johansson, C. G. Strid, and U. Lekholm, "Evaluation of bone density using cutting resistance measurements and microradiography: an in vitro study in pig ribs," *Clinical Oral Implants Research*, vol. 6, no. 3, pp. 164–171, 1995.

[50] P. Trisi and W. Rao, "Bone classification: clinical—histomorphometric comparison," *Clinical Oral Implants Research*, vol. 10, no. 1, pp. 1–7, 1999.

[51] M. R. Norton and C. Gamble, "Bone classification: an objective scale of bone density using the computerized tomography

scan," *Clinical Oral Implants Research*, vol. 12, no. 1, pp. 79–84, 2001.

[52] B. L. Riggs, S. F. Hodgson, M. W. O'Fallon et al., "Effect of fluoride treatment on the fracture rate in postmenopausal women with osteoporosis," *The New England Journal of Medicine*, vol. 322, no. 12, pp. 802–809, 1990.

[53] M. Endo, T. Tsunoo, N. Nakamori, and K. Yoshida, "Effect of scattered radiation on image noise in cone beam CT," *Medical Physics*, vol. 28, pp. 469–474, 2001.

[54] S. Yoo and F. F. Yin, "Dosimetric feasibility of cone-beam CT-based treatment planning compared to CT-based treatment planning," *International Journal of Radiation Oncology Biology Physics*, vol. 66, no. 5, pp. 1553–1561, 2006.

[55] P. Sukovic, "Cone beam computed tomography in craniofacial imaging," *Orthodontics and Craniofacial Research*, vol. 6, supplement 1, pp. 31–36, 2003.

[56] W. Becker, B. E. Backer, A. Alsuwyed, and S. Al-Mubarak, "Long-term evaluation of 282 implants in maxillary and mandibular molar positions: a prospective study," *Journal of Periodontology*, vol. 70, no. 8, pp. 896–901, 1999.

[57] V. Arisan, N. Bölükbaşi, S. Ersanli, and T. Ozdemir, "Evaluation of 316 narrow diameter implants followed for 5–10 years: a clinical and radiographic retrospective study," *Clinical Oral Implants Research*, vol. 21, pp. 296–307, 2010.