Comparison of Initial Implant Stability of Implants Placed Using Bicortical Fixation, Indirect Sinus Elevation, and Unicortical Fixation

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Purpose: *The aim of this study was to determine if self-threading dental implants placed using stopper drills to bicortically engage both the alveolar crest and sinus floor (bicortical fixation) achieved primary and/or secondary stability comparable to that of short implants only engaging alveolar crest cortical bone (unicortical fixation) or implants engaging both the crest and sinus floor but via greenstick fracture and grafting (indirect sinus elevation).* ***Materials and Methods:*** *Thirty-eight patients exhibiting 7 to 11 mm of bone coronal to the sinus floor as confirmed by preoperative CBCT were recruited. Forty-five implants were randomly assigned to one of the placement techniques. No patient received more than two implants, which were placed in opposite sides of the maxilla while using different surgical techniques. An Osstell ISQ was employed immediately after implant placement to measure stability six times in a buccolingual dimension. Secondary stability was measured at stage-two surgery after a 3- to 6-month healing period.* ***Results:*** *The greatest primary implant stability was achieved via indirect sinus elevation. However, no statistically significant difference was found among the three surgical techniques (P = .13; bicortical fixation: 71.4 [standard error = 2.1]), unicortical fixation: 69.6 [2.1], indirect sinus elevation: 75.9 [2.3]). The three techniques had similar secondary stability (P > .999; 79.9 [1.2], 80.0 [1.2], and 80.0 [1.3], respectively). Baseline residual ridge height measured on CBCT was similar (P = .1; 8.8, 9.9, and 9.4 mm, respectively), but implant diameter and length placed in the maxilla differed (P = .03/P < .001; 4.7/11.4 mm, 4.3/8.1 mm, and 4.7/11.8 mm, respectively). Primary implant stability was significantly correlated to CBCT bone density (r = 0.37).* ***Conclusion:*** *Primary and secondary implant stabilities of bicortical fixation did not differ significantly from those of unicortical fixation and indirect sinus elevation. However, use of the bicortical fixation technique is warranted since it is simpler and more economical than indirect sinus elevation; plus, it allows for longer implants than the unicortical fixation while yielding similar secondary implant stability.* Int J Oral Maxillofac Implants 2016;31:459–468. doi: 10.11607/jomi.4142

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Loss of a maxillary posterior tooth is followed by diminished ridge height in conjunction with ridge resorption and sinus pneumatization.[1] Residual alveolar bone height of ≤ 4 mm has been associated with reduced initial implant stability[2–4] and reduced implant survival rate diminished from 96% to 86%.[4] In addition to deficient bone quantity, the posterior maxilla is characterized by a thin bony cortex with poor medullary strength and low trabecular density.[5] These anatomical characteristics make it difficult to achieve initial stability.[6,7] Since primary implant stability is an important predictor for osseointegration,[8–10] surgeons may vary their surgical technique and select a specific implant design that will optimize success.

Various surgical techniques have been developed to overcome these limitations. A lateral window technique has been advocated in severely resorbed ridge height (≤ 6 mm) for maxillary sinus augmentation[2,11] in order

to gain up to 10 to 12 mm of bone[12] with or without simultaneous implant placement. However, this surgery is complex, invasive, and requires a variable healing period (6 to 9 months).[13] In the presence of a mildly reduced ridge height with 7 to 11 mm remaining but still requiring vertical gain, the less-invasive osteotome technique (indirect sinus elevation) can be used, with or without additional bone grafting material at the apex of the implant.[14–16] Although surgeons may be able to elevate the sinus membrane by 6 to 8 mm, the risk of perforation is greatly diminished when it is limited to 3 to 4 mm.[17] Without additional bone grafting, the osteotome technique has consistently shown a minimum of 2 mm intrasinus radiographic bone gain.[16,18–21] Complications associated with indirect sinus elevations employing bone grafting or not include an incidence of sinus perforation of 3.7%,[21,22] minor postoperative nasal bleeding,[18,23] and rare sinus infection at a rate of 0.8%.[22] Alternatively, shorter implants can be used to avoid involving the sinus cavity. The aforementioned sinus grafting procedures are often performed to place longer implants. Recent findings indicate no significantly greater failure rate among short implants as compared with longer implants,[24–27] when using textured-surface implants. These implants are characterized by a rough surface, thus providing a greater bone-to-implant contact percentage compared with the smooth surface found on machined-surface implants.[25] According to Fugazzotto's data collected over 7 years, short implants (6 to 9 mm) and long implants (> 10 mm) exhibit comparable survival rates (98.1% to 99.7%)[27] when using textured-surface implants and adapted surgical preparation. This is in contrast to the failure rate of machined-surface implants < 7 mm long, which was double that of longer implants ($P = .01$, 9.5% and 3.8%, respectively).[28]

While these traditional sinus augmentation techniques have well-established guidelines, they vary in complexity, invasiveness, extent of intra- and postoperative complications, and cost of additional nonautogenous grafting materials. The use of short implants potentially sidesteps these difficulties, but compared with longer implants, they may be less stable initially, and with the prevalence of peri-implant bone loss ranging from 11% to 47%,[29] may raise a concern about having less leeway in the long run.

Bicortical fixation is a novel approach intended to increase implant stability in the maxillary posterior by engaging two layers of cortical bone at the cervical crest and apically into the sinus floor. The technique involves protruding a modest portion of the implant into the sinus cavity, thereby allowing for longer implants to be placed. The use of a stopper drill and self-threading implants contributes to tight engagement with the sinus floor for superior initial implant stability compared with an indirect sinus elevation, which induces a green-stick fracture of the sinus floor. Since the sinus floor has a similar elastic modulus to the alveolar crest cortical bone and is considerably higher than that of the middle trabecular bone,[30] intentional engagement of the sinus floor when placing implants may increase initial implant stability[31–33] and potentially improve long-term survival of maxillary posterior implants. In vitro and animal studies that measured insertion/removal torque or resonance frequency analysis have reported notably favorable results for bicortical fixation over unicortical fixation[32,34] in terms of greater implant stability, 20% to 50% greater stress reduction under various loading conditions,[34–36] and no difference in marginal bone loss regardless of bicortical or unicortical implant anchorage.[36]

An implant protruded in a controlled manner has the potential to preserve the integrity of the sinus membrane, creating a tent shape space under the membrane that will be filled by a blood clot. The presence of stem cells in the periosteum of the maxillary sinus floor[37] as well as the innate osteogenic potential within the sinus membrane[38,39] allow for bone formation if the space around the implant is stable. Approximately 2 mm of bone formation has been observed after elevation of the sinus membrane and clot formation around the protruded implant without additional grafting material.[40] This bone formation around the longer implant used provides a biomechanical advantage in a limited bone quantity area such as the posterior maxilla, compared with a shorter implant placed with a unicortical fixation technique, and potentially increases the chance for long-term survival. Since bone graft materials are not used with this technique, it is more economical than the conventional indirect sinus elevation technique requiring graft materials.

The concept of bicortical stabilization using surgical drills with vertical stoppers to precisely control the amount of implant apex protrusion into the sinus, and applying self-threading implants to maintain intimate contact between implant threads and the dense sinus floor without additional bone graft materials in low-density bone, has not been tested for its safety and efficacy compared with other conventional surgical techniques. Therefore, the primary purposes of this preliminary study were *(1)* to determine if initial implant stability is comparable between a dental implant engaging both the alveolar crest cortical bone and sinus floor using a stopper drill and self-threading concept (bicortical fixation), short implants engaging only alveolar crest cortical bone (unicortical fixation), and/or implants engaging both the crest and sinus floor but with green-stick fracture (indirect sinus elevation technique); and *(2)* to determine if different surgical techniques, residual bone height, bone density, and length and width of the implants used affect initial implant stability in the posterior maxilla.

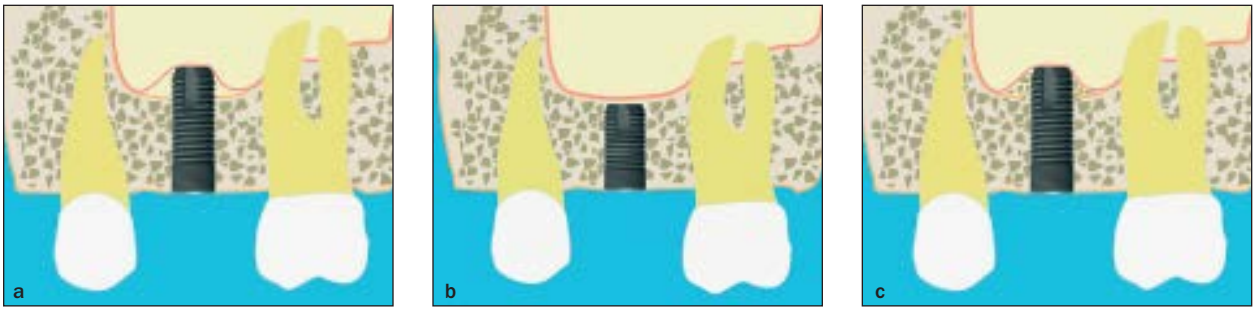

Fig 1 Schematic of implant placed using three different surgical techniques: *(a)* bicortical fixation, *(b)* unicortical fixation, and *(c)* indirect sinus elevation.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board at the University of Minnesota. This pilot study presents the findings of a prospective single-center, randomized controlled clinical trial.

Patients

Patients were recruited from the Graduate Periodontics program, Graduate Prosthodontics program, and the Faculty Dental Practice clinic at the University of Minnesota and treated between March 2010 and July 2013.

Eligible volunteers had to be partially edentulous in the maxillary posterior region, meet the standard criteria for implant placement, and have a residual 7 to 11 mm of bone height coronal to the sinus floor as confirmed by CBCT scan for diagnosis and treatment planning. Exclusion criteria consisted of smoking, overall health contraindication to implant surgery or sinus augmentation procedures, and/or implants with bone dehiscence and/or fenestration at the time of placement.

Examination

A periapical radiograph was used to perform an initial screening assessment of ridge height. Once a patient met the inclusion criteria and agreed to participate in the study, a cone beam computed tomography (CBCT) scan of the maxilla was taken prior to surgical placement of the implant. The three surgical implant placement techniques that were compared for the maxillary posterior were:

- Group 1: bicortical fixation (implants intentionally engaging the sinus floor up to 1 to 2 mm into the sinus without graft but using a stopper drill and self-threading concept)
- Group 2: unicortical fixation (short implants placed in proximity of the sinus without sinus floor involvement)
- Group 3: indirect sinus elevation technique (Fig 1)

Each patient was randomly assigned to one of the three surgical techniques, with a maximum of two implants per patient. If a patient had two implants, they were placed using different randomly assigned surgical techniques and in different quadrants. In the event where a patient was randomized to receive a unicortical technique, yet the ridge height required an implant size that was unavailable in the manufacturer's repertoire, the patient was placed in the next randomization group. The subsequent subject enrolled was then assigned to the group that was previously skipped due to limitations of existing implant sizes. The recruiting investigator was strictly blinded to the allocation of the surgical techniques until the CBCT was reviewed and the patient's enrollment into the study was completed. The study sequence is shown in Fig 2.

Clinical Procedures

Full-thickness flaps were reflected to access the alveolar bone for all treatment groups. The unicortical group and the bicortical group followed the drilling protocol recommended for soft bone Astra Tech implants (Dentsply), whereby the osteotomy was underprepared by one drill size. However, the bicortical fixation group differed in the use of stoppers engaged onto each drill. A set of stoppers fabricated to fit each implant drill would rest on the alveolar ridge crest and limit vertical advancement into the sinus (Figs 3a to 3c).

These stoppers were secured at the shortest distance from the alveolar crest to the sinus floor, based on ridge height measurements obtained from preoperative CBCT scan. Consequently, sequential drilling with depth-determining stoppers created an adequate hole at the sinus floor, enabling the self-threading implant to engage the cortical bone and protruded approximately 1 to 2 mm through the sinus floor.

The initial implant drill for the indirect sinus elevation group was set to stop 1 mm short of the sinus floor. The concave-tapered osteotome (Summers Osteotomes, Biomet 3i) carrying some bone was then tapped with a mallet to create a greenstick fracture of the sinus floor. The osteotomy was sequentially widened as bone was condensed apically into the sinus. A maximum of 4 mm of implant length was protruded into the sinus. The integrity

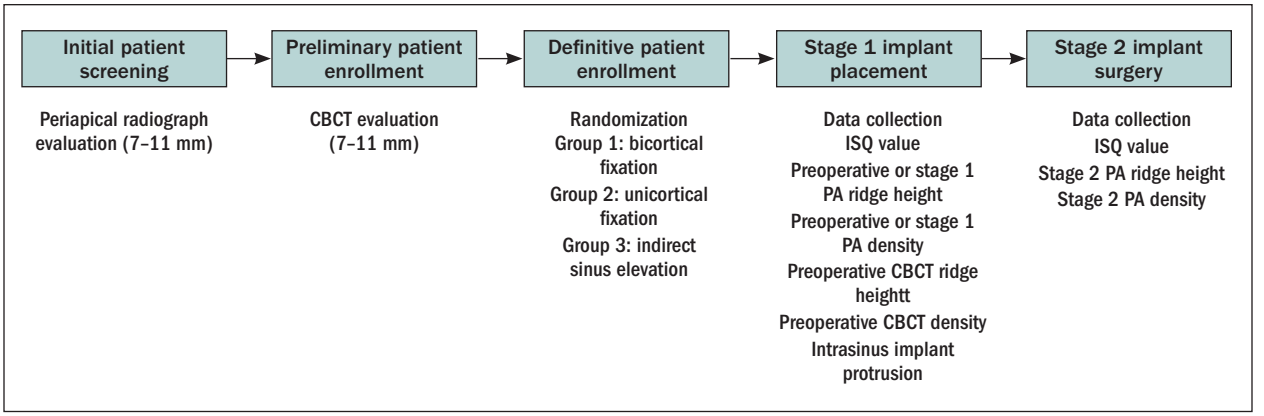

Fig 2 Schematic of study design and treatment sequence.

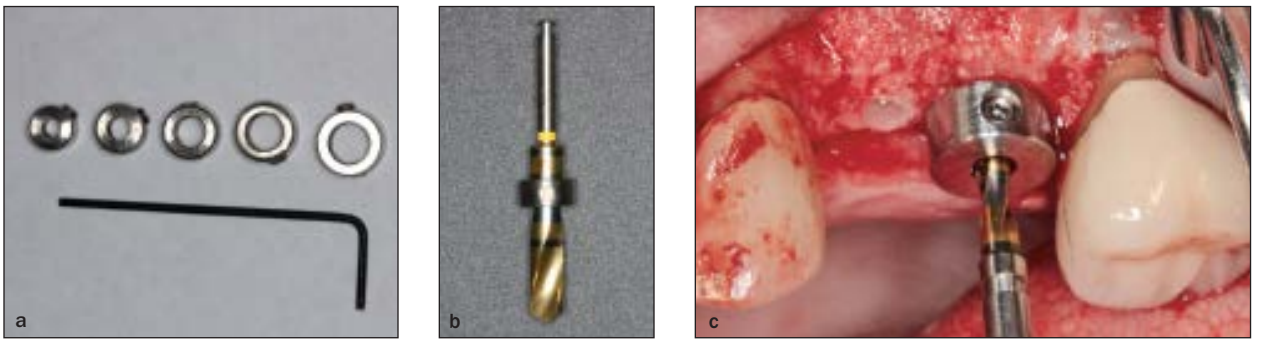

Fig 3 *(a)* Vertical stopper; a set of stoppers, fabricated to fit each implant drill diameter. *(b)* A vertical stopper screwed at the desired drilling depth and used in the bicortical fixation group. *(c)* Intraoral picture of the drill with stopper resting on the alveolar crest.

of the sinus membrane was confirmed for both the bicortical fixation and indirect sinus elevation groups by using the Vasalva maneuver (nose blowing test) and by light tactile sensation with a blunt instrument rebounding on the membrane prior to placement of the implant.

Once the fluoride-modified nanostructure, parallel walled with tapered apex implant (Astra Tech OsseoSpeed TX implant, Dentsply) was placed, the implant stability was taken as three consecutive measurements in a buccal and lingual direction, using a resonance frequency analysis (RFA) device (Osstell ISQ, Integration Diagnostics). This value was recorded as the implant stability quotient (ISQ; Figs 4a to 4c).

An aluminum (Al) step-wedge periapical radiograph was taken immediately before and after implant placement using an extension cone paralleling technique (Figs 5a to 5c). All stage-one radiographs were taken using F-speed films (Kodak Insight), processed through the same developing machine, and digitized using the same machine under the same settings at 1200 dpi. Stage-two radiographs were taken initially with conventional radiographs, and later on with a digital sensor.

Preoperative and Postoperative Management

A cover screw was placed, and primary closure was obtained over the implant. All patients were given a preoperative loading dose of antibiotic and continued for 7 to 10 days following surgery. Postoperative analgesic was prescribed as needed, and 0.125% chlorhexidine mouthrinse was utilized twice daily. Postoperative complications and patients' subjective symptoms were recorded throughout the follow-up periods.

Second Stage

The implant was uncovered between 3 and 6 months after initial implant placement. Osseointegration was confirmed clinically and radiographically as well as by using RFA. A healing abutment was placed, and an Al step-wedge periapical radiograph was taken. Secondary implant stability was again measured in triplicate with the Osstell device.

Radiographic Examination and Evaluation

The preoperative CBCT scan was used to determine ridge height, the average of the buccal and lingual ridge height of the most mesial and most distal slices of the hypothetical implant position, in millimeters (mm). Bone density was calculated from the CBCT in Hounsfield units (HU) using the HU density-measuring tool (iCAT, Imaging Sciences International). Density was gauged from a 1.0-mm-thick slice selected immediately

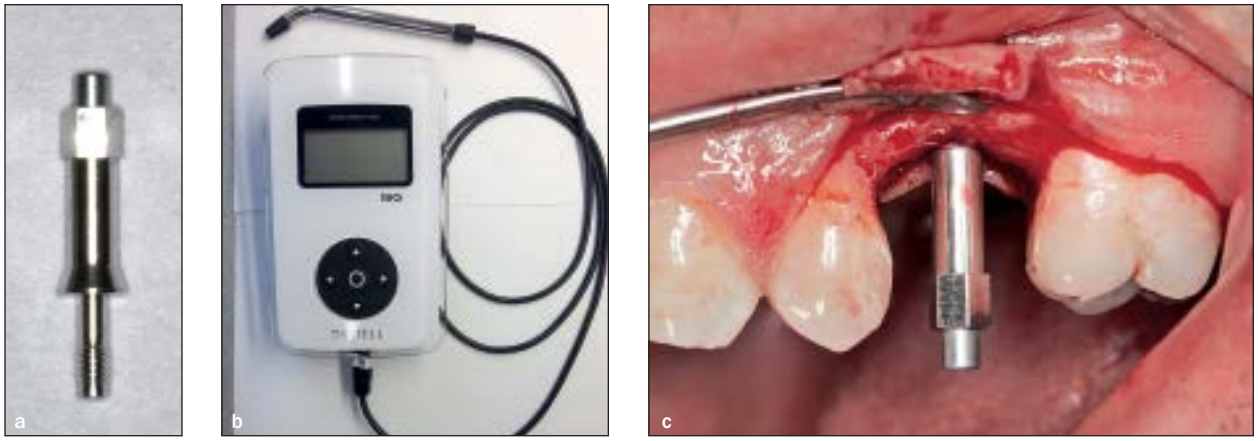

Fig 4 *(a)* Transducer. *(b)* Resonance frequency analysis (RFA) Osstell measurement device. *(c)* Transducer screwed on implant for RFA measurement.

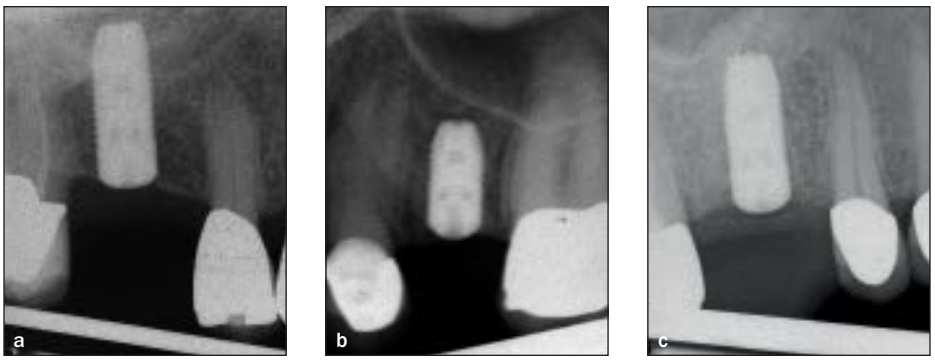

Fig 5 Radiograph of stage-one implant placement. *(a)* The bicortical fixation group shows the implant apex protruding into the sinus. *(b)* The unicortical fixation group shows the implant apex not involving the sinus floor. *(c)* The indirect sinus elevation shows a radiopaque dome created by the mineralized bone graft, surrounding the apex of the implant.

mesial and distal to the planned implant diameter. The selected area excluded crestal cortical bone, the sinus floor, and adjacent tooth structure while representing the implant position within the bone. The bone density was calculated as an average of the mesial and distal selected slices.

The periapical radiograph ridge height was measured at the shortest distance (in mm) from the sinus floor to the alveolar crest using graphic design software (Adobe Illustrator CS5, Adobe Systems). The periapical bone density measurement was calculated by taking the best available Al step-wedge (preoperative radiograph or the stage-one implant). Using Adobe Photoshop CS5, a rectangular area was selected mesial and distal to the implant (or the anticipated implant position if a preoperative radiograph was used). The selected area excluded the implant structure, the adjacent root structure, the sinus floor, and the crestal cortical bone. All data were inputted into a table to obtain a graph from which an Al step-wedge equivalent radiodensity (Al eRD) was calculated. The best available Al step-wedge periapical radiograph (either stage-one or stage-two surgery) was selected for the intrasinus implant protrusion measurement. The average of the mesial and distal protrusion was measured using Adobe Illustrator CS5.

Only one researcher measured the CBCT ridge height (in mm) and bone density (in HU) and periapical ridge height (in mm) and bone density (Al eRD in mm) and was blinded to the surgical technique used for the images being measured.

Statistical Analyses

Descriptive statistics were expressed as frequencies, percentages, or mean and standard error (SE), where appropriate. The *P* value for comparing baseline characteristics among three surgical techniques was calculated from the generalized linear mixed model to account for within-subject correlation. This method was also used to compare primary and secondary stability between surgical techniques as well as different implant diameters and lengths. The correlation between stability and baseline characteristics was assessed by Pearson's correlation coefficient (*r*) using the bootstrap method to account for within-subject correlation. The bootstrap median and 95th percentile interval are presented. Adjusted analysis was done to compare primary and secondary stability controlling for ridge height or bone density effect by the linear mixed model. All analyses were carried out using the SAS system (version 9.3; SAS Institute). All *P* values were two-sided, and .05 was considered statistically significant.

Table 1 Baseline Patient Demographic Information and Outcome Parameters (Average and SE) for the Three Treatment Groups

Variables	Estimate (SE)			*P* value
	Bicortical fixation (n = 15)	Unicortical fixation (n = 15)	Indirect sinus elevation (n = 15)	
Age (y)[a]	60.40 (7.90)	60.00 (13.00)	52.87 (12.52)	.14
Sex (n%) [a]				.63
Male	9 (60.00)	6 (40.00)	7 (46.67)	
Female	6 (40.00)	9 (60.00)	8 (53.33)	
Periapical ridge height (mm)	8.62 (0.41)	9.40 (0.40)	9.16 (0.44)	.41
Periapical bone density (AI eRD; mm)	6.73 (0.40)	6.52 (0.41)	7.52 (0.38)	.09
CBCT ridge height (mm)	8.81 (0.33)	9.89 (0.33)	9.39 (0.33)	.09
CBCT bone density (HU)	349.08 (43.59)	444.44 (43.40)	371.03 (44.45)	.29
Implant location (n%)[b]				< .01*
First premolar: #14, 24	0	4 (26.67)	1 (6.67)	
Second premolar: #15, 25	3 (20.00)	8 (53.33)	3 (20.00)	
First molar: #16, 26	9 (60.00)	2 (13.33)	10 (66.67)	
Second molar: #17, 27	3 (20.00)	1 (6.67)	1 (6.67)	
Implant diameter (mm)	4.69 (0.13)	4.25 (0.13)	4.72 (0.13)	.03*
Implant diameter (n%)[c]				.04*
4.0 mm	3 (21.43)	9 (75.00)	4 (26.67)	
5.0 mm	11 (78.57)	3 (25.00)	11 (73.33)	
Implant length (mm)	11.39 (0.38)	8.11 (0.37)	11.81 (0.38)	< .01*
Intrasinus implant protrusion	3.48 (0.29)	–1.50 (0.29)	3.42 (0.30)	< .01*

*Indicates statistically significant differences ($P < .05$)
SE = standard error.
[a]The table presents person-level characteristics; because seven patients had two implants and different surgical techniques were used for each implant, these patients are counted twice, once for each pertinent technique.
[b]FDI tooth-numbering system.
[c]3.5 and 4.5 mm are omitted due to small sample size.

RESULTS

A total of 45 dental implants were placed among 38 patients. The data of two patients were not included at stage-two surgery. One patient wished to withdraw at stage-two surgery and did not proceed because of a newly diagnosed severe illness. One patient proceeded with stage-two, but the data were removed from analyses because of significant inconsistency in the reported ISQ (initial stability ranged from 25 to 44 for a clinically stable implant placed using an indirect sinus elevation technique) and the clinical findings. The only postoperative complication reported was one patient experiencing vertigo symptoms but no involuntary eye movements (common with benign paroxysmal positional vertigo) subsequent to the indirect sinus elevation, but symptoms resolved on their own after a couple of months.

The baseline patient demographic information and outcome parameters for the three treatment groups are depicted in Table 1. A total of seven patients received two implants. There was no significant difference in age and sex among the groups. There was a significant difference ($P < .01$) in the implant position depending on the treatment group. A greater number of implants in molar sites were used with either bicortical fixation (11 implants) or indirect sinus elevation (11 implants), while premolar sites more frequently received unicortical fixation of implants (12 implants). Implant diameter and length were significantly greater in indirect sinus elevation (4.7/11.8 mm) and bicortical fixation (4.7/11.4 mm) compared with unicortical fixation (4.3/8.1 mm). Even though CBCT-based ridge height and bone density (HU) for the bicortical group were 1 mm shorter and 100 HU less dense than ones for the unicortical group, there was no statistically significant difference in baseline ridge heights and bone density between the three treatment groups. The mean intrasinus implant protrusion was 3.5 mm [SE 0.3] in the bicortical fixation group and 3.4 mm [0.3] in the indirect sinus elevation group, while the implant apex was usually 1.5 mm [0.3] coronal to the sinus floor in the unicortical

Table 2 Primary and Secondary Implant Stability Based on Treatment Group, As Measured with Resonance Frequency Analysis

Variables	Estimate (SE) Bicortical fixation (n = 15)	Unicortical fixation (n = 15)	Indirect sinus elevation (n = 14)	*P* value
Primary stability (ISQ)	71.37 (2.14)	69.55 (2.14)	75.91 (2.27)	.13
Secondary stability (ISQ)	79.89 (1.20)	80.02 (1.16)	79.96 (1.27)	> .999

ISQ = implant stability quotient.

Table 3 Correlation (*r*) Between Primary and Secondary Implant Stability and Other Variables for Implants in All Three Study Groups

Variables	Primary stability Estimate	95% CI	Secondary stability Estimate	95% CI
Periapical ridge height (mm)	0.03	(–0.27, 0.30)	–0.12	(–0.36, 0.17)
Periapical bone density (AI eRD)	0.05	(–0.22, 0.35)	0.19	(–0.17, 0.43)
CBCT ridge height (mm)	–0.01	(–0.34, 0.31)	0.02	(–0.32, 0.31)
CBCT bone density (HU)	0.37*	(0.08, 0.58)	0.25	(–0.05, 0.49)
Implant length (mm)	0.18	(–0.13, 0.45)	0.01	(–0.24, 0.32)

*Indicates a correlation significantly different from zero.

Table 4 Primary and Secondary Implant Stability Comparisons of the Three Surgical Techniques, Adjusted for Ridge Height and Bone Density

Outcome	Adjusted variables	Estimate (SE) Bicortical fixation	Unicortical fixation	Indirect sinus elevation	*P* value
Primary stability (ISQ)	Periapical ridge height (mm)	71.41 (2.22)	69.53 (2.19)	75.91 (2.30)	.14
	Periapical bone density (AI eRD)	71.38 (2.20)	69.61 (2.20)	75.88 (2.40)	.17
	CBCT ridge height (mm)	71.34 (2.27)	69.60 (2.25)	75.93 (2.30)	.14
	CBCT bone density (HU)	72.14 (1.89)	67.76 (1.94)	77.23 (2.00)	< .01*
Secondary stability (ISQ)	Periapical ridge height (mm)	79.67 (1.24)	80.09 (1.17)	80.12 (1.28)	.96
	Periapical bone density (AI eRD)	79.63 (1.22)	80.23 (1.18)	79.75 (1.34)	.93
	CBCT ridge height (mm)	79.92 (1.29)	80.01 (1.20)	79.95 (1.29)	> .999
	CBCT bone density (HU)	80.07 (1.19)	79.65 (1.17)	80.10 (1.25)	.96

*Indicates statistically significant differences ($P < .05$).
ISQ = implant stability quotient.

fixation group. Periapical bone density ($P = .09$) and the CBCT bone density ($P = .29$) were similar among treatment groups.

While primary stability was highest with the indirect sinus elevation (ISQ = 75.9 [2.3]), this did not differ significantly from the other two groups ($P = .13$; Table 2). Secondary stability measured after healing demonstrated that all three surgical techniques achieved high and almost identical implant stability, approximately 80 ($P > .999$).

Correlation between primary and secondary implant stability and other variables is shown in Table 3. There was a statistically significant positive correlation ($r = 0.37$) between primary stability and CBCT bone density (HU), but not ridge height (periapical and CBCT), periapical bone density, or implant length and diameter. Secondary stability was not impacted by the surgical technique used, the implant site, ridge height or density, or the implant diameter or length.

Results for primary and secondary implant stability adjusted for ridge height and bone density for the three surgical techniques are shown in Table 4. Only CBCT bone density showed a significant difference in primary stability among different surgical techniques, with the indirect sinus elevation demonstrating a higher primary stability ($P < .01$). However, secondary stability was similar for all three surgical techniques regardless of adjustment in ridge height or bone density (Table 4).

DISCUSSION

The primary conclusion in this investigation demonstrated that implants placed through bicortical fixation achieved comparable primary and secondary implant stability to those placed using the indirect sinus elevation or unicortical fixation techniques.

The majority of bicortical implant stability studies compared their findings primarily to unicortical fixation.[32,34] Although not statistically significant, the indirect sinus elevation group had the highest mean ISQ value (75.9) in the present study. This ISQ value was similar to the mean ISQ of 69.1 obtained in Lai et al's study,[41] in which Straumann SLA implants were placed using indirect sinus elevation without bone grafting. On the other hand, without the added effect of the osteotome lateral condensation and simply creating a greenstick fracture of the sinus floor, Markovic et al found a lower initial implant stability.[42] The latter study sequentially drilled up to the sinus floor without underpreparing the osteotomy, without grafting, and without laterally condensing bone, and reported a mean ISQ value of 59.6 ± 7.1, with a minimum value of 47.0 and maximum value of 75.0.

In the present study, several factors may have contributed to the lower ISQ value (71.4) of the bicortical fixation group compared with the indirect elevation. The design of the Osseospeed TX Astra Tech implant has an apical portion that tapers over a length of 2.5 mm. Both 4.0S and 5.0S diameter implants have their implant body diameter tapered to 2.4 and 3.2 mm at the end of the implant apex, respectively. This is narrower than the diameter of the final twist drill (3.2 and 4.2 mm, respectively) used to prepare the osteotomy of those implants. With the intended 1- to 2-mm implant intrasinus protrusion, it may be possible that the sinus floor puncture was wider than the apex of the implant. As a result, the implant walls may not have engaged the sinus floor using the self-threading concept. It is also possible that when the implant was countersunk, the shoulder of the implant no longer engaged the alveolar crest cortex, and therefore, there are questions whether bicortical fixation was truly achieved. Although a postoperative periapical radiograph was taken to confirm implant position relative to the sinus floor, the only way to ascertain this would have been to take a CBCT postoperatively. In the future, these surgical variables should be addressed with particular attention to apical implant design as well as control over the last drill bit used to improve engagement of the sinus floor to achieve true bicortical fixation.

The majority of implants were allowed to heal for 3 to 4 months before stage-two. However, depending on patients' personal reasons and/or scheduling difficulties, some implants were uncovered as late as 10 months after stage-one. Secondary stability as measured at stage-two was similar among all three surgical techniques with an ISQ of 80.

The mean intrasinus implant protrusion for bicortically fixated implants was 3.5 mm. This is higher than the intended 1 to 2 mm. When initially selecting the implant length, it was based on the CBCT buccal and lingual bone height, at the position where the implant sides would engage the bone. However, the postoperative intrasinus protrusion measurement was taken from the periapical radiograph. Using this two-dimensional image, the intrasinus protrusion can only be calculated mesial and distal of the implant and corresponds to the dip in the sinus floor where the shortest distance ridge height would be located. Therefore, it is most likely that the implant does protrude 1 to 2 mm beyond the buccal and lingual bone, but protrudes more in the mesial and distal aspects. Even though implant protrusion was greater than the intended 1 to 2 mm in the bicortical fixation group, the risk of sinus membrane perforation was low since stoppers in the bicortical fixation group allowed for depth control during the osteotomy preparation.

In both the bicortical fixation and indirect sinus elevation techniques, the sinus membrane was elevated on average by 3.5 and 3.4 mm, respectively. Nkenke et al[17] showed that the sinus membrane could be safely elevated by 3 ± 0.8 mm without increased perforation risk. In the present study, the surgeons reported no sinus membrane perforation during the procedure. However, since direct visualization of the sinus membrane was not possible, one cannot be completely certain that the integrity of the sinus membrane was maintained. Except for a mild self-resolving postoperative vertigo in one patient treated with the indirect sinus elevation, there were no sinus infections, nosebleeds, or postoperative infections. This is in comparison to the systematic review on the osteotome technique by Tan et al,[22] which reported membrane perforation (3.8%, range 0 to 21.4%) as the most common complication, and low risk of postoperative infection (0.8%, range 0 to 2.5%) and other potential complications such as postoperative bleeding, epistaxis, nasal blockage, hematomas, and suppuration due to loosened cover screws.

Other studies have used the osteotome approach to fracture the sinus floor. Without grafting and protruding the implants 3 to 5 mm, intrasinus bone gain has been observed ranging from 2 to 4 mm.[16,18–21] However, predictability of bone regeneration using this technique varied. This intrasinus bone formation in the bicortical fixation and the indirect sinus elevation groups will be reported in the next 1-year postrestoration follow-up study. It would be very interesting to see how much intrasinus bone formation has been achieved in each group when both the bicortical fixation without graft and indirect sinus elevation with graft groups had similar sinus protrusion (3.48 vs 3.42 mm) at baseline implant placement surgery.

RFA has been used to objectively and noninvasively determine initial implant stability at the time of surgical placement. The device assigns an ISQ value that is dependent on the stiffness of the bone-implant surface[43,44] and

therefore is influenced more by cortical bone thickness than by implant length.[45,46] In fact, implant macrogeometry such as length and diameter do not appear to affect primary stability as measured by RFA[47,48] as much as local bone quality.[49] As Lai et al[41] observed, RFA is most affected by bone type classified using Lekholm and Zarb.[50] The present results agree with these reports.

The present findings support the predictive value of CBCT bone density in determining primary implant stability, with a significant positive correlation of 0.37. According to Bergkvist et al,[51] bone mineral density measured from preoperative CT examination (and confirmed on postoperative CT) was significantly correlated ($P = .03$) with RFA stability values and bone quality. These density results taken from medical CT can be repeated with accuracy using a CBCT,[51] which emits less radiation and is more routinely used in the dental field. Similar correlation findings from Schnitman and Wang[52] and Turkyilmaz et al[53] suggest that preoperative CBCT bone density may be a useful objective pretreatment tool to predict initial implant stability and the potential of early loading, particularly in sites with bone density > 600 HU. The present CBCT bone density was not as high with a mean range of 349 HUs to 444 HUs between the three treatment groups. In the present protocol, the implant site selected in the preoperative scan was a hypothetical placement site. Due to the initial scanning setting, the thinnest slice was 1.0 mm. To avoid including root structures of adjacent teeth, an additional slice devoid of tooth structure was preserved before selecting the slice immediately adjacent to the implant for bone density measurement. However, this technique has limitations. At times, the evaluated slice may be part of the bone that would be drilled out when the implant is placed.

Compared with indirect sinus elevation, bicortical fixation still allows for longer implants to be placed without the need for additional cost of nonautogenous grafting material. The risk of benign paroxysmal positional vertigo, which has an incidence of < 3%,[54] can be eliminated since no malleting of osteotome is needed. One contraindication of indirect sinus elevation is the presence of an oblique sinus floor, leading to difficulty in infracture of the sinus floor. The use of controlled sequential drilling using stoppers and self-threading implants to achieve bicortical fixation offers an alternative to a direct sinus elevation that would need to be performed in this clinical situation. The use of short implants is still a viable option, but the expected physiologic bone loss around a restored implant, not to mention peri-implantitis, and the lack of long-term research of more than 10 years, make the use of short implants less attractive, especially in the weak bone like the posterior maxilla. Moreover, the limited repertoire of short implants in the combination of length and diameter presents additional challenges to surgeons. With the potential of intrasinus bone growth with bicortical fixation, it may be possible to opt for a longer implant.

CONCLUSIONS

Within the limits of this study, the results show that the bicortical fixation technique achieved comparable primary and secondary implant stabilities to that of the unicortical fixation and indirect sinus elevation techniques. Thus, the results of this study support the use of the bicortical fixation technique, which offers a more economical and safe alternative to placement of longer implants, with low postoperative complications. Nevertheless, while primary implant stability is a strong predictor of implant success, further long-term studies are needed to truly evaluate the success of bicortically placed implants.

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REFERENCES

1. Sharan A, Madjar D. Maxillary sinus pneumatization following extractions: A radiographic study. Int J Oral Maxillofac Implants 2008;23:48–56.
2. Jensen OT, Shulman LB, Block MS, Iacono VJ. Report of the sinus consensus conference of 1996. Int J Oral Maxillofac Implants 1998;13(suppl):11–45.
3. Misch CE. Maxillary sinus augmentation for endosteal implants. Organized alternative treatment plans. Int J Oral Implantol 1987;4:49–58.
4. Rosen PS, Summers R, Mellado JR, et al. The bone added osteotome sinus floor elevation technique: Multicenter retrospective report of consecutively treated patients. Int J Oral Maxillofac Implants 1999;14:853–858.
5. Seong WJ, Kim UK, Swift JQ, Hodges JS, Ko CC. Correlations between physical properties of jawbone and dental implant initial stability. J Prosthet Dent 2009;101:306–318.
6. Conrad HJ, Jung J, Barczak M, Basu S, Seong WJ. Retrospective cohort study of the predictors of implant failure in the posterior maxilla. Int J Oral Maxillofac Implants 2011;26:154–162.
7. Javed F, Ahmed HB, Crespi R, Romanos GE. Role of primary stability for successful osseointegration of dental implants: Factors of influence and evaluation. Interv Med Appl Sci 2013;5:162–167.
8. Lioubavina-Hack N, Lang NP, Karring T. Significance of primary stability for osseointegration of dental implants. Clin Oral Implants Res 2006;17:244–250.
9. Meredith N. Assessment of implant stability as a prognostic determinant. Int J Prosthodont 1998;11:491–501.

10. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: Biological and biomechanical aspects and clinical implications. Periodontol 2000 2008;47:51–66.
11. Boyne PJ, James RA. Grafting of maxillary sinus floor with autogenous marrow and bone. J Oral Surg 1980;38:613–618.
12. Zitzmann NU, Schärer P. Sinus elevation procedures in the reabsorbed posterior maxilla. Comparison of the crestal and lateral approaches. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;85:8–17.
13. Brånemark PI, Hansson BO, Adell R, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg Suppl 1997;16:1–132.
14. Summers RB. A new concept in maxillary implant surgery: The osteotome technique. Compendium 1994;15:152p,154–156,158 passim; quiz 162.
15. Ferrigno N, Laureti M, Fanali S. Dental implants placement in conjunction with osteotome sinus floor elevation: A 12-year life-table analysis from a prospective study on 588 ITI implants. Clin Oral Implants Res 2006;17:194–205.
16. Pjetursson BE, Ignjatovic D, Matuliene G, et al. Transalveolar maxillary sinus floor elevation using osteotomes with or without grafting material. Part II: Radiographic tissue remodeling. Clin Oral Implant Res 2009;20:677–683.
17. Nkenke E, Schlegel A, Schultze-Mosgau S, Neukam FW, Wiltfang J. The endoscopically controlled osteotome sinus floor elevation: A preliminary prospective study. Int J Oral Maxillofac Implants 2002;17:557–566.
18. Bruschi GP, Scipioni A, Calesini G, Bruschi E. Localized management of sinus floor with simultaneous implant placement: A clinical report. Int J Oral Maxillofac Implants 1998;15:853–858.
19. Lundgren S, Andersson S, Gualini F, Sennerby L. Bone reformation with sinus membrane elevation: A new surgical technique for maxillary sinus floor augmentation. Clin Implant Dent Relat Res 2004;6:165–173.
20. Nedir R, Bischof M, Vazquez L, et al. Osteotome sinus floor elevation technique without grafting material: 3-year results of a prospective pilot study. Clin Oral Implants Res 2009;20:701–707.
21. Leblebicioglu B, Ersanli S, Karabuda C, Tosun T, Gokdeniz H. Radiographic evaluation of dental implants placed using an osteotome technique. J Periodontol 2005;76:385–390.
22. Tan WC, Zwahlen M, Lang NP, Pjetursson BE. A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. Part II—trans-alveolar technique. J Clin Periodontol 2008;35(suppl 8):241–254.
23. Nedir R, Bischof M, Briaux JM, et al. 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. Clin Oral Implants Res 2004;15:150–157.
24. Renouard F, Nisand D. Impact of implant length and diameter on survival rates. Clin Oral Implants Res 2006;17(suppl 2):35–51.
25. Anitua E, Orive G, Aguirre JJ, Andía I. Five-year clinical evaluation of short dental implants placed in posterior areas: A retrospective study. J Periodontol 2008;79:42–48.
26. Corrente G, Abundo R, des Ambrois AB, Savio L. Perelli M. Short porous implants in the posterior maxilla: A 3-year report of a prospective study. Int J Periodontics Restorative Dent 2009;29:23–29.
27. Fugazzotto PA. Shorter implants in clinical practice: Rationale and treatment results. Int J Oral Maxillofac Implants 2008;23:487–496.
28. Bahat O. Treatment planning and placement of implants in the posterior maxillae: Report of 732 consecutive Nobelpharma implants. Int J Oral Maxillofac Implants 1993;8:151–161.
29. Koldsland OC, Scheie AA, Aass AM. Prevalence of peri-implantitis related to severity of the disease with different degrees of bone loss. J Periodontol 2010;81:231–238.
30. Seong WJ, Hsu A, Wolff R, Chong J, Conrad H, Olin P. Bi-cortical fixation of implants in maxillary sinus area. 91th IADR Poster Session, Seattle, WA, 2013 March.
31. Jeong CM, Caput AA, Wylie RS, Son SC, Jeon YC. Bicortically stabilized implant load transfer. Int J Oral Maxillofac Implants 2003;18:59–65.
32. Ahn SJ, Leesungbok R, Lee SW, Heo YK, Kang KL. Differences in implant stability associated with various methods of preparation of the implant bed: An in vitro study. J Prosthet Dent 2012;107:366–372.
33. Bahat O. Osseointegrated implants in the maxillary tuberosity: Report on 45 consecutive patients. Int J Oral Maxillofac Implants 1992;7:459–467.
34. Ivanoff CJ, Sennerby L, Lekholm U. Influence of mono and bicortical anchorage on the integration of titanium implants. A study in the rabbit tibia. Int J Oral Maxillofac Surg 1996;25:229–235.
35. Huang HL, Fuh LJ, Ko CC, Hsu JT, Chen CC. Biomechanical effects of a maxillary implant in the augmented sinus: A three-dimensional finite element analysis. Int J Oral Maxillofac Implants 2009;24:455–462.
36. Ivanoff CJ, Gröndahl K, Bergström C, Lekholm U, Brånemark PI. Influence of bicortical or monocortical anchorage on maxillary implant stability: A 15-year retrospective study of Brånemark system implants. Int J Oral Maxillofac Implants 2000;15:103–110.
37. Boyne PJ. Augmentation of the posterior maxilla by way of sinus grafting procedures: Recent research and clinical observations. Oral Maxillofac Surg Clin North Am 2004;16:19–31,v-vi.
38. Srouji S, Ben-David D, Lotan R, Riminucci M, Livne E, Bianco P. The innate osteogenic potential of the maxillary sinus (Schneiderian) membrane: An ectopic tissue transplant model simulating sinus lifting. Int J Oral Maxillofac Surg 2010;39:793–801.
39. Graziano A, Benedetti L, Massei G, et al. Bone production by human maxillary sinus mucosa cells. J Cell Physiol 2012;227:3278–3281.
40. Jung JW, Choi BH, Zhu SJ, et al. The effects of exposing dental implants to the maxillary sinus cavity on sinus complications. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;102:602–605.
41. Lai H, Zhang ZY, Wang F, Zhuang LF, Liu X. Resonance frequency analysis of stability on ITI implants with osteotome sinus floor elevation technique without grafting: A 5-month prospective study. Clin Oral Implants Res 2008;19:469–475.
42. Markovic A, Snjezana C, Radojica D, et al. Resonance frequency analysis as a reliable criterion for early loading of sandblasted/acid-etched active surface implants placed by the osteotome sinus floor elevation technique. Int J Oral Maxillofac Implants 2011;26:718–724.
43. Meredith N, Alleyne D, Cawley P. Quantitative determination of the stability of the implant-tissue interface using resonance frequency analysis. Clin Oral Implants Res 1996;7:261–267.
44. Sennerby L, Meredith N. Resonance frequency analysis: Measuring implant stability and osseointegration. Compend Contin Educ Dent 1998;19:493–502.
45. Miyamoto I, Tsuboi Y, Wada E, Suwa H, Iizuka T. Influence of cortical bone thickness and implant length on implant stability at the time of surgery—clinical, prospective, biomechanical, and imaging study. Bone 2005;37:776–780.
46. Nkenke E, Hahn M, Weinzierl K, Radespiel-Tröger M, Neukam FW, Engelke K. Dental implant stability and histomorphometry: A correlation study in human cadavers. Clin Oral Implants Res 2003;14:601–609.
47. Ersanli S, Karabuda C, Beck F, Leblebicioglu B. Resonance frequency analysis of one-stage dental implant stability during the osseointegration period. J Periodontol 2005;76:1066–1071.
48. Bischof M, Nedir R, Szmukler-Moncler S, Bernard JP, Samson J. Implant stability measurement of delayed and immediately loaded implants during healing. A clinical RFA study with SLA ITI implants. Clin Oral Implants Res 2004;15:529–539.
49. Meredith N. A review of nondestructive test methods and their application to measure the stability and osseointegration of bone anchored endosseous implants. Crit Rev Biomed Eng 1998;26:275–291.
50. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark PI, Zarb GA, Albrektsson T (eds). Tissue-Integrated Prostheses–Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985.
51. Bergkvist G, Koh KJ, Sahlholm S, Klintström E, Lindh C. Bone density at implant sites and its relationship to assessment of bone quality and treatment outcome. Int J Oral Maxillofac Implants 2010;25:321–328.
52. Schnitman PA, Wang JW. To immediately load, expose or submerge in partial edentulism: A study of primary stability and treatment outcome. Int J Oral Maxillofac Implants 2011;26:850–859.
53. Turkyilmaz I, Tumer C, Ozbek EN, Tözüm TF. Relations between the bone density values from computerized tomography, and implant stability parameters: A clinical study of 230 regular platform implants. J Clin Periodontol 2007;34:716–722.
54. Di Girolamo M, Napolitano B, Arullani CA, Bruno E, Di Girolamo S. Paroxysmal positional vertigo as a complication of osteotome sinus floor elevation. Eur Arch Otorhinolaryngol 2005;262:631–633.