Review

Sinus Floor Elevation Using Osteotomes: A Systematic Review and Meta-Analysis

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Background: Various techniques of sinus floor elevation (SFE) are described. The elevation with osteotomes (OSFE) from a crestal approach is a relatively new technique. The aim of this systematic review and meta-analysis was to evaluate the clinical outcome of implants placed into the maxillary sinus augmented with an OSFE technique.

Methods: A systematic online and manual review of the literature identified articles dealing with OSFE. Applying rigid inclusion criteria, screening and data abstraction were performed independently by two reviewers. The follow-up of loaded implants was a minimum of 6 months. The identified articles were analyzed regarding implant outcome and defined surgical aspects. Survival and success rates were estimated by Kaplan-Meier curves.

Results: Eight out of 44 articles dealing with osteotome sinus floor elevation met the inclusion criteria. Five of the studies met established success criteria. The survival and success rates were 95.7% and 96.0% after 24 months and 36 months, respectively. The median and mean follow-up periods were 24 and 18.73 months for the survival rate and 24 and 19.7 months for the success rate. Regarding different surgical elements, i.e., osteotome techniques, implant types, and augmentation materials, the database was multivariate. Thus, no statistical analysis could be performed on these parameters.

Conclusions: Short-term clinical success/survival (≤3 years) of implants placed with an osteotome sinus floor elevation technique seems to be similar to that of implants conventionally placed in the partially edentulous maxilla. Controlled prospective clinical studies are needed to evaluate the long-term outcome and various surgical modifications of OSFE. *J Periodontol 2005; 76:1237-1251.*

KEY WORDS

Dental implants; follow-up studies; maxillary sinus/surgery; osteotomy; outcome assessment; review literature.

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Implant insertion in the posterior region of the maxilla is a challenging procedure. The reduced bone quantity and low bone quality are limiting factors.[1-5] Due to these restrictions, different methods, such as tilted implants, short implants or additional vertical bone augmentation, have been described.

Limited long-term data are available on the success or survival rates of tilted implants.[6,7] Implants <10 mm are less successful than longer implants.[4,8-11] Many techniques have been introduced addressing vertical bone augmentation: sinus floor elevation (SFE) from a lateral window[12] or SFE from a crestal approach using osteotomes, onlay graft,[13,14] guided bone regeneration,[15,16] appositional bone graft/saddle-graft,[17] or combinations of these techniques.[13,17,18]

The most commonly used bone augmentation technique is the SFE from a lateral window, which was first presented in 1977 by Tatum and first published in 1980 by Boyne and James.[12,19,20] Tatum changed his initial technique of SFE from a complex crestal access to a more versatile and practical technique of a lateral access. The long-term success of this often modified augmentation procedure has been documented.[21,22] Different bone graft materials, types of implants, timing of implant placement, failure analysis, radiographic analysis, indications or contraindications, and prosthetic aspects have all been analyzed.[21,22]

A less invasive procedure for sinus floor elevation with immediate implant

placement was introduced by Summers in 1994.[23] This technique is characterized by the use of specific root analog instruments (osteotomes). The Schneiderian membrane is elevated using these osteotomes from a crestal approach without the preparation of a lateral window. To optimize the procedure, Summers[24] described the possibility of an auxiliary bone addition, explaining that the added material would function like a hydraulic plug, which would reduce the risk of perforating the Schneiderian membrane during the sinus floor elevation. Regardless of optional bone addition, the local bone of the alveolar crest is condensed and the primary stability of implants can be improved.[24,25] The Summers osteotome technique has been modified by several authors.[26-32] The common links of these procedures are the surgical approach to the maxillary sinus from the alveolar crest and the elevation of the sinus membrane using osteotomes. The use of osteotomes should produce a higher bone density and a higher primary implant stability.[23,30] In comparison to SFE with a lateral window approach, the osteotome procedures are less invasive, operation time is reduced, and the postoperative discomfort is minimized.[30,33,34]

When reviewing the literature, little information was found on the predictability of osteotome-supported sinus floor elevation with a crestal approach (OSFE). The aim of this systematic literature review was to evaluate the survival and success rates of implants inserted with OSFE through a meta-analysis. Meta-analyses allow a statistical pooling of single studies with a common underlying issue to draw conclusions with a reduced bias.[35]

METHODS

Definitions

The following abbreviations are used to describe the surgical techniques reviewed: 1) CSFE: conventional sinus floor elevation (lateral approach); 2) OSFE: osteotome sinus floor elevation (crestal approach using osteotomes); 3) oOSFE: original OSFE as described by Summers;[23] 4) mOSFE: modified original OSFE; and 5) sOSFE: separate OSFE.

Literature Search

A systematic online and manual search of literature was performed through 2003. The online search included MEDLINE (National Library of Medicine) implementing PubMed, Web of Science, and Silverplatter; the Cochrane Library, and the Deutsche Zahnärztliche Zeitschrift (DZZ online). Multiple key words including sinus, graft, indirect, osteotome, implant, maxillary, internal, elevation, lift, Summers technique, crestal, Sinuslift, Sinusbodenelevation, and Osteotom and different strategies (connecting different key words with OR, NOR, and AND; truncation of the stem of words using *, $, ?, or other signs according to information given from the database) were used. The hand search was performed in the following journals from 1994 until 2003: *European Journal of Prosthodontics; Implantologie; Mund-, Kiefer- und Gesichtschirurgie; Parodontologie; Quintessence International;* and *Zeitschrift für Zahnärztliche Implantologie*. Additionally, the bibliographies of relevant publications were checked for further studies.

Articles were screened by two examiners based on the following criteria: 1) no abstracts (i.e., clinical studies published only in abstract form); 2) no case reports; 3) no technical reports (i.e., reports about a new or modified [surgical] technique); 4) at least 10 patients; 5) root-form implants used; 6) at least 6 months of functional loading; and 7) data on implant survival/success were adequately reported. No language restrictions were set. The identified articles were evaluated in detail regarding 1) number of patients; 2) number of implants; 3) employed technique (oOSFE, mOSFE, sOSFE); 4) elevation of the sinus membrane without or with the use of autogenous bone/bone substitute/collagen sheet (no, no bone substitute or autogeneous bone; bs, bone substitute; ab, autogeneous bone; co, collagen sheet); 5) transgingival or subgingival healing; 6) recommended or measured preoperative bone height; 7) measured bone gain; 8) success/survival rates after loading; 9) time of functional loading; 10) Albrektsson et al.[36] success criteria (individual implant is clinically immobile; no peri-implant radiolucency; <0.2 mm annual peri-implant vertical bone loss after the first year of loading; absence of signs and symptoms such as pain, infections, neuropathies, paresthesia, or violation of the mandibular canal; and success rate of 85% after 5 years and 80% after 10 years based on these criteria) applied (Y) or other/own/no success criteria (N).

Meta-Analysis (Kaplan-Meier Method)

The included studies were carefully analyzed concerning data on implant success and survival. To be included into the meta-analysis of implant success/survival, the follow-up period had to be exactly described for each implant or set of implants. If this information was less precise, a worst case scenario was utilized for the meta-analysis; that is, the reported follow-up periods were reduced to the shortest time; e.g., a set of implants described as successful for 0 to 12 months was not evaluated; those described as successful for 12 to 24 months were regarded as successful over 12 months. Only studies with a minimum 6-month follow-up after loading were used for the meta-analysis. Data were processed at the Institute of Medical Biometry and Medical Informatics of the University of Freiburg, Germany. Survival and success rates were estimated by Kaplan-Meier curves.§[37,38]

§ Proc Lifetest, SAS version 6.12, SAS Institute, Cary, NC.

The success rate was determined using the Albrektsson et al. criteria.[36] The median and mean follow-up periods were calculated by means of a reverse Kaplan-Meier estimation and the homogeneity of the curves of the selected studies was checked with the log rank test.

RESULTS

Selection of Literature

The online search identified 40 articles relating to the principal item of osteotome sinus floor elevation (OSFE). Four additional articles were found through hand search and search of the cited literature. Eight studies[31,33,34,39-43] published over a 5-year period from 1997 to 2002 (Table 1) met the inclusion criteria. No randomized controlled trials or controlled clinical trials could be found. The longest follow-up period for loaded implants was 90 months.[39] The implant success/survival rates in the studies ranged from 88.6% to 100% (Table 1).

The excluded studies and (multiple) reasons for their exclusion are listed in Table 2. Twenty-two studies were excluded as case reports, studies with less than 10 patients, or technical reports.[23-26,30,44,45,47-51,54,56,57,60,62,63,65-68] Nine studies could not be factored into the meta-analysis either because of a follow-up less than 6 months or inadequate data report.[23,27,29,32,52,53,55,58,69] Five narrative reviews,[28,46,57,59,70] two radiographic[64,69] and two human cadaver investigations,[44,61] and one abstract publication[52] were identified.

Meta-Analysis

Five[34,39-42] of the eight studies used the Albrektsson et al. criteria to measure success. The other three used their own definitions. Coatoam and Krieger[33] defined success by affirming soundness and radiographic integrity at 6-month intervals. DePorter et al.[31] judged success with standardized radiographs, mobility measurements, probing depths, clinical attachment levels, and bleeding on probing. Rosen et al.[43] reported a survival rate with criteria based on the implant remaining in function but also meeting "modified" Albrektsson et al.[36] criteria. None of the three studies reported any major complications such as peri-implant bone loss. Therefore, survival rate was calculated for all eight studies and success rate for five studies using the Albrektsson et al.[36] criteria. A primary success/survival rate was not reported in all studies. Thus, implant loss prior to the second-stage surgery or functional loading was counted at the 6-month time point. This resulted in a success/survival

Table 1.

Eight Studies in Meta-Analysis: Surgical Technique, Implant Loading, and Implant Success/Survival

Reference (Study Type) (alphabetically by author)	N*	Surgical Technique†	Bone Addition	Loading Period 1‡ in Months (average)	Loading Period 2§ in Months (average)	% Success/ Survival
Bruschi et al.[40] (N/A)	P: 303 I: 499	sOSFE 2	co	24-60	24	97.5 A‖
Cavicchia et al.[39] (N/A)	P: N/A I: 97	mOSFE 2	co ab	6-90 (35)	6	88.6 A
Coatoam and Krieger[33] (N/A)	P: 77 I: 89	mOSFE 2	ab bs	6-48	6-42	92.1 O
Deporter et al.[31] (prospective)	P: 16 I: 26	mOSFE 2	ab bs	6-36 (11.1)	6	100 O
Fugazzotto and De Paoli[41] (N/A)	P: N/A I: 137	sOSFE 2	bs	0-36	12-24	97.8 A
Fugazzotto[42] (N/A)	P: 103 I: 116	sOSFE 1	None	0-48	12-36	98 A
Rosen et al.[43] (retrospective)	P: 101 I: 174	oOSFE 1 (N = 35) 2 (N = 139)	ab bs	6-66 (20.2)	6-36	95.4 O
Zitzmann and Schaerer[34] (prospective)	P: 20 I: 59	oOSFE 2	bs	6-24 (16.5)	6	95 A

* P = number of patients; I = number of implants.
† 1 = transgingival healing; 2 = subgingival healing.
‡ Total loading period as reported.
§ Period used for meta-analysis.
‖ A = success criteria of Albrektsson et al.[36]; O = other/own/no success criteria.

Table 2.

36 Excluded Studies and Reasons for Exclusion

Reference (alphabetically by author)	Case Report/ <10 Patients	Technical Report	<6 Month Loading	Inadequate Data	Other
Baumann and Ewers[44]	+				Human cadaver and clinical study
Brass and Steffens[45]		+			
Coatoam[46]					Narrative review
Cosci and Luccioli[29]				+	
D'Amato et al.[47]	+				
Davarpanah et al.[30]		+			
Defrancq and Vanassche[48]	+				
Deporter et al.[49]	+	+			
Fugazzotto[50]	+	+			
Fugazzotto[26]		+			No implant insertion
Fugazzotto[51]		+			
Fugazzotto[32]				+	
Gerber et al.[52]				+	Meeting abstract
Glauser et al.[53]				+	
Hahn[54]		+			
Horowitz[55]			+	+	
Igelhaut[56]	+	+			
Ioannidou and Dean[57]	+				Narrative review
Komarnyckyj and London[58]			+	+	
Lazzara[59]					Narrative review
Leonetti et al.[60]	+	+			
Nkenke et al.[27]			+		Preliminary data
Reiser et al.[61]					Human cadaver study
Saadoun and Le Gall[62]		+			
Schmidinger[63]		+			
Strietzel and Nowak[64]					Radiographic study (crestal bone loss)
Summers[23]		+		+	
Summers[24]	+	+			
Summers[65]	+	+			
Summers[66]	+	+			
Summers[25]		+			Interview
Summers[67]		+			
Summers[68]	+	+			
Toffler[28]					Narrative review
Yildirim et al.[69]			+		Radiographic study
Yuen[70]					Narrative review

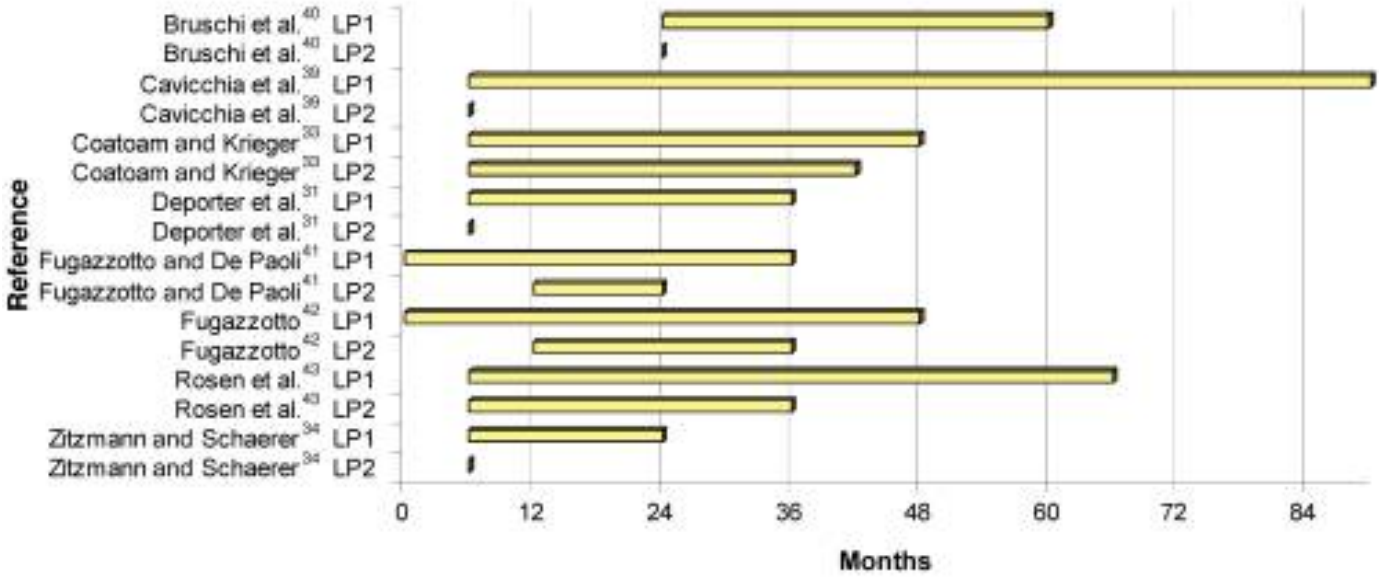

Figure 1.
Loading periods of the implants as reported in the eight included studies (loading period 1 = LP1) and as used for meta-analysis (loading period 2 = LP2).

rate of 100% within 6 months of loading (see dotted line in Figs. 2 and 3).

The time periods of implant loading reported in the studies (loading period 1) could not be utilized. Only reduced loading periods (loading period 2) could be referred precisely to implant success/survival (Table 1 and Fig. 1). A statistical analysis of implant shape, implant surface, surgical technique, recommended bone height before elevation, use of autogenous bone or bone substitute, and soft tissue healing procedure was not possible due to the small number of studies.

Survival Rate (Kaplan-Meier Method)

Out of the eight included studies, a total of 1,139 implants were appropriate for meta-analysis of implant survival (i.e., we were able to determine how many implants had been loaded for at least 6 months). The survival rate was 98.2%, 97.5%, 95.7%, and 90.9% after 6, 12, 24, and 36 months of loading, respectively. The slope of the survival rate from 95.7% at 24 months to 90.9% at 36 months is attributed to the loss of one implant (Table 3 and dashed line in Fig. 2). The median follow-up period was 24 months and the mean follow-up period was 18.73 months (standard error = 0.2303). The survival curves of the selected studies were not homogeneous ($P = 0.0001$; log rank test). Standard error and the result of the log rank test were not adjusted with respect to the inter-dependence of each patient's implants.

Success Rate (Kaplan-Meier Method)

A total of 848 implants could be included in the meta-analysis of implant success. The implant success rate

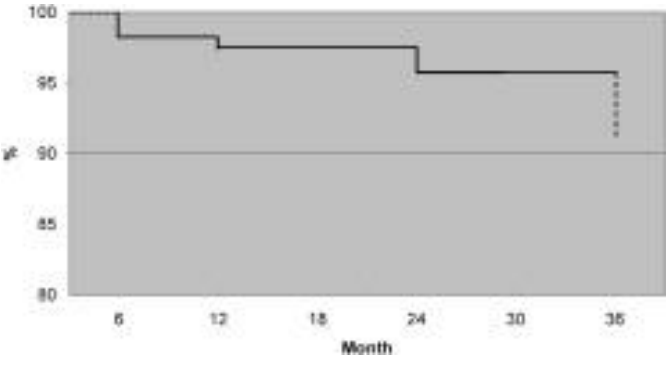

Figure 2.
Implant survival as estimated with Kaplan-Meier curves (eight studies). The slope of the success rate at 36 months is due to the loss of one implant.

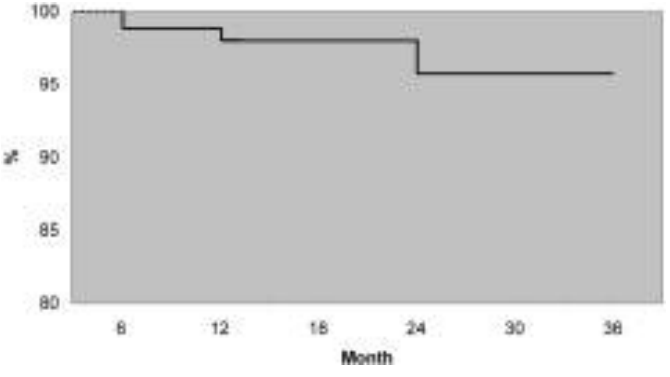

Figure 3.
Implant success as estimated with Kaplan-Meier curves (five studies).

Table 3.

Implant Survival by Kaplan-Meier Estimation

Loading (months)	Survival (%)	Failure (%)	Survival Standard Error	N Failed Implants	N Implants Under Observation
0	100	0	-	0	1139
6	98.2	1.8	0.399	21	1118
12	97.5	2.5	0.470	27	926
24	95.7	4.3	0.697	39	631
36	90.9	9.1	0.471	40	0

Table 4.

Implant Success by Kaplan-Meier Estimation

Loading (months)	Success (%)	Failure (%)	Survival Standard Error	N Implants Failed	N Implants Under Observation
0	100	0	-	0	848
6	98.7	1.3	0.389	11	837
12	98.0	2.0	0.500	16	687
24	96.0	4.0	0.758	28	568
36	96.0	4.0	0.758	28	0

was 98.7%, 98.0%, 96.0%, and 96.0% after 6, 12, 24, and 36 months of loading, respectively (Table 4 and Fig. 3). The median follow-up period was 24 months and mean follow-up period was 19.7 months (standard error = 0.2659). The survival curves of the selected studies were not homogeneous ($P = 0.0001$; log rank test). Standard error and the result of the log rank test were not adjusted with respect to the interdependence of each patient's implants.

Surgical Characteristics

Information about clinical locations, patient condition, implant and augmentation material, causes of implant failure, and bone levels were given in most of the included studies (Table 5).

All implants were root-form implants (Table 5). The most frequently used implant forms were cylinders,[33,39-41,43] stepped cylinders and/or stepped screws,[39-42] and screws.[33,34,41-43] The surface morphology varied (turned; titanium plasma sprayed [TPS] coating; hydroxyapatite [HA] coating; grit blasted and acid etched; TPS and grit blasted; porous surface with titanium beads). Some authors preferred longer (>10 mm) implants.[34,39]

The surgical techniques also differed among the studies (Table 1). The maxillary sinus was lifted from a crestal approach with osteotomes by all techniques accordingly. The original Summers technique (oOSFE), a modified Summers technique (mOSFE), and separate osteotome techniques (sOSFE) with a crestal approach were described in two, three, and three of the eight investigations, respectively. In one study, no bone was added.[42] In two further studies,[39,40] a collagen sheet was used as a buffer to fracture the floor of the sinus and to stabilize the blood clot. Cavicchia et al.[39] also added autogenous bone to support bone formation. The use of different grafting materials (autogenous, allograft, xenograft, or synthetic) was described in the other five studies. The autogenous bone was usually harvested from the drilling site, the adjacent crest, or the tuber. It was not possible to determine a correlation between implant failure and the augmentation material. Transgingival healing was performed in two studies (N = 151)[42,43] and subgingival in all other implants (N = 995) (Table 1).

The minimum bone height recommended for osteotome-supported sinus elevation ranged from 3 mm[31,43] to 6 mm (Table 5).[34] The preoperative bone height was radiographically measured in two studies.[34,43] The average bone height was measured in two studies and yielded 2.9[39] or 3.5[34] mm (Table 5). Cavicchia et al.[39] evaluated the bone height levels before surgery, at abutment connection, after delivery of the prosthesis, after 6 and 12 months, and then annually. The bone gain ranged between 1 and 6 mm. Zitzmann and Schaerer[34] investigated the preoperative bone height and the bone gain; the difference between initial and final bone height was significant ($P < 0.001$; Kruskal-Wallis test).

DISCUSSION

The aim of this study was to evaluate the long-term prognosis of implants inserted into the maxillary sinus elevated with osteotomes from a crestal approach. A systematic review of the literature and a meta-analysis were combined.

Statistical Analysis

New therapy concepts can be evaluated with different methods. Controlled prospective studies compare different treatment options. Reviews gather results from relevant published studies. Systematic reviews are superior to narrative reviews because the results are more reliable and the bias is reduced.[71-73] Meta-analyses based on systematic reviews combine and

analyze data from similar studies.[35,74,75] This can be especially useful when the clinical procedures have been performed for a shorter time.[35,75] Data from single studies are often too limited to draw clinically relevant conclusions because the sample size may be small or the follow-up period short. The negative impact of these factors can be reduced in a meta-analysis. Thus, results and conclusions from systematic reviews and meta-analyses usually have a positive tendency. Positive results are published more frequently than negative results (publication bias).

In this investigation, both systematic electronic and manual literature searches were carried out. Rigid inclusion criteria were applied to select only relevant articles. Prospective randomized clinical trials that directly compared the OSFE with other approaches were not identified. Abstract publications, case reports, technical reports, and studies with less than 10 patients were not included in order to reduce publication bias.

In order to draw conclusions for clinical applicability, all implants had to be loaded for at least 6 months. A significant number of implants fail prior to functional loading.[76] Most implant failures after loading are detected during the first year of service.[5,77] Another inclusion criteria for meta-analysis was the ability to calculate the success and/or survival rate from the presented data. The precise follow-up period of all implants or set of implants included in the analysis had to be reported. For calculating the success rate, the criteria of Albrektsson et al.[36] had to be applied in the studies. Five studies met this criterion.[34,39-42] In three other studies,[31,33,43] the authors applied their own success criteria. Data from these studies were pooled with the previously mentioned studies to calculate the survival rate. In order to evaluate the survival and success rates, the implants were placed in categories: success, survival, and lost to follow-up or failure.

Survival and Success Curves

A main problem for evaluating the success and survival rates was that not all studies gave exact timing of each implant loss. However, for the statistical analysis using the Kaplan-Meier method, each implant loss has to be correlated to a certain time point. Therefore, a worst case scenario was assumed in order to include these data. Implant failures during the reported loading periods (loading periods 1) were referred to as reduced loading periods of this meta-analysis (loading periods 2). Exact information on the number of the successfully loaded implants for these reduced loading periods was given. For example, Bruschi et al.[40] stated in their investigation that all of the 499 implants were loaded for at least 24 and up to 60 months. The total failure rate was 2.5% for all implants. No further information was given on the implant success. Therefore, the total failure rate was credited to the 24-month period.

The Kaplan-Meier success and survival curve of the meta-analysis stayed at 100% until the 6-month time point. The drop of the curve at the 6-month time point was caused by failure of the implants between the time of implant insertion and the 6-month time point of loading. This can be considered a false-positive description of implant survival. However, this procedure was necessary since the exact time of implant loss was not reported in all studies. Differences between the primary success rate until uncovering of the implants and the secondary success rate after loading were mostly not distinguished. The drop in the survival rate at the 36-month time point (from 95.7% to 90.9%) was caused by a single implant loss. Therefore, the validity of this value can be considered questionable.

A success rate of 96.0% and a survival rate of 95.7% were calculated at the 36-month time point and 24-month time point, respectively. These values are comparable to those of implants placed in the partial edentulous maxilla without bone augmentation.[78-83] The meta-analysis of Goodacre et al.[83] reported an overall implant loss rate of 6% in the partially edentulous maxilla restored with fixed partial dentures. Compared to implants placed in type IV bone, implants placed with the osteotome sinus lift procedure seem to have performed better. Goodacre et al.[83] also reviewed the literature for studies comparing implant loss due to different bone qualities. They reported that 113 (3.5%) out of 3,192 implants placed in type I, II, and III bone were lost and 160 (16%) of 1,009 implants placed in type IV bone were lost.[83]

OSFE and implant placement seem to perform better than conventional sinus floor elevation (CSFE) and implant placement. Concerning the latter technique, predominantly survival rates are available in studies with pooled data, but no success rates. The meta-analysis of the Sinus Consensus Conference of 1996 revealed a survival rate of 90.0% for implants that were functionally loaded for 3 years or more.[22] In this report, retrospective data from 38 surgeons on 1,007 sinus grafts involving placement of 2,997 implants over a 10-year period were pooled. Similar to this investigation, a number of different grafting modalities, implant surfaces, and timing protocols were applied. It was concluded that the sinus graft should be considered a highly predictable and effective therapeutic modality.[22]

A meta-analysis of implants placed with CSFE reported an implant survival after a functional loading period of 18 months or longer.[21] The survival rate of implants was 90% when using autogenous bone alone (484 implants followed for 6 to 60 months), 94% when using a combination of hydroxyapatite and autogenous bone (363 implants followed for 18 months),

98% when using a combination of demineralized freeze-dried bone and hydroxyapatite (215 implants followed for 7 to 60 months), and 87% with hydroxyapatite alone (30 implants followed for 18 months).[21] It was suggested that implant survival rates were similar for the different grafting materials. The authors reported

Table 5.

Information About Clinical Locations, Patient Condition, Implant and Augmentation Material, Causes of Implant Failure, Preoperative Bone Height, and Bone Gain

Reference (alphabetically by author)	Clinical Location	Patient Condition	Implant and Augmentation Material	Cause of Failure
Bruschi et al.[40]	Private practice, Rome, Italy	No sinusitis; no periodontitis	•Cylinders, rough surface* (N = 317); stepped cylinders and/or screws, rough surface† (N = 182) •Collagen sheet	12 clustered failures (i.e., 3 failures in one patient with removable partial denture and clasps to teeth)
Cavicchia et al.[39]	Private practice, Rome, Italy	None	•Cylinders, rough surface*‡ (N = 25); stepped screws, rough surface† (N = 72); length usually 10 mm, six 8 mm •Collagen sponge, autogenous bone	11 failures: -8 due to lack of primary stability (all type IV bone, 3 with removable denture, 6 with local bone <50% of final implant length) -2 after almost 9 months -1 after 4 years (8 mm implant type IV bone, heavy smoker)
Coatoam and Krieger[33]	Private practice and Faculty of Periodontics, University of Florida	None	•Turned screws§ (N = 2); cylinders, rough surface‖ (N = 13); cylinders, rough surface¶ (N = 5); flared cylinders, rough surface# (N = 69) •Demineralized freeze-dried bone allograft and autogenous bone	7 failures: -5 due to lack of primary stability -1 by occlusal trauma -1 implant migrated into maxillary sinus
Deporter et al.[31]	Faculty of Dentistry, University of Toronto, ON	No history of sinusitis; no periodontitis; no smokers	•Tapered press fit implants, rough surface;** length: mean 6.9 mm •Anorganic bovine bone mineral¶¶	No failures
Fugazzotto and De Paoli[41]	Private practice, Milton, MA	No sinusitis; no periodonitis; less than 20 cigarettes	•Self-tapping screws;‡ screws, rough surface;†† length: 8-11.5 mm •Anorganic bovine bone mineral¶¶	3 failures: -2 failed to integrate -1 after 8 months due to parafunction
Fugazzotto[42]	Private practice, Milton, MA	No sinusitis; no periodonitis; less than 20 cigarettes	•Self-tapping screws‡ (N = 7); screws, rough surface§§ (N = 109); length 7-11 mm, no correlation to failure •No bone substitute added	2 failures: implants mobile at abutment connection

that a Kaplan-Meier analysis could not be performed because most of the included studies did not provide a precise follow-up period for each patient.[21]

Table 5. (continued)

Information About Clinical Locations, Patient Condition, Implant and Augmentation Material, Causes of Implant Failure, Preoperative Bone Height, and Bone Gain

Preoperative Bone Height (mm)†		
Recommended	Measured	Radiograph Bone Gain (mm)‡
5-7	N/A	N/A
5-7	N/A	1-6 (Mean: 2.9)
≥5	N/A	N/A
≥3	N/A	N/A
N/A	N/A	N/A
4-5	N/A	N/A

A systematic review by Wallace and Froum of the effect of maxillary sinus augmentation on the survival of endosseous dental implants loaded for at least 1 year analyzed data from 43 studies.[84] Different techniques for SFE were described. The overall survival rate for the 3,354 interventions and 6,443 implants was 92.6%. The survival rate of 5,267 implants placed in 2,178 conventionally elevated sinuses (CSFE, 34 studies) was 91.8%. No overall survival rate was calculated for the five osteotome sinus augmentation studies, the two localized management of sinus floor studies, or the two crestal core elevation studies. No life-table analysis was performed to determine a survival rate with respect to the number of implants under risk.

Similar data were presented by another systematic review of Del Fabbro et al.[85] The authors reported on 39 included CSFE studies with an overall survival rate of 91.49% for 6,913 implants in 2,046 patients. As in the Wallace and Froum study, implants were loaded for at least 12 months and only an overall survival rate, but no life-table analysis, was performed. The range of follow-up was 12 to 75 months.

When comparing the results of these studies with the data of the present investigation, one has to consider that the indications for the applied techniques are not the same. The OSFE is performed when the residual bone height is 3 mm or more.[24,29,31,34,39,40,42,43,58] In contrast, CSFE can be performed when the residual bone height is less than 3 mm.[34,86,87] Usually, only single implants are placed when applying OSFE. When CSFE is performed, one to four implants can be inserted.

One clinical trial which compared different sinus floor procedures was included in this analysis.[34] OSFE was carried out with a residual bone height of ≥6 mm. CSFE with simultaneous implant placement was usually possible (seven implants) when the bone height was 4 to 6 mm. In cases of severe resorption (bone height ≤4 mm), implant placement was performed 6 to 8 months after CSFE (13 implants). No implant failure was reported with CSFE. Three of 59 implants were lost with OSFE, resulting in a success rate of 95%. The authors concluded that the different sinus elevation techniques do not seem to affect the implant success rate.

The good performance of implants inserted with the osteotome technique may be explained by the favorable influence of the osteotome technique. The implant bed is compressed and thus may allow a better primary stability and perhaps a greater implant-to-bone contact area.[23,34] With osteotomes, type IV bone can be changed into type III or type II bone.[54] Further negative influences may be due to the reduced tactile sense and difficult control of a drill in the posterior maxilla.[68] Randomized controlled clinical trials are necessary to compare these treatment options and to draw definite conclusions.

Table 5. (continued)

Information About Clinical Locations, Patient Condition, Implant and Augmentation Material, Causes of Implant Failure, Preoperative Bone Height, and Bone Gain

Reference (alphabetically by author)	Clinical Location	Patient Condition	Implant and Augmentation Material	Cause of Failure
Rosen et al.[43]	Multicenter study dental schools and private practices, U.S.	No immune disease, uncontrolled diabetes, chemotherapy, radiation, alcohol/ drug abuse, or psychologic instability	•Standard screws;‡ ## §§ ‖‖ cylinders, rough surface;*‡ screws, rough surface†† •Autogenous bone, demineralized freeze-dried bone allograft, freeze-dried bone allograft, anorganic bovine bone minerals¶¶ ##	8 failures: -3 before loading -3 between 6 and 12 months loading -2 after >1 year of loading -93%/96% survival rate in smokers/non-smokers, respectively -All implant types: survival rate >93% -Initial bone height ≤4 mm: 85.7% >4 mm: 96% -6 mm implants: 80%
Zitzmann and Schaerer[34]	Department of Fixed and Removable Prosthodontics, Universities at Basel/Zürich, Switzerland	No sinus pathology	•Turned screws;‖‖ length usually ≥10 mm, 8.5 mm acceptable if splinted •Anorganic bovine bone mineral¶¶	3 failures: -2 mobile at abutment connection -1 mobile 4 weeks after abutment connection

Implants:
* IMZ, Dentsply Inc., York, PA.
† Frialit 2 implants, Dentsply Inc.
‡ 3i, West Palm Beach, FL.
§ Screw Vent, Paragon Implant Co. Sulzer Medica, Enicno, CA.
‖ Bio-Vent, Paragon Implant Co. Sulzer Medica.
¶ Steri-Oss, Nobel Biocare, Göteborg, Sweden.
# PACE implants, CAL-Form Inc., Longwood, FL.
** Endopore, Innova LifeScience Corp., Toronto, ON.
†† ITI Straumann AG, Waldenburg, Switzerland.
‡‡ Not specified; Dentsply standard screws, Dentsply Inc.
§§ Not specified; Implamed standard screws, Impla-Med, Sunrise, FL.
‖‖ Brånemark implants, Nobel Biocare.
Augmentation material:
¶¶ BioOss, OsteoHealth Co., Shirley, NY.
Osteograf-N, Dentsply/CeraMed, Lakewood, CO.

Because of the small number of studies included, all data were pooled for meta-analysis. However, the studies included in the meta-analysis showed differences regarding surgical aspects such as implant shape, implant surface, recommended or measured bone height before elevation, adding of bone or bone substitutes, and soft tissue healing procedures.

Implant Shape and Surface

The influence of implant shape and surface was discussed in some of the included investigations.[31,33,39,40] It has been assumed that the shape of the implant may have an effect on the failure rate, because it influences the primary stability.[88] The tapping of straight cylinder implants and the turning of straight implant screws may reduce primary stability in the coronal part of the residual bone. A tapered implant shape may be beneficial to primary stability because friction created between implant and bone arises just before the implant is placed. In the case of sinus floor elevation, the primary stability is provided only by a reduced amount of residual bone, which is in contact with the coronal part of the implant.

Some authors report that high primary stability and success rates can be achieved with press-fit implants.[31,33] Summers[23] also preferred the use of press-fit cylindrical implants as he introduced the osteotome technique for sinus floor elevation. In

Table 5. (continued)

Information About Clinical Locations, Patient Condition, Implant and Augmentation Material, Causes of Implant Failure, Preoperative Bone Height, and Bone Gain

Preoperative Bone Height (mm)†		
Recommended	Measured	Radiograph Bone Gain (mm)‡
≥3	≥3	N/A
≥6	Mean 8.8	Mean 3.5

another publication he stated that implants of any shape can be used.[68] Few authors switched the type of implant system used.[39,40] Bruschi et al.[40] initially inserted 317 TPS cylinders of which six were lost; later they used stepped cylinders and/or screws. Of the 182 stepped cylinders and/or screws which were tapped into position, six were lost. No problems with the primary stability were reported with these two implant systems. Cavicchia et al.[39] initially used TPS press-fit implants (N = 25) and subsequently sand-blasted, acid-etched stepped screws (N = 72). They reported higher primary stability with the stepped screws, but not a better success rate. Coatoam and Krieger[33] used four different implant systems. They preferred coronally flared, press-fit implants and reported more failures with the other implant systems. In the multicenter study of Rosen et al.,[43] various implant types (standard screws, TPS screw, HA screw, TPS cylinder) achieved survival rates of 93% or better. The lowest survival rate was yielded by the standard screws.

Data from the studies included in this meta-analysis were insufficient for statistical analysis of implant shape or surface. Therefore, no impact on the long-term success could be determined. High success and survival rates could be found for all implant types. This finding is supported by a meta-analysis on different types of root-formed implants,[89] where nine implant types were compared and no differences were found concerning failures, marginal bone level changes on intraoral radiographs, or peri-implantitis. The findings of Cochran[90] illustrate that high success rates can be obtained with different implant surfaces, which also seems to be true for OSFE. Regarding the long-term success of single tooth replacement, for which OSFE is often performed, no statistical difference could be found between different surfaces. However, there is evidence that implants with rough surfaces yield higher success rates in the maxilla. Cochran[90] reported significantly (P <0.001) higher success rates for implants with a rough surface than with a smooth surface in the partially edentulous maxilla. Wallace and Froum[84] reported higher survival rates for rough versus machined surface (91.6% versus 84%) implants placed after CSFE. Because of insufficient data, the authors could not perform a statistical analysis to compare the survival rates of rough versus machined implants placed after OSFE. Del Fabbro et al.[85] also reported higher implant survival rates for rough versus smooth surfaces when performing CSFE (95.98% and 85.64%, respectively).

Pretreatment Bone Height and Bone Gain

The pretreatment bone height is a major issue when discussing the indication for the osteotome supported sinus elevation. Summers[24] claimed a preoperative bone height of at least 5 to 6 mm was needed. Other authors reduced this value to 3 mm.[31] Rosen et al.[43] showed that implant success is reduced with a lower bone quantity. The implant survival rates were more than 96% (160 implants) and 85.7% (14 implants) with pretreatment bone heights of ≥5 mm and 3 to 4 mm, respectively. The bone height was determined with peri-apical radiographs. The implants were monitored over a period of 6 to 66 months. No other study gave precise information relating pretreatment bone height to implant success or survival.

In two of the included studies,[34,39] the bone gain of osteotome sinus floor elevation was evaluated with radiographs. In these studies, the original Summers technique[34] or a modified technique was applied.[39] The average measured bone gain was 2.9 mm[39] and

3.5 mm.[34] Other studies reported similar or even higher values of sinus elevation. Komarnyckyj and London[58] performed OSFE with preoperative measured bone heights between 3 and 9 mm (average 5.4 mm) and yielded bone gains between 2 and 7 mm (average 3.25 mm). Their study was not included in the meta-analysis because of the short follow-up period. Baumann and Ewers[44] presented case reports in which an augmentation of up to 13 mm was obtained with OSFE under endoscopic control. The bone gain was measured using dental computed tomography (CT). Five patients with a pretreatment bone height (before surgery) of 6 to 8 mm and two patients with a pretreatment bone height of 3 to 5 mm were treated with 13 mm implants. One membrane perforation without clinical complications (endoscopic control) was reported. Another study of 25 human cadavers illustrated a bone gain of 4 to 8 mm.[61] Five of six membrane perforations occurred when the membrane was lifted more than 5 mm. Nkenke et al.[27] searched the literature for reports on membrane perforations with OSFE and summarized that an endoscopic control is recommended when the sinus membrane is lifted >3 mm.

One longitudinal radiographic case cohort study investigated the bone gain and the patterns of tissue remodeling after placement of dental implants using OSFE.[91] The preoperative measured bone height was 2.3 to 10.3 mm (mean 7.0 mm). The mean distance between initial sinus floor and implant apex was 3.66 mm mesially and 4.44 mm distally. The mean height of new bone apically to the implants was about 1.52 mm at surgery, 1.24 mm at 3 months, and 0.29 mm at 12 months. The authors concluded that the area apical to the implants underwent shrinkage and remodeling.

Bone Quality of Augmentation

Summers[24] described the osteotome sinus floor elevation without and with bone/bone substitute. Yildirim et al.[69] measured the bone density with a CT scan in the areas augmented with the OSFE technique of Summers (4 mm bone gain). They concluded that it is possible to create an adequate and loadable bone augmentation around dental implants without additional bone replacement. Only one study could be identified where biopsies were harvested after osteotome sinus floor elevation.[33] The authors collected trephined biopsies at second-stage surgery 6 months after implantation and augmentation. Hard tissues (38% to 52%) and soft tissues were identified. The smallest amount of bone was seen in cases where no autogenous bone or only autogenous bone was used. The best results were obtained when a combination of autogenous bone and demineralized freeze-dried bone was added. Further histological studies are needed to determine whether the adding of autogenous bone or bone substitute is needed and which kind of material is most appropriate for OSFE.

Healing Conditions

Implants were allowed to heal subgingivally or transgingivally (Table 1). In these studies, no disadvantages were reported with transgingival healing. Little evidence is given on the impact of healing conditions on the long-term success of implants. Boioli et al.[92] assessed the long-term behavior of subgingival and transgingival healing in a meta-analysis in which 13,049 submerged implants and 5,515 non-submerged implants were evaluated. Non-submerged implants integrated better initially, but were subject to osseointegration loss, which persists over a longer period of time.

CONCLUSIONS

Within the limits of a small amount of long-term data, the following conclusions could be drawn: 1) the short-term clinical success/survival (up to 3 years) of implants placed with an osteotome sinus floor elevation technique seems to be similar to that of implants which are conventionally placed in the partially edentulous maxilla; 2) the long-term outcome (>5 years) of implants placed with OSFE is not well documented; and 3) further studies are needed to evaluate the impact of surgical factors on the short-term and long-term behavior of implants when performing OSFE.

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