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Review Article

Meta-regression analysis of the initial bone height for predicting implant survival rates of two sinus elevation procedures

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Abstract

Aim: To undertake a systematic review for the association between the initial alveolar bone height and the success of dental implants with sinus elevation procedures.

Materials and Methods: An online search was performed using the following electronic databases: PubMed, Medline, Science Direct, and Blackwell synergy. Two investigators independently assessed publications for inclusion and extracted data. Meta-regression analyses were used to test the associations between the initial alveolar bone height and implant survival with lateral window or osteotome sinus elevation procedures.

Results: Of 635 studies, 21 were included for analysis. A quadratic curve-fitting meta-regression showed an increasing trend of implant survival rate with greater initial bone height for the lateral window technique ($p<0.0001$, adjusted $R^2=0.97$). The result of the meta-regression for hazard rates showed a decreasing trend ($p=0.0041$, adjusted $R^2=0.89$). No association was found for the osteotome technique.

Conclusions: For the lateral window technique, meta-regression analysis suggested a positive association between the initial alveolar bone height and implant survival rates. No relationship was found between the initial alveolar bone height and implant survival rate for the osteotome technique due to a lack of data below 4 mm of initial bone height.

Key words: bone height; dental implant; implant survival; meta-regression; posterior maxilla; sinus elevation; sinus lift

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Implant therapy in the posterior region of maxilla is a great challenge due to its anatomic features. In addition to the low bone density frequently found in this area, the resorption of edentulous alveolar crest and the pneumatization of maxillary sinus usually give rise to an inadequate alveolar bone height. Maxillary sinus floor elevation is a well-accepted procedure to resolve the problem. This surgical technique, first presented by Tatum at an Alabama implant conference in 1976 (Tatum 1986) and subsequently published by Boyne and James in 1980 provides a way to increase the alveolar bone height and to facilitate implant placement.

To date, there are two common approaches to maxillary sinus floor elevation: the lateral approach and crestal approach. The lateral approach, the so-called lateral antrostomy or lateral window technique, was originally described by Tatum (1986). After Tatum's initial crestal approach using socket formers (Tatum 1986), Summers (1994a) advocated a new approach: the osteotome technique. Compared with the lateral window approach, the osteotome procedure is now considered a less-invasive technique. It is reported to reduce operative time and post-operative discomfort. It requires less grafting material and also improves peri-implant bone density, thereby allowing greater initial stability of implants. Despite having so many advantages, the crestal approach has nevertheless some restrictions on patient selection. The most critical one is the initial alveolar bone height.

Numerous articles have discussed the influence of graft materials, implant

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surface preparation, and timing of implant placement on the success of implant therapy combined with sinus lift procedures. However, only a few clinical reports have discussed the issue of initial alveolar bone height. For instance, the decision between one- or two-stage approaches for lateral window procedure, is generally thought to be based on initial alveolar bone height. An early study (Smiler et al. 1992) suggested that a two-stage procedure would be indicated when alveolar crestal bone is <3–4 mm. Fugazzotto (1994) suggested that 4 mm of initial bone height appeared to be sufficient to give the implants sufficient stability and allowed to place implants simultaneously with the sinus lift procedure. In 1998, a clinical study (Zitzmann & Scharer 1998) proposed criteria for selecting procedures of sinus floor elevation. In patients with severe resorption, such as those with bone heights of 4 mm or less, the two-step lateral antrostomy was indicated. With residual bone heights of 4–6 mm, simultaneous implant placement could be performed. Several studies have made similar observations and suggestions for 4–5 mm as the minimum initial bone height for the one-stage procedure (Peleg et al. 1999, Mazor et al. 2000, Toffler 2004a, b, Woo & Le 2004).

For the osteotome procedure, it has been suggested that there should be at least 5–6 mm of alveolar crestal bone remaining below the sinus floor when this indirect sinus elevation is performed together with implant placement (Summers 1994b). A prospective clinical study showed that when more than 6 mm of residual bone height was present, the osteotome technique could increase 3–4 mm bone height, and the success rate was about 95% after 30 months of follow-up (Zitzmann & Scharer 1998). Another multicentre retrospective study also reported a high survival rate of 96%, when the pretreatment bone height was >5 mm, but it was reduced to 85.7% when the pretreatment bone height was <5 mm (Rosen et al. 1999).

A consensus report in a recent European Workshop on Periodontology (Tonetti & Hämmerle 2008) indicated that in cases with <6 mm of residual bone height, 17% of subjects experienced implant loss in the first 3 years following the lateral window procedure (Pjetursson et al. 2008). For the osteotome procedure, better results were found in patients with ≥ 5 mm of residual bone (Tan et al. 2008). The aim of this study was, therefore, to undertake a meta-analysis on the associations between the average initial alveolar bone height and implant survival rates, and to examine whether the associations were different for these two sinus lift procedures. In this study, we also looked at whether there is an optimal residual alveolar bone height, such as 5 mm, recommended commonly in the literature for maxillary implant placement combined with sinus floor lifting using lateral window or osteotome technique.

Materials and Methods

Aim

The research question of this systematic review was ''What is the impact of the initial alveolar bone height (residual bone height) on implant survival with either the lateral or vertical approach in patients receiving dental implant therapy combined with a sinus lift procedure?'' We attempted to assess whether the initial alveolar bone height is a critical factor for the success of sinus elevation surgery and whether there are differences in the outcomes between the lateral window and osteotome techniques.

Literature search

A comprehensive online search for all related articles up to September 2009 was performed using the following electronic databases: PubMed, Medline, Science Direct, and Blackwell synergy. Keywords used for the search included ''maxillary sinus, sinus elevation, sinus lift, sinus augmentation, sinus graft, bone grafting, osteotome, Caldwell Luc, lateral window, crestal approach, and dental implants'', which were used alone or in combination. Non-English publications without English abstracts were not considered. Additional hand searches included *International Journal of Oral and Maxillofacial Implants* and *The International Journal of Periodontics and Restorative Dentistry* from 1994 to September 2009, along with the bibliographies of relevant papers and review articles.

Selection and data extraction

All studies obtained from the above search were first screened on the basis of titles and abstracts. The full texts of identified studies were retrieved for in-depth evaluation. Screening and selection of papers for inclusion were conducted independently by two investigators (Y. L. C. and C. C. M.) according to the following inclusion criteria:

(1) human case series reports, prospective clinical studies, or randomized clinical trials;
(2) root-form/cylinder implants placed in the augmented maxillary sinus;
(3) no additional surgical intervention (e.g., onlay ridge augmentation);
(4) implant success/survival reported;
(5) a minimum of 10 patients;
(6) a mean follow-up time of at least 18 months after implant placement or 12 months after loading;
(7) pre-operative initial alveolar bone height measured and reported; and
(8) no sinusitis or other systemic disease in subjects.

For each eligible study, two investigators independently extracted data regarding the study design, surgical technique, the number of participants, initial alveolar bone height, implant survival evaluation, and duration of follow-up. Disagreements were resolved by discussion and consultation with an instructor for a third opinion. Inter- and intra-reviewer reliability was measured by Cohen's κ coefficients (Rigby 2000).

Statistical analysis

In order to investigate the impact of the initial alveolar bone height on implant survival following a sinus lift procedure, we extracted information from each study to conduct the first meta-regression analysis with the mean initial alveolar bone height treated as the independent variable and the survival rate of implants as the dependent variable. As the cumulative survival rate in each study was affected by its follow-up time, we used the hazard rate to analyse the outcome measurement in the second meta-regression analysis in order to reflect an instantaneous potential for an event in a very short time in the subject at risk. The hazard rate in our study was defined as the failure rate of an implant per month. The hazard rate of each study was calculated using the conventional formula of $\lambda = -\log(S/T)$, where S represents the survival rate and T the follow-up time (in months). The linear regressions including either the linear term only or a combination of linear and quadratic terms for both analyses were performed. The weights in both regression models were the number of implants in each study. By applying the regression equation, the probability of implant survival at any given residual alveolar bone height was estimated. The meta-regression analyses were undertaken using the function metareg in the statistical software package Stata version 10.1 (StataCorp., College Station, TX, USA).

Results

Data extraction

The flow chart for the literature search is shown in Fig. 1. An initial search identified 635 relevant studies and 438 full-text papers were retrieved for a more-detailed evaluation. In total, 22 studies met the inclusion criteria: 13 utilizing the lateral window technique and nine utilizing the osteotome technique. Two studies using the lateral technique were deemed duplicate except for the follow-up time, and the earlier one was excluded. The 12 studies using the lateral window technique contributed 406 patients and 1644 implants to the analysis, and the nine osteotome technique studies contributed 383 patients and 618 implants. The details of the included studies are summarized in Tables 1 and 2.

Validity assessment

The inter-reviewer reliability was measured by Cohen's κ coefficients and yielded a value of $\kappa = 0.89$. The intra-reviewer reliability levels of the two investigators were $\kappa = 0.95$ and 0.93. Both inter- and intra-reviewer κ-values indicated an excellent agreement (Landis & Koch 1977, Kundel & Polansky 2003).

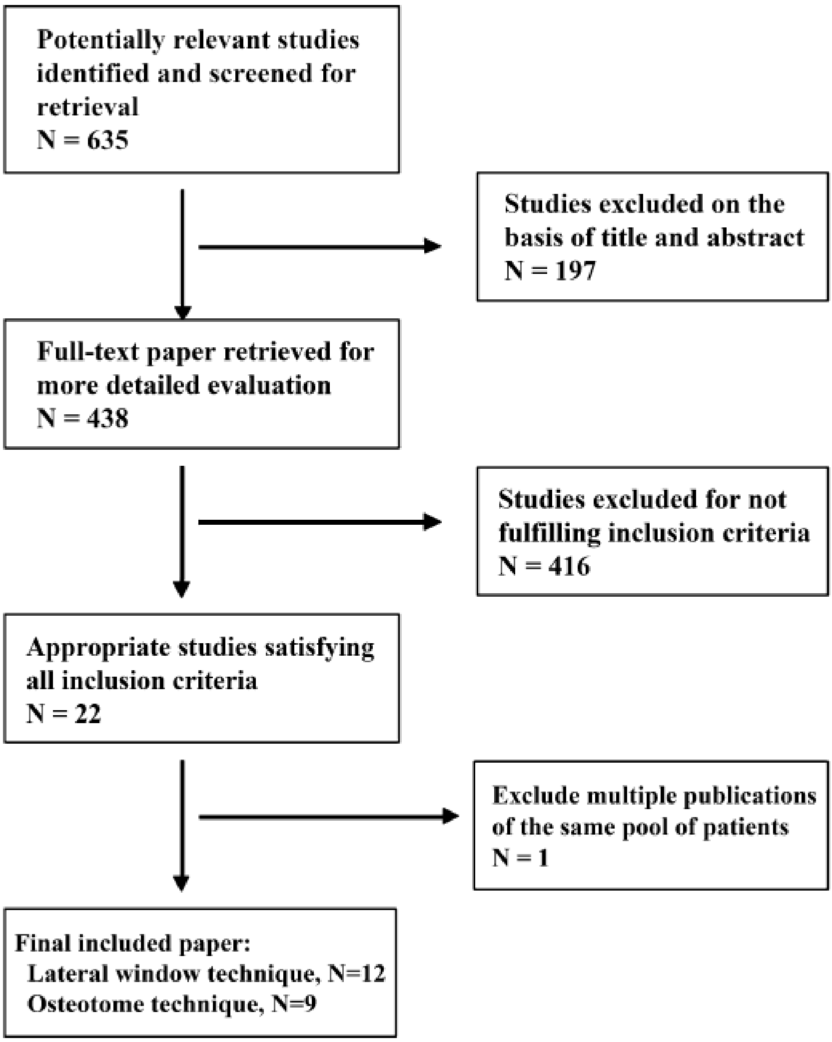

Fig. 1. Flow chart.

Meta-regression analysis for the lateral window technique

The results of the meta-regression model showed a significant trend, indicating that the implant survival rates increased with a greater residual bone height (adjusted $R^2 = 0.83$, Fig. 2). The quadratic meta-regression model fit the empirical data even better (adjusted $R^2 = 0.97$, Fig. 2). The implant survival rate showed an increasing positive trend when the initial bone height rose from approximately 1 to 5 mm, and became stable at a high survival level when the initial bone height was >5 mm or so.

Considering that different follow-up times across studies might have influenced the outcome measure of implant survival, we transformed implant survival into a hazard rate as described previously. Two of the 12 studies did not provide a mean value for follow-up time and were excluded from this calculation. The results of the quadratic regression model showed a well-fitted curve (adjusted $R^2 = 0.89$, Fig. 3). With increasing initial alveolar bone height, the hazard rate for the failure of an implant significantly declined.

Meta-regression analysis of the osteotome technique

Figure 4 shows the results for the osteotome technique. There was no evidence of a linear ($p = 0.56$ for linear term) or a quadratic trend ($p = 0.51$ for quadratic term) in the relationship between initial alveolar bone height and implant survival rates. Similar results were found in the hazard rate analysis ($p = 0.34$ and 0.49 for the linear and quadratic trend, respectively). However, it was noted that the initial bone height in all of the included studies was no <4 mm.

Discussion

The initial alveolar bone height has been considered as an important factor for selecting sinus lift procedure for implant placement. The aim of this study was to evaluate the impact of the initial bone height on the survival rates of dental implants treated with different sinus lift procedures. We hypothesized that there might be two different implant survival curves for the lateral window and osteotome techniques. These two curves might cross at approximately 4–6 mm of residual bone height as 5 mm of alveolar bone has been suggested as

Table 1. Summary of papers included utilizing the lateral window sinus elevation technique

References	Year	Study description	Subject	Age in years (range)	Smokers	Graft material	Initial alveolar bone height in mm (range)	Implant staging	Evaluation criteria	Survival rate/ Success rate	Follow-up time in months (range)	Hazard rate λ per month
Mazor et al.	1999	Clinical trial	10 patients (7 F; 3 M) 10 implants	35 (25–50)	Not mentioned	Autogenous composite bone graft (50% autograft+50% DFDB)	5.4 (5–7) SD: 0.699	1-stage	Albrektsson et al. & Cox and Zarb	Success rate 100%	36 after loading 47 after implant placement	0
Raghoebar et al.	2001	Clinical trial	99 patients (58 F; 41 M) 182 sinuses 392 implants	48 ± 12 (17–73)	Not mentioned	Autogenous bone graft (iliac crest, mandibular symphysis, maxillary tuberosity)	3 ± 2 (1–7)	1-stage: 25 pt, 86 implants 2-stage: 74 pt, 306 implants	Failure evaluation criteria	Survival rate 91.8%	58 ± 27 (12 ~ 124) after implantation	0.001475
Cordioli et al.	2001	Clinical trial	12 patients (8 F; 4 M) 27 implants	48 ± 10 (35–68)	Non-smoker	Bioactive glass (Biogran) combined with autogenous bone	4.40 (3–5) SD: 0.63	1-stage	Albrektsson et al.	Survival rate 96.3%	12 after loading 22.83 after implant placement	0.00165
Karabuda et al.	2001	Clinical and histological study	8 patients (4 F; 4 M) 9 sinuses 19 implants	41 (29–65)	Not mentioned	Demineralized freeze-dried bone particle; deproteinized bovine bone granules	6.3 (1–8)	1-stage: 5 pt, 10 implants 2-stage: 3 pt, 9 implants	Implants continue to remain in function	Survival rate 100%	12 (9 ~ 24) after loading	0
Reinert et al.	2003	Clinical trial	30 patients (19 F; 11 M) 58 sinuses 170 implants	Not mentioned	Not mentioned	Autogenous bone graft from iliac crest	3.7	2-stage	Implant loss	Survival rate 93.53%	> 12 after loading	Could not calculate
Lundgren et al.	2004	Clinical trial	10 patients (9 F; 2 M) 12 sinuses 19 implants	51	Not mentioned	Without additional grafting material	7 (4–10)	1-stage	Radiographic, clinical, and RFA showed a status quo situation.	Success rate 100%	44 after loading	0
Zijderveld et al.	2005	Prospective clinical study	10 patients (4 F; 6 M) 16 sinuses 41 implants	52.2 (28–65)	Smokers included	β-Tricalcium phosphate+ autogenous chin bone	5.94 (4–8)	2-stage	Implant loss	Survival rate 100%	12	0
Hallman et al.	2005	Prospective clinical study	20 patients (14 F; 6 M)	62 (48–69)	9 smokers 7 smoking history	Autogenous bone+deproteini-	Lowest 1.6 (1–3 mm)	2-stage	Albrektsson et al.	Survival rate 86.2%	36 after loading 42.7 after	0.003478

Table 1. (Contd.)

References	Year	Study description	Subject	Age in years (range)	Smokers	Graft material	Initial alveolar bone height in mm (range)	Implant staging	Evaluation criteria	Survival rate/ Success rate	Follow-up time in months (range)	Hazard rate λ per month
			30 sinuses 108 implants			zed bovine bone mixture (20:80)	Highest 3.8 (2–5 mm)				implant placement	
Ewers	2005	Retrospective clinical report	118 patients 209 sinuses 614 implants	Not mentioned	Smokers included	Marine-derived carbonated red algae chemically converted into hydroxyapatite (HA)	3.6 (1–5)	2-stage	Not mentioned	Survival rate 95.6%	~ 156 (longest observation period)	Could not calculate
Thor et al.	2007	Clinical trial	20 patients (9M;11F) 27 sinus 44 implants	59 (19–78)	2 smokers	Without graft material	4.6 (2–9)	1-stage	Implant loss	Survival rate 97.7%	27 (14–45) after implant placement	0.0008618
Chen et al.	2007	Retrospective clinical trial	33 patients (23M;10F) 47 implants	55	Not mentioned	Without bone grafting	7.5 ± 2.1	1-stage	Infection, pain, or more than 2 mm peri-implant bone loss	Survival rate 100%	Minimal 24 After prosthesis delivery	0
Kahnberg & Vannas-Löfqvist	2008	Prospective clinical trial	36 patients (22F;14M) 47 sinus 153 implants	59.86	4 smokers All quitted 6 months before surgery	Autogenous bone (iliac crest, mandibular angle or chin region) 10 cases add Bio-Oss augmentation	5.8 ± 2.5	2-stage	Implant loss	Survival rate 100%	27 patients for 5 years, 32 patients for 4 years, 36 patients for 3 years After grafting surgery	0

the minimum bone height required for the osteotome procedure (Summers 1994a, b, Rosen et al. 1999, Deporter et al. 2000, 2005, Reiser et al. 2001, Berengo et al. 2004, Toffler 2004a, b, Woo & Le 2004). Nevertheless, our results suggested that there is a positive association between initial alveolar bone and implant survival rates for the lateral window technique, but no such relationship was found for the osteotome technique.

Lateral window technique

Results from our study appear to support that the initial alveolar bone height may be crucial for implant survival with the lateral window technique. As shown in Fig. 2, the implant survival rates were well-fitted by a quadratic trend. When the expected survival rate on the y-axis is set as 96%, as that of ITI and Brånemark implants with up to 10 years of follow-up (Schnitman et al. 1997, Noack et al. 1999, Lambrecht et al. 2003, Blanes et al. 2007), a minimal initial bone height of 4.03 mm may be required according to Fig. 2.

The trend of this quadratic model may be explained by considering the influence of the primary implant stability and sinus membrane perforation. It has been suggested that a residual bone height of <4–5 mm was associated with reduced primary implant stability (ten Bruggenkate & van den Bergh 1998, Nkenke et al. 2002), and primary implant stability is crucial for successful osseointegration (Lioubavina-Hack et al. 2006). This concept is in agreement with our findings from the quadratic meta-regression in Fig. 2. Probably due to the reduced primary implant stability, a residual bone height of <4 mm was correlated with poorer implant survival rates in our analysis.

As to the complications associated with sinus augmentation, maxillary sinus membrane perforation was found to occur more frequently with a shorter height of the residual alveolar bone mainly due to technical difficulties (Ardekian et al. 2006, Shalabi et al. 2007). It has also been suggested that a larger amount of the Schneiderian membrane may have to be elevated when dealing with a smaller initial alveolar bone height, which might lead to an increased risk of sinus membrane perforation (van den Bergh et al. 2000). Furthermore, perforation and repair of the sinus membrane may jeopardize new

Table 2. Summary of papers included utilizing the osteotome sinus elevation technique

Reference	Year	Study description	Subject	Age in years (range)	Smoker	Graft material	Initial alveolar bone height in mm (range)	Evaluation criteria	Survival rate/Success rate	Follow-up (months)	Hazard rate λ
Komarnyckyj & London	1998	Clinical report	16 patients 16 sinuses 43 implants (16 implants in grafted sites)	Not mentioned	Not mentioned	Autogenous graft from the tuberosity or maxillary edentulous ridge	Buccal 5.31 (3–8) Palatal 5.50 (3–9) Average 5.4	Albrektsson et al.	Survival rate 93.75%	9–47 after implant placement 3–38 after loading	Could not calculate
Artzi et al.	2003	Clinical report	10 patients (3 F; 7 M) 10 implants	47.5 (34–58)	Non-smokers/ light smokers	Natural inorganic bovine bone mineral or synthetic β-tricalcium phosphate (TCP)	7.8	Stability and support for the prosthesis	Survival rate 100%	24 after loading	0
Toffler	2004b	Clinical trial	167 patients 276 implants	56.8 (27–82)	Smokers included	Bovine bone mineral, autogenous bone harvested from the tuberosity or posterior mandible	7.1 (3–10)	Implant loss, implant fracture, progressive bone loss	Survival rate 93.5%	27.9 (1–84) after loading	0.00241
Bragger et al.	2004	Longitudinal cohort study	19 patients (12 F; 7 M) 25 implants	59 (39–78)	Non-smokers	Deproteinized bovine bone material, Bio-Oss, mixed with autologous bone chips	7.0 (2.3–10.3)	Implant loss	Survival rate 96%	12 after implant placement 6 after loading	0.00340
Leblebicioglu et al.	2005	Clinical trial	40 patients (19 F; 21 M) 75 implants	46.7	10 smokers 30 non- smokers	None	9.05	Not mobile, still in function	Success rate 97.3%	25 after loading	0.00109
Deporter et al.	2005	Retrospective assessment	70 patients 104 implants	Not mentioned	Not mentioned	Bovine hydroxyapatite	4.2 (2 ~ 6.7)	Implant loss	Survival rate 98.08%	37.68 after loading	0.000515
Sotirakis & Gonshor	2005	Clinical trial	11 patients (6 F; 5 M) 16 implants (13 in grafted sites)	50 (24–70)	Not mentioned	Inorganic bone mineral xenograft (BioOss) mixed with autogenous bone	4	Implant loss	Survival rate 100%	2–30 after loading	0
Diserens et al.	2005	Clinical trial	33 patients (20 F; 13 M) 44 implants	59.8 ± 7.2	Not mentioned	39% bone chips only 61% bone chips+Bio-Oss	5.78 ± 1.4	Implants stable in situ	Success rate 100%	14.4 after loading	0
Nedir et al.	2006	Prospective study	17 patients (14 F; 3 M) 25 implants	54.2 ± 9.6 (38 ~ 69)	Not mentioned	None	5.4 ± 2.3	Survival criteria: Buser (1997) and Cochran (2002)	Survival rate 100%	12 after implant placement >6 after loading	0

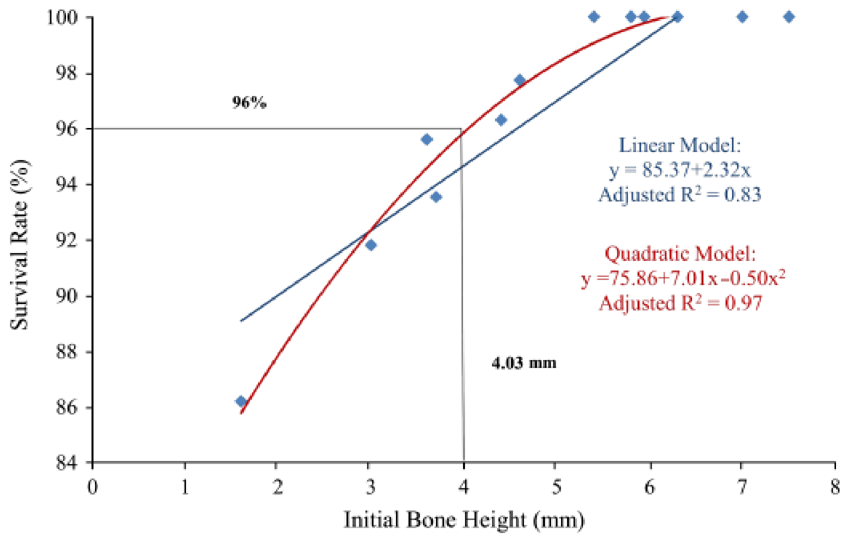

Fig. 2. Lateral window technique. Scatterplot, linear regression, and quadratic regression of the implant survival rate against the initial alveolar bone height.

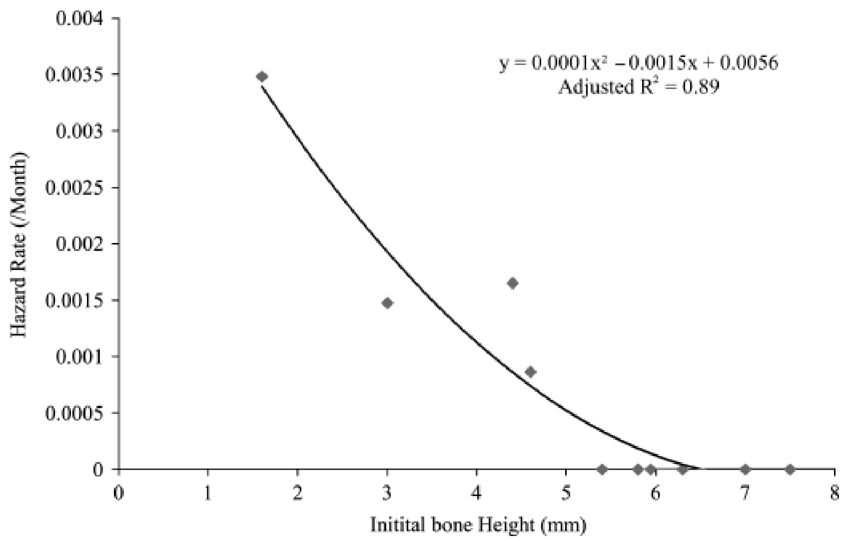

Fig. 3. Lateral window technique. Scatterplot and meta-regression of the implant hazard rate against the initial alveolar bone height.

bone formation and implant survival (Proussaefs et al. 2004). These findings supported our results that the initial bone height may affect the survival rates of dental implants in lateral sinus augmentation (Fig. 2), in spite of the different opinions from some recent studies (Barone et al. 2006, Karabuda et al. 2006), which showed no correlation between sinus perforation and the osseointegration process or the subsequent implant failure rate.

Osteotome technique

The results regarding the osteotome technique did not show a significant relationship between the initial alveolar bone height and implant survival rate. The explanations may be the higher reported implant survival following osteotome techniques (Tan et al. 2008, Tonetti & Hämmerle 2008) and the patient selection criteria in terms of residual bone height adopted by studies using the osteotome technique. All the included studies reported high success rates, and the range of initial bone heights were 4–9 mm. This appears to suggest that most studies tended to observe the rule of ''minimal bone height'' when selecting patients for this surgical technique. Therefore, the implant survival rates with <4 mm of bone height are not available in the literature. If we excluded studies with <4 mm initial bone heights using the lateral window technique, the positive relationship would diminish, as the remaining studies had a survival rate close to 100%. Therefore, while we did not find a positive association between the implant survival rates and initial bone heights among studies using the osteotome technique, this does not mean the survival rates would be the same irrespective of any initial bone height.

From the present data (with all bone heights exceeding 4 mm), there is a greater variation in implant survival rates among the osteotome group than the lateral window technique. In our opinions, the osteotome technique is a blind procedure and is highly technique sensitive. Clinicians who have little experience in doing such a procedure may have a greater risk of perforating the sinus membrane without noticing that perforation has occurred. In addition, several ''modified'' crestal approaches such as the localized management of the sinus floor (Bruschi et al. 1998, Winter et al. 2002), crestal core elevation techniques (Toffler 2001, Fugazzotto & De 2002), and hydraulic pressure technique (Chen & Cha 2005) were proposed, and a great variety of operative skills were used. All of these uncertainties might have contributed to the wide diversity of implant survival rates when using the osteotome technique.

Use of bone grafts in sinus lifting surgery

Apart from the initial bone height, several other factors may be associated with survival rates of implants placed with sinus lifting techniques, e.g., the use of bone augmentation materials (Pjetursson et al. 2008). To assess the role of bone grafting, it may be incorporated as a covariate in the meta-regression analysis. However, while there were only 12 and nine studies included in our meta-analysis for lateral window and osteotome techniques, respectively, several different bone grafting materials were used in those studies as shown in Tables 1 and 2. For instance, in studies using the lateral window technique, three studies did not use any bone grafts, one used autogenous bone grafts, one used synthetic bone grafts, and six used autogenous bone in conjunction with allografts or synthetic bone grafts. This made a quantitative estimation of the types of bone grafts almost impossible due to a lack of degree of freedom, as

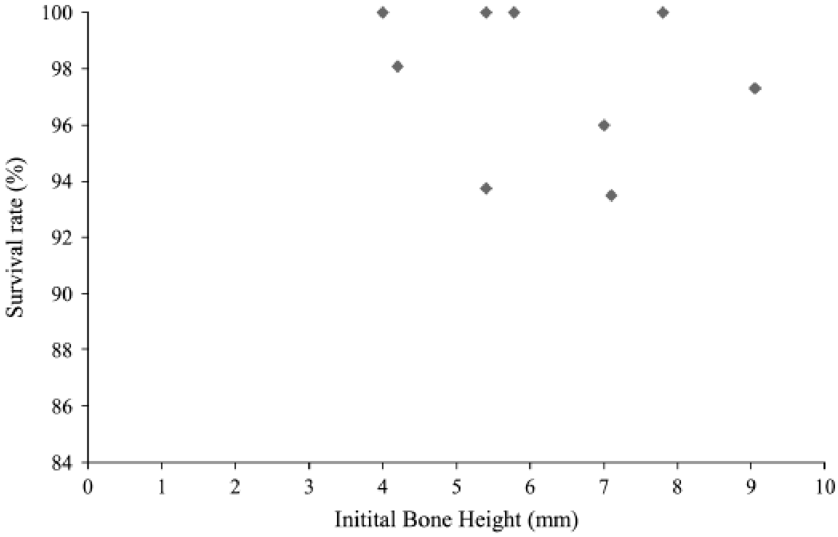

Fig. 4. Osteotome technique. Scatterplot of the implant survival rate against the initial alveolar bone height.

there are too many interaction terms to be included in our meta-regression. Therefore, we assigned studies into two groups: those with or without bone grafts by disregarding the different types of bone grafts being used. Results show that in quadratic models, the interaction between bone grafts and initial bone height are not statistically significant, i.e., our study does not find differential associations between the use of bone grafts and implant survival rates with the consideration of the initial bone height. Nevertheless, this does not necessarily mean that the use of bone grafts does not improve implant survival, as our meta-regression has relatively low statistical power owing to the limited number of studies included. It is also noted that studies without the use of bone grafts tended to have greater initial bone height, and this made estimating the impact of bone grafts on implant survival complicated.

Treatment selection

Inclusion criteria for the lateral and osteotome techniques were proposed by certain studies (Zitzmann & Scharer 1998, Fugazzotto 2003). The proposed hierarchy of treatment selection was primarily based on clinical experience and a literature review. In this study, a relationship between the implant survival rates and initial bone height was found for the lateral window technique but not for the osteotome technique, although, this appears to contradict the general consensus that 4–6 mm of initial alveolar bone height can be used as a single deciding factor for surgical selection between the lateral window and osteotome techniques. However, we still noted that an initial alveolar bone height of >4 mm was associated with higher survival rates when using the lateral window technique. Whether there is a critical initial bone height for the success of maxillary implants with the osteotome technique, as suggested by the current consensus, requires more research.

Limitations of our study

In order to minimize the bias caused by different follow-up times across the studies included, we also conducted a hazard function analysis. The hazard function defines the probability of implant loss as a function of time. Therefore, a 1-year follow-up study could be compared with a 10-year follow-up study. Figure 3 shows that the hazard function is well fitted by a reverse quadratic curve. This finding also confirms the association between the residual alveolar bone height and implant survival using the lateral window technique shown in Fig. 2.

However, there are some theoretical assumptions behind this method. We assumed that the incidences of implant loss were equally distributed throughout the follow-up period, but the risk of implant failures might be greater in the first year of implantation. For instance, one study suggested that when implants failed, they did so soon after placement, and the likelihood of failure steadily decreased through the first 5 years (Weyant & Burt 1993). As a result, we might have overestimated the failure probability of studies with shorter follow-up periods. To overcome this limitation, using individual implant data for meta-analysis is required instead of using the aggregated data with the average value of the initial alveolar bone from each study.

The number of included studies in this systemic review was not large. Only 21 of 635 articles met our selection criteria, and most of them are prospective clinical studies or case reports with a great variety of study designs, implant types, timing of implant placement, prosthesis designs, implant numbers per patient (Weyant & Burt 1993, Naert et al. 2002), patient age and gender, smoking habits, membrane or graft materials used, and quality of local alveolar bone. Therefore, it needs to be cautious in the interpretation of our findings. Furthermore, the evaluation criteria for implant success or survival were not uniform among these studies. As discussed previously, the different lengths of follow-up time even made it difficult to directly compare results across studies.

Conclusions

Results of this systematic review found a positive relationship between the initial alveolar bone height and implant survival rate among the lateral window technique. No such relationship was found for the osteotome technique, and this might be attributed to the fact that the initial bone heights in all the studies using osteotome techniques were greater than 4 mm. It should be noted that the lack of such a relationship should not be interpreted that the osteotome technique can be used regardless of the level of initial bone height. More research is required to ascertain the role of initial bone height in the success of implant placement with the osteotome technique.

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Clinical Relevance

Scientific rationale for study: Limited evidence was available regarding selecting the sinus elevation procedure for maxillary implants.
Principal findings: Our results failed to support that 4–6 mm of initial alveolar bone height is a deciding factor for choosing between the lateral window and osteotome techniques.
Practical implications: For maxillary implants placement with the lateral window procedure, an implant survival rate of 96% may be expected if the initial bone height is at least 4 mm. Critical initial bone height for implants with osteotome techniques cannot be estimated due to a lack of data for initial bone height <4 mm.