Which Hard Tissue Augmentation Techniques Are the Most Successful in Furnishing Bony Support for Implant Placement?

Tara L. Aghaloo, DDS, MD[1]/Peter K. Moy, DMD[2]

Purpose: *A variety of techniques and materials have been used to establish the structural base of osseous tissue for supporting dental implants. The aim of this systematic review was to identify the most successful technique(s) to provide the necessary alveolar bone to place a dental implant and support long-term survival.* ***Methods:*** *A systematic online review of a main database and manual search of relevant articles from refereed journals were performed between 1980 and 2005. Updates and additions were made from September 2004 to May 2005. The hard tissue augmentation techniques were separated into 2 anatomic sites, the maxillary sinus and alveolar ridge. Within the alveolar ridge augmentation technique, different surgical approaches were identified and categorized, including guided bone regeneration (GBR), onlay/veneer grafting (OVG), combinations of onlay, veneer, interpositional inlay grafting (COG), distraction osteogenesis (DO), ridge splitting (RS), free and vascularized autografts for discontinuity defects (DD), mandibular interpositional grafting (MI), and socket preservation (SP). All identified articles were evaluated and screened by 2 independent reviewers to meet strict inclusion criteria. Articles meeting the inclusion criteria were further evaluated for data extraction. The initial search identified a total of 526 articles from the electronic database and manual search. Of these, 335 articles met the inclusion criteria after a review of the titles and abstracts. From the 335 articles, further review of the full text of the articles produced 90 articles that provided sufficient data for extraction and analysis.* ***Results:*** *For the maxillary sinus grafting (SG) technique, the results showed a total of 5,128 implants placed, with follow-up times ranging from 12 to 102 months. Implant survival was 92% for implants placed into autogenous and autogenous/composite grafts, 93.3% for implants placed into allogeneic/nonautogenous composite grafts, 81% for implants placed into alloplast and alloplast/xenograft materials, and 95.6% for implants placed into xenograft materials alone. For alveolar ridge augmentation, a total of 2,620 implants were placed, with follow-up ranging from 5 to 74 months. The implant survival rate was 95.5% for GBR, 90.4% for OVG, 94.7% for DO, and 83.8% for COG. Other techniques, such as DD, RS, SP, and MI, were difficult to analyze because of the small sample size and data heterogeneity within and across studies.* ***Conclusions:*** *The maxillary sinus augmentation procedure has been well documented, and the long-term clinical success/survival (> 5 years) of implants placed, regardless of graft material(s) used, compares favorably to implants placed conventionally, with no grafting procedure, as reported in other systematic reviews. Alveolar ridge augmentation techniques do not have detailed documentation or long-term follow-up studies, with the exception of GBR. However, studies that met the inclusion criteria seemed to be comparable and yielded favorable results in supporting dental implants. The alveolar ridge augmentation procedures may be more technique- and operator-experience–sensitive, and implant survival may be a function of residual bone supporting the dental implant rather than grafted bone. More in-depth, long-term, multicenter studies are required to provide further insight into augmentation procedures to support dental implant survival.* INT J ORAL MAXILLOFAC IMPLANTS 2007;22(SUPPL):49–70

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[1]Assistant Professor, Oral and Maxillofacial Surgery, University of California at Los Angeles (UCLA) School of Dentistry, Los Angeles, California.
[2]Professor, Oral and Maxillofacial Surgery, and Director, Implant Dentistry, University of California at Los Angeles (UCLA) School of Dentistry, Los Angeles, California.

Correspondence to: Dr Peter K. Moy, UCLA School of Dentistry, West Coast OMS Center, 11980 San Vicente Blvd, Suite 503, Los Angeles, CA 90049-6603. E-mail: drmoy@titaniumimplant.com

Management of edentulous patients with dental implants has become common and well accepted. The predictability of implant procedures and the maintenance of long-term stability of implants in function are directly related to the quality and quantity of the available osseous tissue for implant placement. When the alveolar ridges lack the appropriate bone volume, additional surgical procedures are necessary to reconstruct and augment the deficiency. A variety of augmentation procedures, dependent on location and size of defect, have been introduced to provide the osseous support necessary to permit placement of implants. The introduction of new graft materials (ie, allografts, xenografts, and alloplastic materials), as well as various dimensions of these graft materials, have provided alternatives to autogenous bone. The clinician must make the appropriate selection of graft material and technique based on the size, shape, and dimensions of the defect and its location in the mouth. Thus, it is important for the clinician to review the literature to understand which graft material and which surgical technique will provide the best reconstructed osseous ridge to successfully support dental implant placement and long-term function.

Confounding reports have appeared in the literature as to implant success and survival rates for implants placed into bone-grafted sites. Classically, higher implant failure rates have been reported when implants are placed into grafted sites.[1–7] However, many of these studies were based on a single center, contained a limited number of patients, and were limited to the evaluation of a single surgical technique. More recently, very high implant success rates have been reported when bone augmentation procedures have been performed.[8–12] Other studies have not indicated significant differences in implant success rates between implants placed into graft sites compared to implants placed into native bone.[13–16] The variation in published outcomes suggests that making decisions based on the evidence to provide appropriate treatment for the dental implant patient is a very complex and difficult process. In addition, the variables are continually changing through improvement of technology, implant micro-surfaces, and biomaterial macro-structures. It is clear that when making evidence-based decisions, the clinician must have full knowledge of the technique, the advantages and disadvantages of biomaterials used, and the variations of surface characteristics with the selected implant. The aim of this systematic review is to evaluate all existing literature from the last 25 years to determine which hard tissue augmentation techniques are the most successful in providing the necessary bone support for implant placement and maintenance over time. The review examined 2 hard tissue augmentation techniques, sinus floor augmentation and alveolar ridge augmentation, due to the unique differences in the anatomy of recipient sites. The section on alveolar ridge augmentation was further divided into 8 techniques to include evaluations of procedures ranging from the most minimal, ie, extraction socket augmentation, to the most complex, ie, a combination of onlay veneer and interpositional grafts. A secondary aim of the systematic review was to evaluate the quality of existing studies based on levels of evidence used to determine the validity and applicability of the particular study. This assessment helps to determine whether techniques and methodologies are similar and ranks the study in terms of scientific levels of evidence.

MATERIALS AND METHODS

Search Strategy

A PubMed electronic search was conducted to identify potential articles for inclusion in this systematic review. The search included articles between 1980 and 2005. This literature was a completely separate search, not associated with the Academy of Osseointegration master search done for all topics. Searches were performed several times and updated to include new articles between September 2004 and May 2005. Key words utilized included "dental implants," "bone grafts," and "sinus grafts OR sinus lift OR sinus augmentation OR maxillary sinus lift OR maxillary sinus graft OR maxillary sinus augmentation" to identify all articles where the sinus bone augmentation (SG) technique was utilized. A similar approach was used to identify other bone grafting techniques, including guided bone regeneration procedures (GBR) either prior to or at the time of implant placement, onlay or veneer grafting (OVG), combinations of onlay, veneer, and interpositional inlay grafting (COG), and others including distraction osteogenesis (DO), socket augmentation or preservation (SP), ridge splitting or expansion (RS), free and vascularized autografts for discontinuity defects (DD), and mandibular interpositional grafting (MI). References from previous systematic reviews, meta-analyses, and review articles were also evaluated to be certain that no appropriate articles were missed. In addition, specific journals were hand searched up to May 2005, including *International Journal of Oral and Maxillofacial Implants, Clinical Oral Implants Research, Journal of Oral and Maxillofacial Surgery*, and *International Journal of Periodontics and Restorative Dentistry.*

Table 1 Kappa Table of Reviewer 1 by Reviewer 2			
	Reviewer 2		
Reviewer 1	Accept	Reject	Total
Accept	150	13	163
Reject	0	172	172
Total	150	185	335

Agreement between the 2 reviewers was 96.12%; the kappa coefficient was 0.9222.

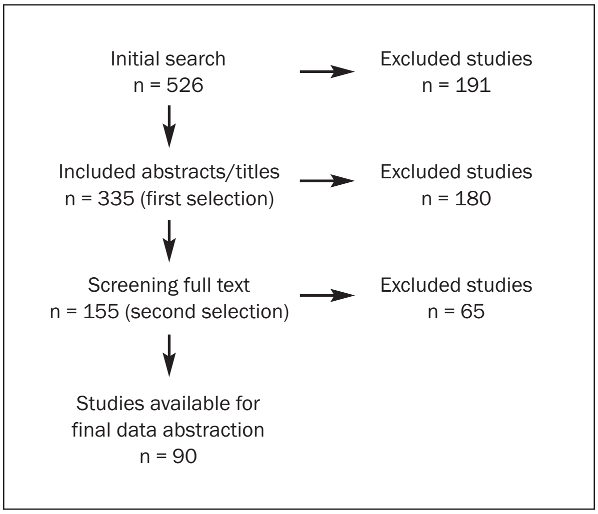

Fig 1 *(right)* Screening process used to identify eligible studies.

Study Selection

From the 526 titles electronically identified from our independent literature search, 335 articles were selected for potential inclusion. The first selection of articles included human clinical studies where hard tissue augmentation procedures were performed either prior to or at the time of implant placement. Implants must have been placed into the grafted bone, and knowledge of the number of patients and period of follow-up was required. Articles were excluded if they were animal or in vitro studies, case reports, technique articles, systematic reviews or meta-analyses, if hard tissue augmentation was not performed, if implants were not placed, and if no follow-up interval was reported. Initially all 155 articles that fit the first selection criteria were included in the sample. At this point, all 155 abstracts were reviewed, and a second set of selection criteria was applied. For this more intense screening, only articles written in English were selected. At least 10 patients had to be included in the study, with a 12-month follow-up period after the placement of implants. The implants had to be placed into augmented bone, and the augmentation technique had to be specified. In addition, implant failure or survival rates had to be reported, unless they could be calculated from the data provided. To identify and record all of this information, the full texts of the 155 articles were reviewed, and 90 studies[6–10,12–14,16–96] were included for complete analysis (Fig 1). A list of the included articles is available in the Web edition of this article.

Validity and Correlation of Reviewers

One reviewer evaluated the titles and abstracts of the 526 articles identified for inclusion or exclusion. The 335 articles identified for potential inclusion were then reviewed by 2 independent examiners and agreement was determined. If a disagreement existed, the articles were discussed individually, and a consensus was reached. A kappa table was formulated based on accepted and rejected articles by reviewer 1 and reviewer 2 (Table 1). Percent agreement was determined as 96.12%, with a kappa coefficient of 0.9222. Similarly at the second selection stage, the same 2 independent reviewers reviewed the full text of the 155 articles. This step excluded 65 articles, leaving 90 articles in the systematic review for data extraction and analysis.

Data Extraction

Articles were evaluated exactly as published, and no additional reference or contact with the authors was sought. The main outcome measure assessed during this review was implant survival, which was defined as the implant remaining in function without reported pain, infection, or mobility at the time of last clinical or radiographic follow-up examination. Studies that reported objective measurements of clinical or radiographic parameters during follow-up are also reported. Only 29 of the 90 studies evaluated included such information. In addition, volumetric analysis of bone graft stability over time was evaluated. This was included in only 8 of the 90 articles reviewed. A quality assessment was also performed for the reviewed articles, which included an investigation of the study methodology, the utilization of objective criteria to evaluate implant survival rate, and the presence of a life table analysis to follow cumulative implant survival.

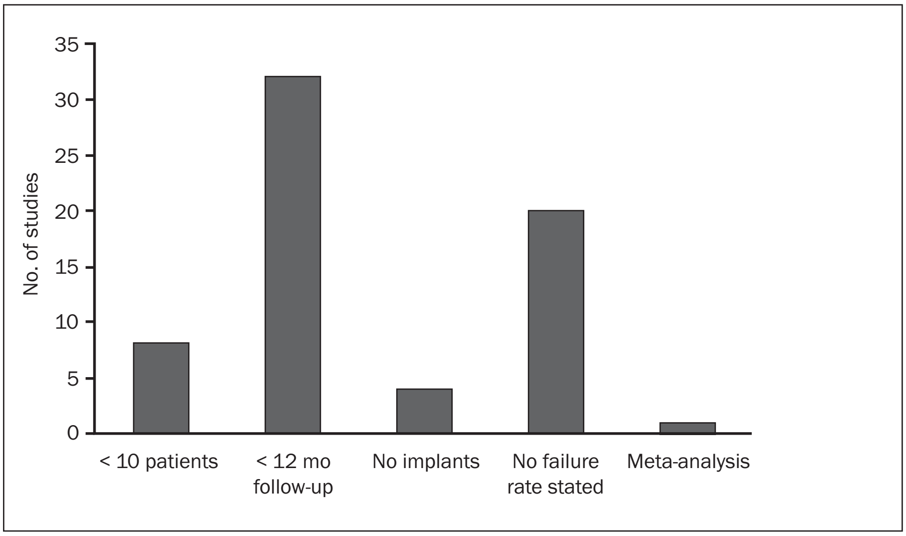

Fig 2 Reasons for study exclusion.

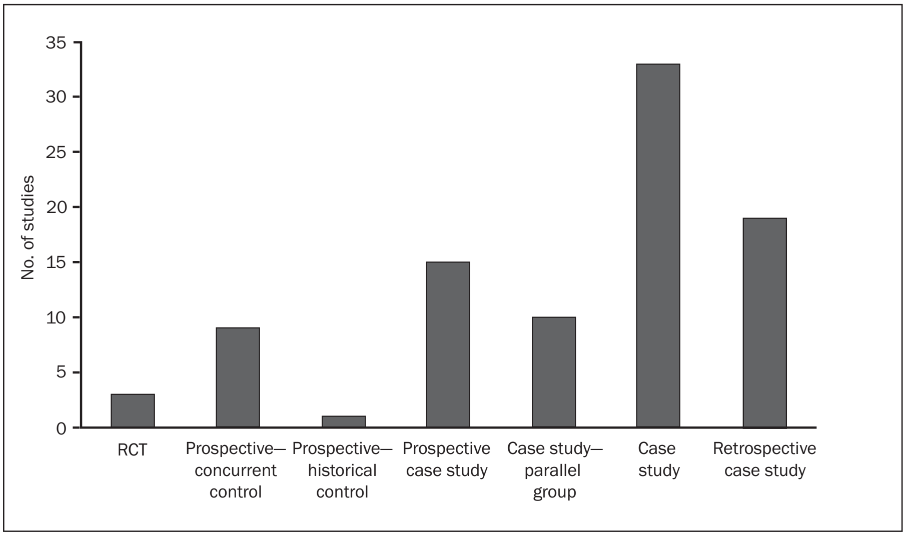

Fig 3 Evaluation of quality by study methodology. Studies are presented in order of descending quality.

Statistical Analysis

Statistical analysis was completed after all data were extracted from included articles by a biostatistician. Implant survival was calculated with a 95% confidence interval utilizing the Wilson score method and displayed as forest plots. The random effects meta-analytical model was employed to evaluate the pooled estimate of effect from a collection of studies with significant heterogeneity.

RESULTS

Study Exclusion, Quality of Included Studies, and Objective Evaluation

Of the 155 studies where full text was evaluated for data extraction, 65 articles were excluded primarily because of the lack of 12-month follow-up. Other reasons for article exclusion included having less than 10 patients, no implants placed in bone grafts, no stated failure rate, or that the article was a meta-analysis (Fig 2).

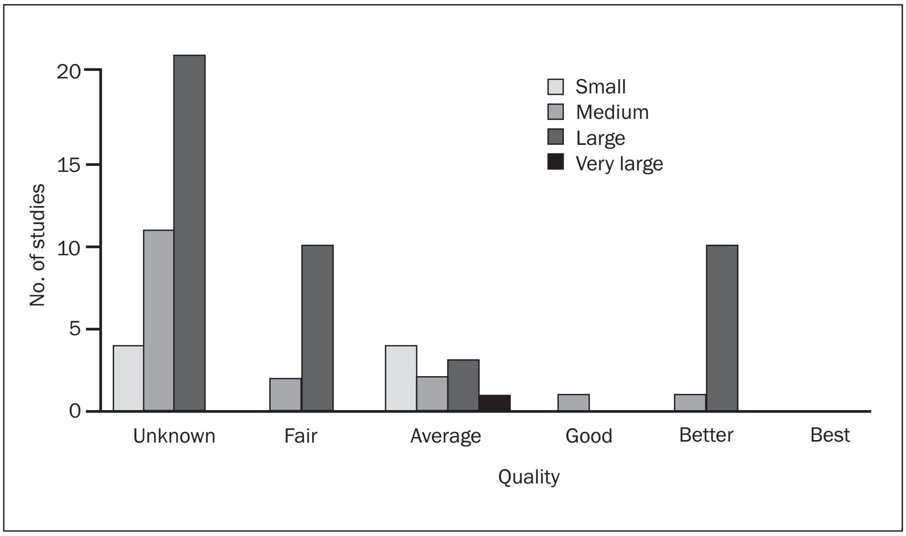

Fig 4 Size and quality of included studies.

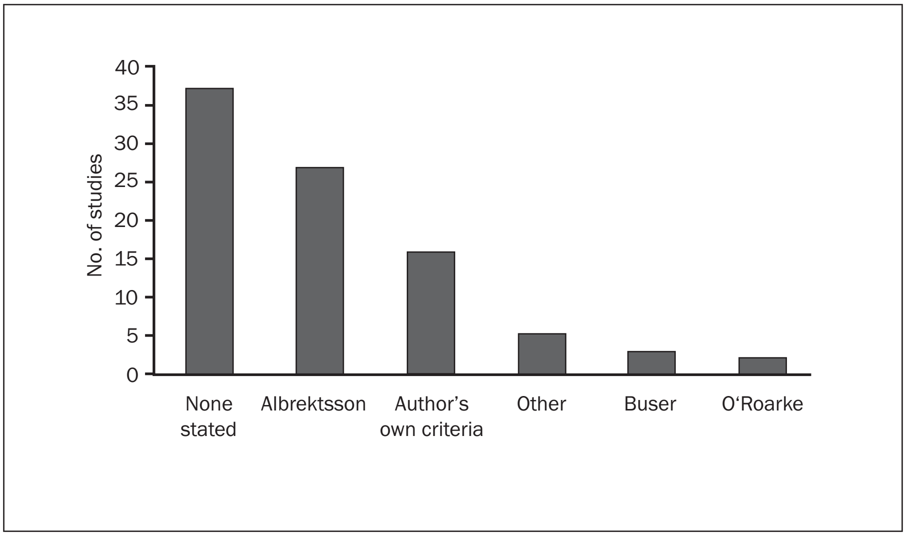

Fig 5 Objective criteria utilized to determine implant survival or failure.

When quality of reviewed articles was evaluated, as measured by study methodology, most of the articles were case studies. These articles did not state whether the data were reviewed retrospectively or prospectively. The next most common study designs included both retrospective and prospective case studies. Only 23 of the 90 reviewed articles included a control group for comparison. Of these, 10 were case studies with parallel groups, 1 was a prospective study with a historical control, 9 were prospective studies with concurrent controls, and 3 were randomized controlled trials (Fig 3).

Further analysis of study quality were performed where both the size and quality of studies were evaluated, with best as randomized controlled trial, better as a prospective study with concurrent controls, good as a prospective study with historical controls, average as a prospective case study, fair as a retrospective case study, and unknown if the study did not fit one of the other categories. Most studies fell into the unknown, fair, or average groups, with very few rated as good, better, or best (Fig 4).

Even though most of the included articles did not contain evaluations of a historical or concurrent control group, many of the articles utilized objective criteria to evaluate implant survival or failure, showing some consistency in how implants were determined as successes or failures. In fact, 53 of the 90 articles utilized objective criteria, most commonly the criteria published by Albrektsson and associates[1] in 1986. Other studies used the authors' own criteria, various other published criteria, or none at all (Fig 5).

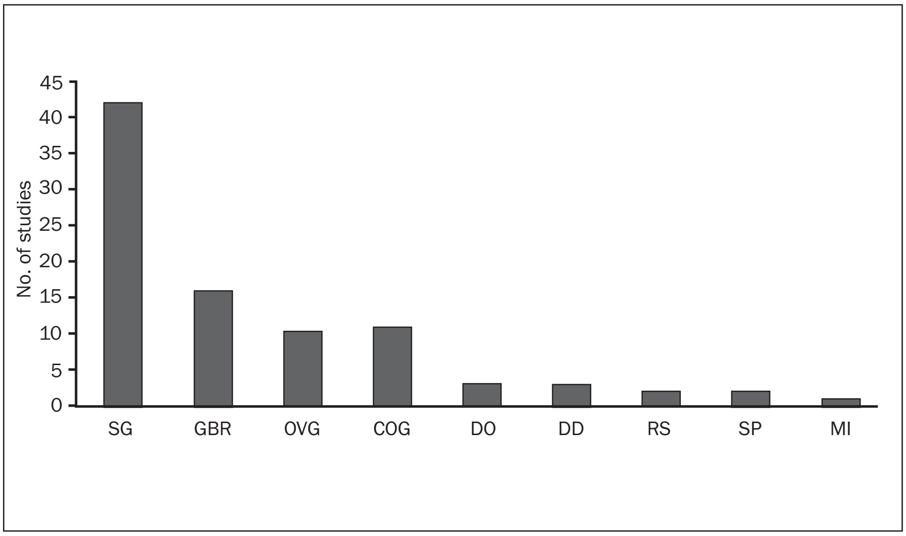

Fig 6 Number of studies by grafting technique.

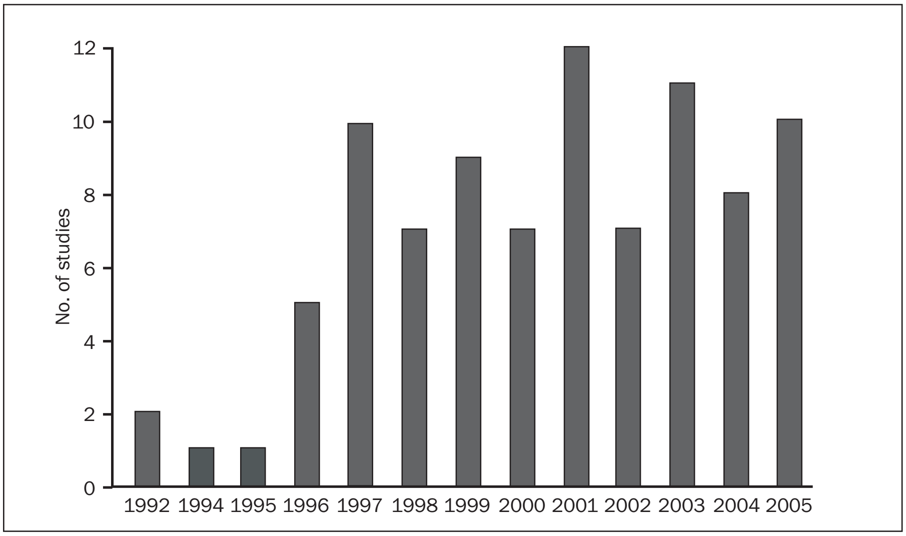

Fig 7 Number of studies by year published from 1992 to 2005.

Though implant survival was reported in all of the included studies, one of the most important statistical tools to evaluate cumulative survival and to determine when dental implants fail is the life table analysis. Although the life table analysis format was reported as early as the late 1980s for dental implants,[2] it has not been consistently reported for all implant studies. In this review, only 26% (23 of 90 articles) reported a life table analysis for dental implant survival. However, this method of statistical evaluation is becoming more common in the implant literature, and recently journals with higher impact factors are requiring inclusion of this analysis.

When studies were evaluated by grafting technique utilized, the majority of the articles focused on sinus grafting. This is not surprising, as a consensus conference on sinus grafts[3] as well as systematic reviews regarding the sinus graft have been published.[4,5] The next most studied technique was GBR, followed by OVG and COG. Studies on other techniques, such as DO, DD, RS, SP, and MI grafting, were few in number (Fig 6). Upon further investigation of objective measurements utilized by individual studies, only 14 studies analyzed parameters such as Plaque Index, Bleeding Index, Gingival Index, attachment loss, probing depth, and distances from the implant to mucosal margin or bone level. Six of these studied the SG technique,[6–11] 4 studied GBR,[12–15] and one each studied OVG,[16] COG,[17] RS,[18] and MI.[19] Only 13 studies evaluated bone loss around implants objectively over time, including 6 SG studies,[20–25] 3 GBR,[15,26,27] 2 COG,[28,29] 1 OVG,[30] and 1 DO[31] study. Even fewer studies (n = 8) measured actual bone

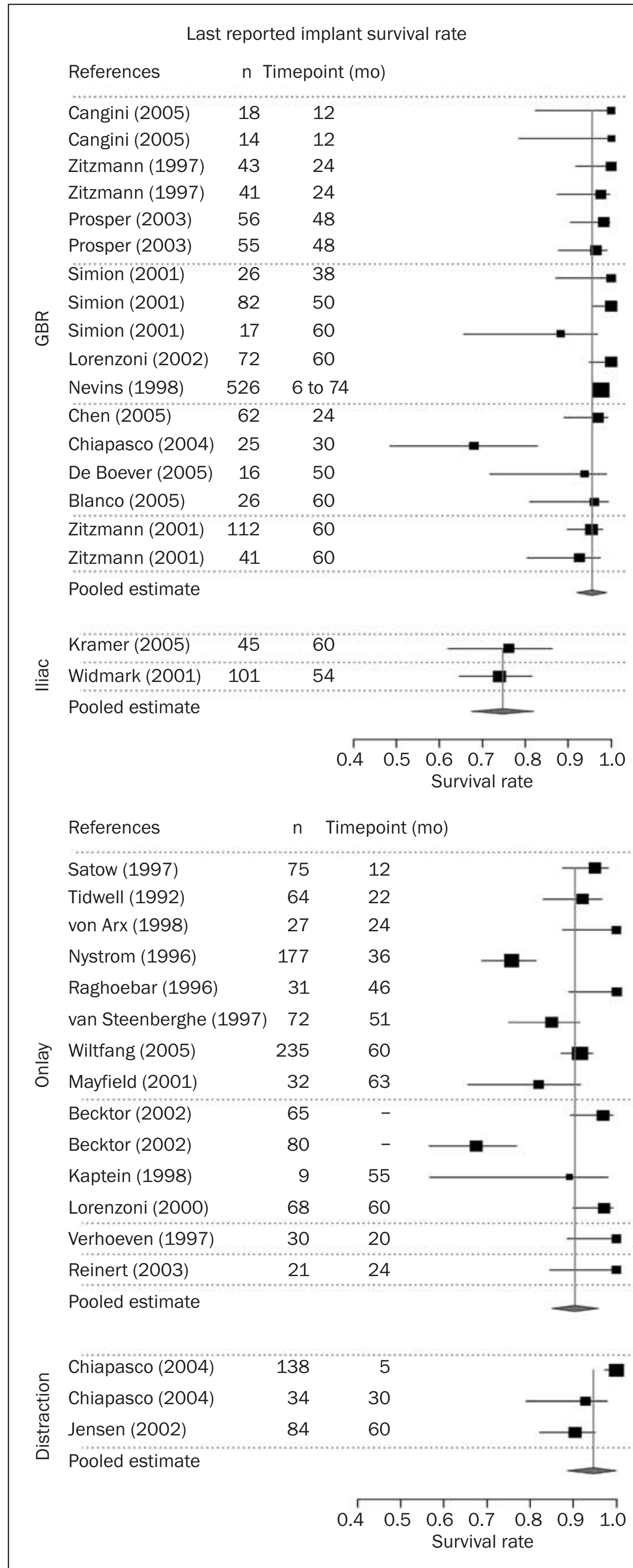

Fig 8 Forest plot analysis of implant survival after bone grafting to increase alveolar height or width.

gained and maintained after grafting by panoramic radiograph or computerized tomographic (CT) scan: 3 SG studies,[1,22,24] 2 COG studies,[32,33] 2 DO,[34,35] and 1 OVG study.[36] This made it difficult to correlate bone graft stability with implant survival based on volumetric measurements, which could not be performed in this analysis.

The distribution of articles by year published was also evaluated, and a fairly even distribution was found from 1997 to 2005 (Fig 7). Interestingly, no articles published before 1992 met the set inclusion criteria for this review.

Implant Survival After Grafting to Increase Alveolar Height or Width

After pooling all of the data extracted from reviewed articles, comprehensive statistical analyses were performed on implant survival after grafting using various techniques and materials. Implant survival was evaluated after grafting techniques to increase alveolar height and/or width, such as GBR, DO, and OVG. In addition, if the iliac crest was reported as the donor bone, this was also analyzed. All articles were included if the words *guided bone regeneration, iliac crest, distraction osteogenesis,* or *onlay* or *veneer grafting* were mentioned specifically, and survival rates were estimated for individual techniques. Because of the variability in follow-up periods between studies, the analysis was conducted using information from the last recorded follow-up examination. This was in the range of 12 to 72 months for the studies described. For GBR, the implant survival rate for the 1,232 implants evaluated was 95.5% (CI: 92–99). The GBR studies were statistically similar, not exhibiting excessive heterogeneity, as determined by their proximity to the line on the forest plot (Fig 8).

Heterogeneity of studies is important in a meta-analysis or systematic review because data from multiple studies are pooled based on the assumption that studies are similar enough to be compared with confidence, and thus, the results may be more generalizable. Similar to the GBR studies, studies where iliac crest bone grafting was utilized also exhibited a close relationship on the forest plot, again indicating that the studies were similar enough to compare. The survival rate for the 146 implants in the 2 studies that were included was 74.7% (CI: 67.4–82). However, these data are not as reliable as that of the GBR studies overall, since only 2 studies could be included for

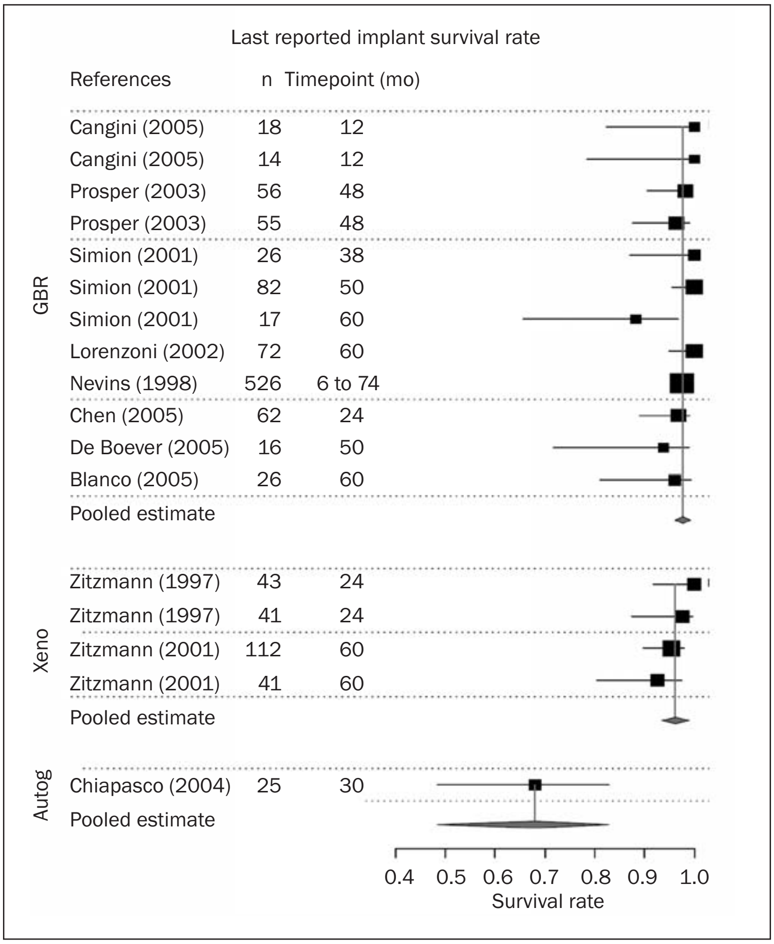

Fig 9 Forest plot analysis of implant survival after GBR to increase alveolar height comparing various grafting materials.

calculation of implant survival. When OVG studies were evaluated, a total of 986 implants yielded a survival rate of 90.4% (CI: 85–95.8). However, looking at the forest plot, it is apparent that these studies were much more heterogeneous and that comparisons between them may not be very accurate (Fig 8). Finally, DO was also evaluated, and the 256 implants that were included in this analysis showed a 94.7% survival rate (CI: 88.6–100). These studies lay close to one another on the forest plot diagram, again showing that combination of extracted data based on assumption that data are comparable may be accurate in this situation. When combinations of onlay, veneer, and interpositional grafting (COG) were analyzed, combining 12 studies, 2,546 of 3,037 implants survived, with a survival rate of 83.8%, which is lower than the overall GBR, OVG, and DO survival rates.[17,29,32,33,37–44]

In the next analysis, the GBR category was further subdivided by grafting material.

Articles that specified whether autogenous or xenograft materials were used were separated from articles where only GBR was stated. Here, the survival rates were similar to the overall rates for GBR, showing a generalized rate of 97.7% (CI: 96.1–99.3) of the 970 implants analyzed, and a rate of 96.2% (CI: 93.4–99) when xenograft materials were used to support 237 implants. However, when autogenous bone grafting was used to support 25 implants, the survival rate was much lower, at 68% (CI: 48.4–82.8). The xenograft category only included 2 studies, and the autograft category only included 1 (Fig 9). This makes it difficult to make comparisons between autogenous and xenograft materials based on these studies.

In the next subset, onlay grafting was subdivided by graft material. Articles were included if the word *onlay* or *veneer grafting* was stated in the Materials and Methods section of the article. These articles were subdivided into the categories of iliac crest,

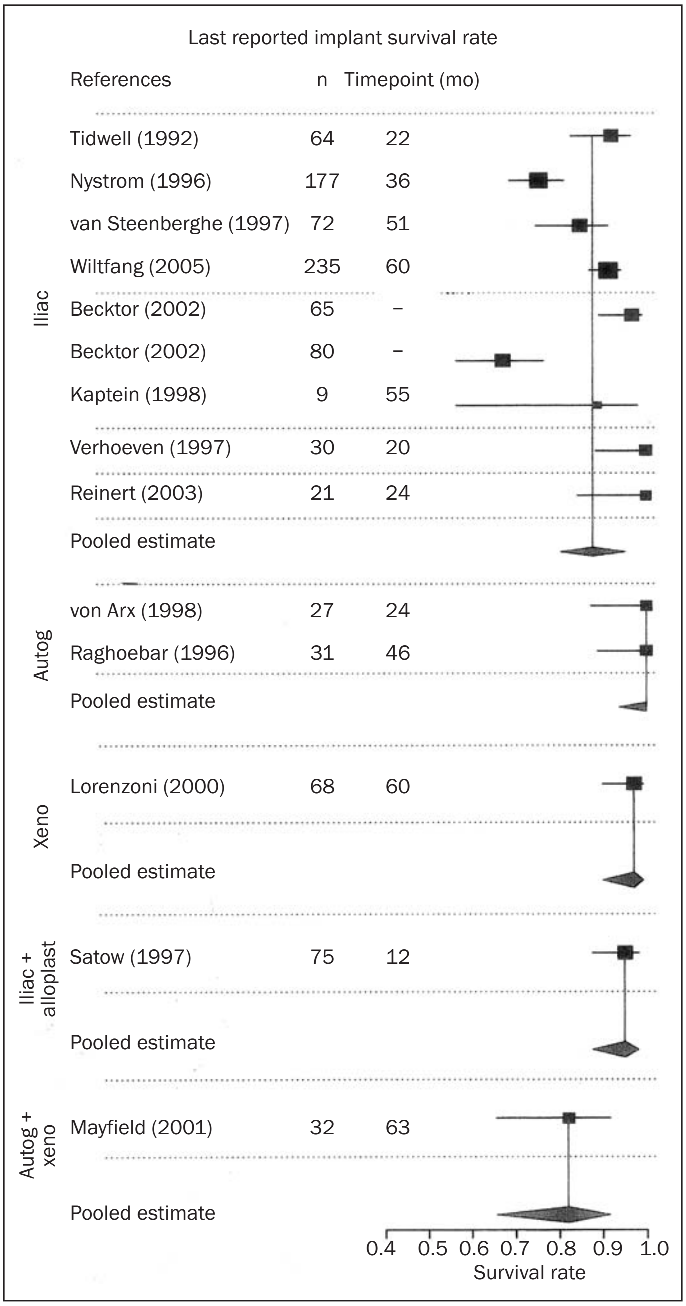

Fig 10 Forest plot analysis of implant survival after OVG to increase alveolar height comparing various grafting materials.

autogenous bone, xenograft, iliac crest + alloplast, or autogenous + xenograft when graft material was specifically mentioned. The latter 3 categories contained only 1 study each, which makes it difficult to form definitive conclusions. Of the 753 implants placed in iliac crest donor onlay bone grafts, 88% survived (CI: 80.6–95.4). Iliac crest grafts were mainly utilized when a larger defect requiring more bone augmentation was indicated. For autogenous grafts, usually intraoral donor sites, the survival rate was 100% (CI: 93.8–100). This subset of data contained 2 studies and a total of 58 implants. In the xenograft category, the implant survival rate was 97.1% (CI: 90–99.2) for 68 implants placed. With respect to the combinations, iliac crest with alloplast had a survival rate of 95% (CI: 87.5–98.1) for 75 implants, and intraoral autogenous bone with xenograft had a survival rate of 82% (CI: 65.5–91.6). Again, it is important to evaluate the forest plots to determine study homogeneity or heterogeneity (Fig 10).

Implant Survival After Maxillary Sinus Grafting

As expected, the majority of the articles included in this review utilized the maxillary sinus grafting technique. SG was described in the early 1980s and has been utilized as a successful technique to increase alveolar bone height in the posterior maxilla for the placement of dental implants.[97] Several systematic reviews on the sinus graft have previously been performed; they have shown varied results.[3–5,45] Again, articles in this main category varied in technique, graft material, and follow-up interval. For this review, implant survival is reported at the last examination stated in each article, ranging from 12 to 102 months for a total of 5,128 implants placed, and is further subdivided by graft material. For the SG technique, implant survival when autogenous bone was grafted was 92% (CI: 87.2–96.8) for 2,904 implants. One study included a large number of implants (2,132) placed into autogenous sinus grafts[46]; when that study was excluded, the survival rate for implants placed in autogenous bone was 91% (CI: 86.2–95.8). When autogenous bone grafting was utilized, it was often combined with other alloplastic or xenograft materials in these studies. When iliac crest specifically was utilized as the donor graft material, 1,845 implants displayed an 88% survival rate (CI: 83.1–92.9). This is comparable to alloplastic materials, where 190 implants showed an 81% survival rate (CI: 67.5–94.5); allograft materials, with 189 implants showing a survival rate of 93.3% (CI: 86.8–99.8); and xenografts, for which a survival rate of 95.6% (CI: 91.1–100) was shown with 443 implants. When the forest plots were evaluated, most of the studies appeared to be comparable based on a lack of excessive heterogeneity for the autogenous and iliac crest donor sites. The studies on alloplast and allograft materials appeared to be more heterogeneous, ie, there was greater divergence from the line on the forest plot and there were larger confidence intervals in these categories (Fig 11).

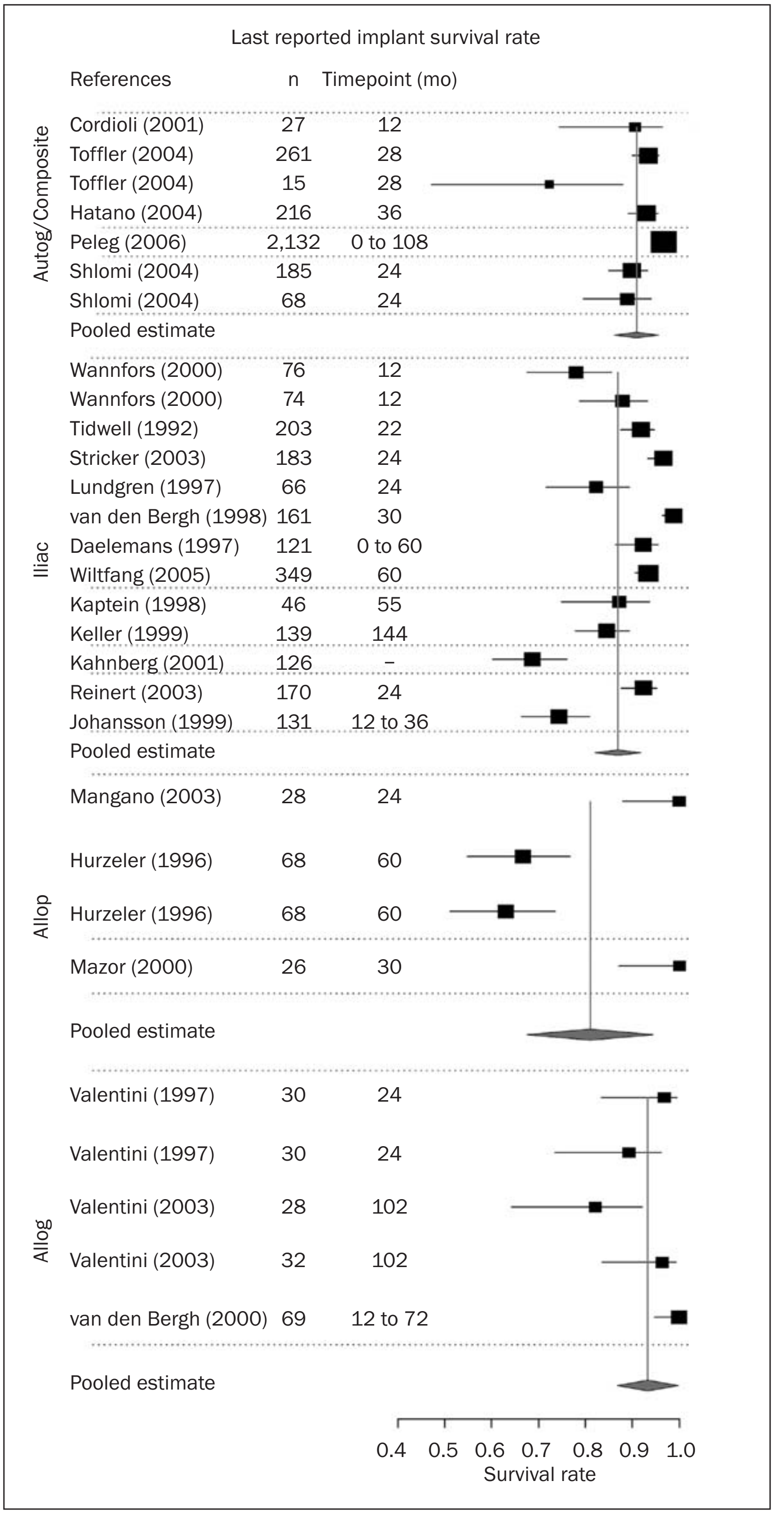

Fig 11 Forest plot analysis of implant survival after maxillary sinus grafting.

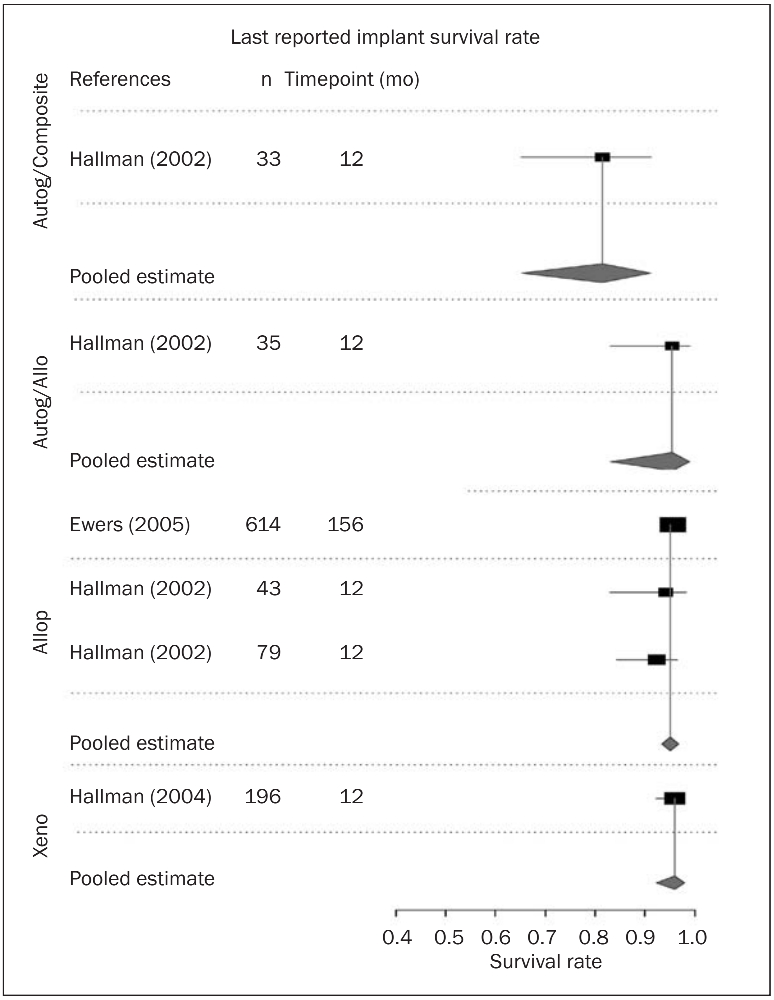

Fig 12 Forest plot analysis of implant survival after maxillary sinus grafting with the addition of adjunctive materials.

Studies on sinus grafting with modifications, which included the addition of adjunct materials such as platelet-rich plasma (PRP), fibrin glue, or venous blood,[22,47–49] were also evaluated. Survival rates were consistent with the previous analysis without these adjunctive materials. However, most of the data subsets with adjunctive materials contained a single study or a few studies. Implant survival in sinuses grafted with autogenous bone with adjunctive materials was 81.2% (CI: 64.9–91) for 33 implants in a single study; autogenous bone combined with allograft and adjunctive materials showed 95.3% (CI: 82.8–98.8) survival for 35 implants in 1 study; alloplast with adjunctive materials showed a 95.1% (CI: 93.4–96.8) survival for 736 implants in 2 studies; and xenograft with adjunctive materials showed a 96% (CI: 92.3–98) survival for 196 implants in 1 study (Fig 12).

In the next statistical analysis, grafting materials were set up hierarchically, with the highest being autogenous bone, followed by allograft, alloplast, and finally, xenograft. Studies were analyzed according to graft material placed in the sinus; if multiple materials were utilized, the study was placed in the higher grafting category. When there are many studies in 1 data subset, using this less stringent criterion does not significantly affect the results, but when few studies are included this may affect the results. Though this criterion was less stringent than that used in the other analyses, this analysis was performed to include studies where grafting materials were combined. Since a combination of materials is often used for grafting of the maxillary sinus in clinical practice, this analysis was considered very important. For the sinus grafts containing autogenous bone, at least in part, without adjunctive materials such as fibrin glue or PRP, 2,904 implants showed a survival rate of 92% (CI: 87.2–96.8). This is very similar to the survival rate for autogenous bone grafts with adjunctive materials such as fibrin glue or PRP, where 309 implants showed a 91.1% survival rate (CI: 77.8–100). The data here were pooled from studies for the first group as compared to 2 studies in the second group. The same comparison was performed for alloplasts and xenografts without and with adjunctive materials. One hundred ninety implants placed into bone grafted with alloplasts alone showed a survival rate of 81% (CI: 67.5–94.5); when alloplasts were combined with adjunctive materials, a survival rate of 95.1% (CI: 93.4–96.8) was obtained for 736 implants. Bone augmented with xenografts alone supported implants with a 95.6% survival rate (CI: 91.1–100) for 443 implants, which was comparable to a 96% (CI: 92.3–98) survival for 196 implants when adjunctive materials were used in combination.

Implant Survival After Minor Augmentation Techniques

As previously mentioned, several grafting techniques were evaluated for ability to support implant placement and survival, including SP, DD, RS, and MI. Though few studies with each technique met the inclusion criteria in this analysis, survival rates were calculated after a follow-up of 6 to 144 months after placement. For the SP technique, 2 studies had a combined implant survival rate of 90.3%, where 65 implants survived of 72 placed.[50,51] Three DD studies evaluated 172 implants that were further divided into implants placed into radiated and nonradiated bone.[52–54] Eighty-six of 103 implants in nonradiated bone survived, with a rate of 83.5%. In radiated bone, fewer implants were placed, and 65 of 69 survived for a rate of 94.2%. This increased survival rate in radiated bone is most likely due to the smaller number of implants in the radiated group. Two studies composed the RS group, where 517 implants survived of 531 placed, with a calculated survival rate of 97.4%.[18,55] Finally, 1 study of MI grafting showed a 100% survival rate when 40 implants were evaluated.[19] From a single or few studies, it is very difficult to draw conclusions about these grafting techniques. As more studies with larger numbers of implants become available, these techniques will be important to evaluate in their ability to support implant survival over time.

DISCUSSION

Systematic reviews can provide an extensive amount of data, but sometimes the existing literature does not provide the quality of data to answer specific questions. If controlled trials or only studies of high quality are evaluated, then a small amount of data may be available for analysis.[57] In other cases, a large amount of data derived from many uncontrolled case studies may be difficult to interpret, and the methodology may be so diverse that comparing studies may not yield meaningful results. In this systematic review, study quality was analyzed as well as the specific data from each study. Though randomized controlled trials yield higher-quality results, only 3 (of all 90 articles reviewed) were found. It would have been impossible to limit the evaluation to only those articles. However, uncontrolled case studies without objective criteria to evaluate implant survival or without life table analyses may not present data that can be generalized from one study to the next. Therefore, the purpose of this review was not only to evaluate the existing literature, but also to begin to set criteria for future studies of higher quality that may be compared to one another in an objective manner. In this analysis, almost half of the articles did not use objective criteria to evaluate implant success, and 75% did not report a cumulative survival rate in the form of a life table analysis. However, many of the more recent studies did include this information, which suggests that the quality of articles may be increasing as the journal submissions increase and the criteria for publication become more stringent.

Before analyzing specific data for this review, the literature was searched to identify other reviews on similar topics. Several reviews and the report of a consensus conference on maxillary sinus grafting were found; the most recent had been published in 2004.[3,4] The consensus conference reported 90% success after at least 3 years in function of 2,997 implants placed in 1,007 sinus grafts compiled from 38 surgeons over a 10-year period. These grafts represented a variety of techniques, bone graft materials, and implant loading protocols of individual practitioners, and concluded that the technique is highly predictable and effective.[3] Another review of sinus grafts answered a more specific question in comparing implants placed in grafted sinuses to those in native posterior maxillary bone. This analysis found a favorable comparison of survival rates for implants in nonaugmented posterior maxillary bone.[4] However, the studies analyzed did not all make direct comparisons between implants in sinus grafts and those in native posterior maxilla; rather, they used historical controls from prospective and retrospective studies.

Another review attempting to answer the same question compared implants in sinus grafts and native posterior maxilla with more stringent criteria, which yielded only 5 studies for inclusion. Since the studies were so heterogeneous, a meta-analysis could not be performed, and implant survival rates from 75% to 100% were seen for both groups.

The authors concluded that prospective studies with larger numbers of patients and implants were urgently needed.[45] The final systematic review of implant survival in maxillary sinus grafts included 6,913 implants placed in 2,046 patients combined from 39 studies. The analyses determined a survival rate of 91.49% overall, and 87.7% survival when autogenous bone alone was used versus 94.88% when it was combined with other materials and 95.98% when bone substitutes were used alone. Smooth-surface implants had an 85.64% survival versus a 95.98% survival for rough-surface implants. Finally, delayed implant placement showed a 92.93% survival, which was similar to the survival rated demonstrated for simultaneous graft and implant placement (92.17%). This analysis had much less stringent inclusion criteria than the previous studies.[98] The present review attempted to address the important question of implant survival based on the residual bone beneath the maxillary sinus, but few studies comparing this aspect met the inclusion criteria. Only 3 studies directly compared residual bone, and 1 study showed a 96.8% survival rate with less than 5 mm and 89.3% survival with greater than 5 mm residual bone.[56] The other 2 studies showed the opposite result, with 73.3% success with less than 4 mm and 94.6% success with greater than 4 mm,[57] and 85.3% success with less than 5 mm and 93.6% with greater than 5 mm.[58] In addition, autogenous bone grafts combined with an alloplast or xenograft material were grouped as autografts. This point is important, since these mixtures are often utilized in clinical practice. The present systematic review showed implant survival rates in maxillary sinus grafts from 81% to 96%, which is comparable to those in previously reported systematic reviews.

Also in the literature, systematic reviews have been carried out to evaluate local ridge augmentation and guided tissue regeneration. One study attempted to answer the focused question of how dental implant survival rates for implants placed following localized ridge augmentation compared to implants placed in nonaugmented sites. Since no controlled studies were found, a descriptive analysis was performed instead of a meta-analysis. Although 13 studies on GBR (1,741 patients) versus 5 studies on DO (92 patients) were evaluated, both were considered to have a high level of predictability, with similar survival rates to those reported for implants in native bone.[99] Another review[100] evaluated the differences in bone augmentation techniques for implant treatment. Four randomized controlled trials were included that only reported augmentation procedures up to the time of abutment placement and did not allow for survival analyses under functional loading. The authors found no evidence to support a superior effect of one technique over another.[100] This analysis was updated in 2006 to include 13 randomized controlled trials. The authors' updated conclusion was that major bone grafting in severely resorbed mandibles may not be justified, that bone substitutes may perform as well as autogenous bone for sinus lift procedures, that GBR and DO procedures may improve vertical height equally, that it is unknown whether bone grafting (GBR) is needed for immediate implant placement, and that membranes may work better for GBR around implant fenestrations. However, the authors pointed out that these conclusions were made from trials with minimal patients, minimal follow-up, and potentially high risk of bias.[101] One final systematic review[98] of implant survival in sites augmented with the GBR technique included 11 studies that all had at least 12 months of follow-up. This review showed that implants placed in augmented sites had a survival rate of 79% to 100% after at least 12 months, which was not significantly different from the survival rate in nonaugmented bone. However, only 2 trials in this review had data with internal controls.[98] Again, these results are consistent with the present systematic review, showing comparable survival rates in GBR-augmented sites from 74.7% to 95.5%.

In the present review, statistical analysis was paramount to help determine which studies could be compared based on the assumption that they were sufficiently similar. For example, the studies evaluating GBR techniques show adequate homogeneity, as seen by the close proximity of the boxes to the line on the forest plot (Fig 8), with minimal outliers. In contrast, the onlay grafting studies showed many more outliers, suggesting that these studies were quite heterogeneous and that comparison between studies may be difficult. In addition, since these studies did not generally compare 2 different techniques within the same study, data on statistically significant differences cannot be given, and specific *P* values are not available for comparison. The significance of the apparent differences can only be estimated. It was also difficult to compare bone grafting materials specifically for the GBR procedures, since the xenograft and autograft groups only included 1 or 2 studies (Fig 9). Comparing various bone grafting materials was also difficult for OVG procedures, especially since several subcategories included only 1 study, and studies were very heterogeneous, as previously mentioned. The implants placed into autogenous bone had 100% survival, but the group comprised only 2 studies reporting on 58 implants. Both xenografts and the iliac crest + alloplast combination also showed favorable results, but again, with only 1 study and small numbers of implants (Fig 10).

When evaluating maxillary sinus grafting, the fact that so many studies have been performed makes analyzing the data even more challenging. Previous reviews have found implant survival between 75% and 100% as recently as 2004.[3–5,45] This is consistent with the present review, where an implant survival rate of 81% to 93% was seen when more stringent criteria were utilized in selecting and separating the data (Fig 11), compared to 81% to 96% when slightly less stringent criteria were utilized. No major differences were apparent between grafting materials except for a slightly lower survival rate when alloplastic materials were utilized. This difference also may be due to the increased heterogeneity of those studies and the small numbers of studies included for analysis. In addition, low numbers of studies utilizing allografts and xenografts were included in the analyses, with autogenous bone graft studies, especially those with the iliac crest as the donor site, composing the largest group. Further, few studies involving combinations of graft materials with adjuncts such as PRP or fibrin glue were included; thus no definitive conclusions could be drawn about their additive effects on implant survival (Fig 12). It was even more difficult to draw conclusions about minor grafting techniques such as SP, DD, RS, and MI since only 1 to 3 studies were included in each of these groups.

Another aim of this review was to provide guidelines for future studies so that one may be able to compare and compile data more easily and accurately in subsequent analyses. In designing studies and analyzing data, the problem of confounding variables affecting outcomes of implant studies, especially in grafted bone, has been well established.[3,45] This systematic review yielded the same conclusions. Since most studies utilized varied criteria for evaluation, 30% of the studies were prospective, and only 14% compared grafted sites to control groups, it is easily apparent that confounding variables may influence outcomes. In general, most studies did not discuss patient and restorative factors such as medical problems, smoking, parafunctional habits, or restorative treatment rendered. In addition, although long-term follow-up was often mentioned, upon more close evaluation of the data, not all patients were followed for the maximum amount of time stated. Most studies did not mention subject dropout rates or reasons and often considered patients as having successful implants even if they were lost to follow-up, which may affect study quality.[102]

From all of these confounding variables, there is the potential for a high risk of bias, which may limit the generalizability of results for clinical decision-making or may cause researchers to overestimate intervention effectiveness.[103,104] It is well known that methodological problems exist in the dental implant literature, and it has been suggested that clinical research methodologists and statisticians be consulted before designing and when analyzing clinical studies.[101,105] In addition, adequate patient and implant numbers may be difficult to obtain when only 1 center is involved in the study. Multicenter studies may be helpful to alleviate some of these problems and often make results more applicable to a wider population.

CONCLUSIONS

The maxillary sinus augmentation procedure has been well documented, and the long-term clinical success/survival (> 5 years) of implants placed into augmented bone, regardless of graft material(s) used, appears to be similar to or better than that of implants placed using conventional protocol with no grafting procedure. However, the alveolar ridge augmentation technique lacks detailed documentation or long-term follow-up studies, with the exception of GBR. Those studies that exist for alveolar ridge augmentation using GBR techniques seem to yield comparable and favorable results. Other alveolar augmentation techniques may be more operator-experience– and technique-sensitive. More in-depth, long-term, multicenter studies and higher-quality study designs are required to provide further evidence into alveolar ridge augmentation techniques' ability to generate new bone to support dental implant placement and the effect of these techniques on long-term implant survival.

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Section 2 Members

Reviewer

Peter K. Moy, DMD
Department of Oral and Maxillofacial Surgery
UCLA School of Dentistry
Los Angeles, California

Co-Reviewer

Tara L. Aghaloo, DDS, MD
Department of Oral and Maxillofacial Surgery
UCLA School of Dentistry
Los Angeles, California

Section Chair

O. Ross Beirne, DMD, PhD
Department of Oral and Maxillofacial Surgery
University of Washington
Seattle, Washington

Section Secretary

Craig M. Misch, DDS, MDS
Sarasota, Florida

Section Participants

Philip J. Boyne, DMD
Department of Oral Surgery
Loma Linda University
School of Dentistry
Loma Linda, California

Daniel Buser, DDS, DMD
Department of Oral Surgery and Stomatology
University of Berne
School of Dental Medicine
Bern, Switzerland

Ole T. Jensen, DDS
Denver, Colorado

Eugene E. Keller, DDS
Rochester, Minnesota

Jay P. Malmquist, DMD
Portland, Oregon

Michael A. Pikos, DDS
Palm Harbor, Florida

Massimo Simion, Prof, MD, DDS
Milan, Italy

Minoru Ueda, DDS, PhD
Department of Oral and Maxillofacial Surgery
Nagoya University
Graduate School of Medicine
Nagoya, Japan

Stephen S. Wallace, DDS
Waterbury, Connecticut

Stephen L. Wheeler, DDS
Encinitas, California

Which Hard Tissue Augmentation Techniques Are the Most Successful in Furnishing Bony Support for Implant Placement?

Members of Section 2 evaluated the systematic review on the relative efficacy of hard tissue augmentation techniques in achieving sufficient bone support for the placement of implants. The focused PICO question addressed by the authors, Tara L. Aghaloo and Peter K. Moy, of the evidence-based systematic review is: Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement?

1. Does the section agree that the systematic review is complete and accurate?

The section found the systemic review to be complete and accurate. Based on the definition of the inclusion criteria for the literature search, the review measured implant survival in grafted bone and not the success of grafting techniques.

Since many of the studies reviewed used a variety of grafting materials, all composite grafts that included autogenous bone were categorized as autogenous bone grafts. To clarify the description of composite grafts using autogenous bone, it was decided to add the term "auto/composite" to the forest plot analysis.

There has been a trend toward the use of composite grafts or bone substitutes alone instead of autogenous bone alone for sinus grafting. Although composite bone grafts using 2 or more materials are frequently utilized in sinus bone grafting, this review did not examine specific graft combinations. It was also questioned whether the inclusion of additional studies using composite bone grafts would change the outcome of the results or the conclusions of the review.

2. Has any new information been generated or discovered since the review cutoff date?

Yes, there is new information on hard tissue augmentation that may be added to the previous review. The section has identified additional publications that meet the inclusion criteria:

- Simion M, Fontana F, Rasperini G, Maiorana C. Long-term evaluation of osseointegrated implants placed in sites augmented with sinus floor elevation associated with vertical ridge augmentation: A retrospective study of 38 consecutive implants with 1- to 7-year follow-up. Int J Periodontics Restorative Dent 2004;24:208–221.
- Boyne PJ, Lilly LC, Marx RE, Moy PK, Nevins M, Spagnoli DB, Triplett RG. De novo bone induction by recombinant human bone morphogenetic protein-2 (rhBMP-2) in maxillary sinus floor augmentation. J Oral Maxillofac Surg 2005;63: 1693–1707.
- Butz SJ, Huys LW. Long-term success of sinus augmentation using a synthetic alloplast: A 20 patients, 7 years clinical report. Implant Dent 2005;1:36–42.
- Stellingsma K, Raghoebar GM, Meijer HJ, Stegenga B. The extremely resorbed mandible: A comparative prospective study of 2-year results with three treatment strategies. Int J Oral Maxillofac Implants 2004;19:563–577.
- Herzberg R, Dolev E, Schwartz-Arad D. Implant marginal bone loss in maxillary sinus grafts. Int J Oral Maxillofac Implants 2006;21:103–110.

However, these studies are unlikely to alter the conclusions drawn from the previous publications. The Boyne study does introduce a new technique for ridge augmentation using rhBMP-2. One study on sinus bone grafting published beyond the 2005 cutoff date was inadvertently included in the review (Peleg M, Garg AK, Mazor Z. Predictability of simultaneous implant placement in the severely atrophic posterior maxilla: A 9-year longitudinal experience study of 2132 implants placed into 731 human sinus grafts. Int J Oral Maxillofac Implants 2006;21:94–102). An additional statistical analysis indicated that inclusion of the study had insignificant influence on the results and conclusions.

3. Does the section agree with the interpretation and conclusion of the reviewers?

Yes, the section agrees with the interpretation of the reviewers. However, due to the diversity of augmentation techniques and limited number of publications that met the inclusion criteria, the conclusions are rather broad in nature.

The inclusion criteria for this section placed significant constraints on our ability to select papers for reviewing bone augmentation techniques. Only 90 studies were available for review out of 526 screened articles and almost half were on sinus bone grafting (42). This left a paucity of data to evaluate other ridge augmentation techniques.

4. What further research needs to be done relative to the PICO question?

Randomized clinical trials that compare new graft materials to no graft (negative control) may not be applicable to studying bone augmentation procedures. We strongly support the use of prospective consecutive case series studies to evaluate these techniques. However, the inclusion criteria, patient selection, and outcome variables must be well defined. This will create historical controls for future reference.

The quality of the evidence generated from this review is fair. It is evident from the limited number of studies that met the inclusion criteria for the systematic review that an improvement in the quality of the research on this topic is necessary. Most of the articles attempted to evaluate too many confounding factors instead of focusing on specific questions. Future studies should be designed to produce more meaningful data. Standardized outcome reports are necessary to measure results of a particular treatment. Furthermore, it is evident that implant survival data have limited value. In future studies, objective success criteria should be validated and utilized.

The sinus bone graft has the greatest number of studies and has proven to be a very predictable technique for bone augmentation in the posterior maxilla. At this time, comparative studies using different graft materials (ie, autograft vs xenograft) may be of less value. However, only 2 publications specifically examining minimal residual bone below the sinus met the inclusion criteria for review. As such, further examination of grafting techniques and materials for the large, pneumatized sinus are warranted.

The systematic review found homogeneous outcomes for the studies on ridge augmentation using guided bone regeneration techniques. The effectiveness of nonresorbable barrier membranes in combination with autogenous bone grafts has been documented in management of horizontal and vertical bone defects. There is a trend toward the use of resorbable barrier membranes over bioinert materials such as expanded polytetrafluoroethylene in localized bone defects. Additional research is necessary to determine the effectiveness of resorbable membranes in the treatment of various ridge deficiencies and the long-term stability of implants in bone regenerated using this method. Guided bone regeneration procedures have been increasingly utilized for contour augmentation to enhance esthetic outcomes. Criteria to evaluate the success and long-term stability of these procedures should be established.

The techniques of onlay augmentation to enhance bone volume for implant placement require further investigation. Studies that compare different techniques, such as block bone grafts (with and without barrier membranes), particulate bone grafts (with and without barrier membranes), interpositional bone grafts, ridge splitting, and distraction osteogenesis, are necessary to determine the effectiveness of these methods in different clinical situations.

The future use of tissue engineering and growth factors to repair bone defects is an area of intense research and clinical interest. These procedures can reduce patient morbidity and improve clinical outcomes. Presently rhBMP-2 is used for spinal fusion and non-union tibial fracture repair. The approval for its use in sinus augmentation and alveolar ridge preservation is imminent. Suitable scaffolds or carriers for these growth factors need to be developed as well. The use of mesenchymal stem cells and autologous growth factors is currently under investigation. The cost of these materials is of concern in clinical practice.

The routine need for osseous augmentation when limited bone volume is available is currently under question. The use of shorter implants (< 10 mm) may be an acceptable alternative. However, this approach requires further investigation to determine the long-term stability of implants under these constraints.

The ability to shorten treatment length is desired by both clinicians and patients. Further research on the required healing times of graft materials and the timing of implant placement as well as methods to accelerate healing are needed.

The effectiveness of ridge augmentation techniques in the compromised patient should also be evaluated. The influence of systemic factors such as smoking, diabetes, bisphosphonate therapy, and local conditions on graft survival are of particular interest. The present review did not specifically examine the results of failed augmentation procedures.

New radiographic techniques can be helpful in assessing recipient and graft donor sites as well as measuring bone volume and graft incorporation. CAD/CAM technology may have applications in customizing alloplastic grafts and carriers for growth factors.

5. How can the information from the systematic review be applied for patient management?

Sinus Bone Graft. The evidence supports the conclusion that implants placed into sinuses grafted with autogenous bone and/or bone substitutes can achieve high levels of survival. The studies in this review, however, did not provide adequate data for comparison of implant survival for the different graft materials. The use of various materials in fully pneumatized sinuses needs more research. The optimal length of time for graft healing and the timing of implant placement and loading needs to be further determined.

Guided Bone Regeneration. Barrier membranes today are used in combination with graft materials. Guided bone regeneration using a barrier membrane with graft material is an effective technique in the repair of localized bone defects. The studies in this review have predominantly examined nonresorbable membranes. Future research with resorbable membranes is necessary.

Onlay/Veneer Grafts. The review identified a heterogeneous group of studies that evaluated the use of onlay/veneer bone grafts in the management of local defects and large reconstructions. Although the use of autogenous veneer grafting is successfully used in clinical practice, the data were inadequate to support a consensus statement. The number of studies that met the inclusion criteria was disappointing. Further research and comparisons are needed between localized versus extensive defects in the maxilla and mandible.

Distraction Osteogenesis. Although the number of studies is limited, there is evidence to suggest that distraction osteogenesis can be an effective method to enhance bone volume for implant placement.

Free and Vascularized Autografts for Discontinuity Defects/Ridge Splitting/Socket Preservation/Mandibular Interpositional Grafting. There were insufficient data to draw any conclusions on this collection of techniques.

WEB ONLY

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