Bone Augmentation Procedures in Localized Defects in the Alveolar Ridge: Clinical Results with Different Bone Grafts and Bone-Substitute Materials

Simon Storgård Jensen, DDS[1]/Hendrik Terheyden, MD, DDS, PhD[2]

Purpose: *The objective of this review was to evaluate the efficacy of different grafting protocols for the augmentation of localized alveolar ridge defects.* ***Materials and Methods:*** *A MEDLINE search and an additional hand search of selected journals were performed to identify all levels of clinical evidence except expert opinions. Any publication written in English and including 10 or more patients with at least 12 months of follow-up after loading of the implants was eligible for this review. The results were categorized according to the presenting defect type: (1) dehiscence and fenestration-type defects, (2) horizontal ridge augmentations, (3) vertical ridge augmentations, and (4) maxillary sinus floor elevations using the lateral window technique or transalveolar approach. The review focused on: (1) the outcome of the individual grafting protocols and (2) survival rates of implants placed in the augmented bone.* ***Results and Conclusion:*** *Based on 2,006 abstracts, 424 full-text articles were evaluated, of which 108 were included. Eleven studies were randomized controlled clinical trials. The majority were prospective or retrospective studies including a limited number of patients and short observation periods. The heterogeneity of the available data did not allow identifying one superior grafting protocol for any of the osseous defect types under investigation. However, a series of grafting materials can be considered well-documented for different indications based on this review. There is a high level of evidence (level A to B) to support that survival rates of implants placed in augmented bone are comparable to rates of implants placed in pristine bone.* Int J Oral Maxillofac Implants 2009;24(suppl):218–236

Key words: *bone grafting, bone-substitute material, dental implant, ridge augmentation, sinus floor elevation*

Resorption of the edentulous or partially edentulous alveolar ridge or bone loss due to periodontitis or trauma frequently compromises dental implant placement in a prosthetically ideal position. Therefore, augmentation of an insufficient bone volume is often indicated prior to or in conjunction with implant placement to attain predictable long-term functioning and an esthetic treatment outcome.[1] Autogenous bone grafts are still considered the gold standard in bone regeneration procedures.[2] However, donor site morbidity, unpredictable resorption, limited quantities available, and the need to include additional surgical sites are drawbacks related to autografts that have intensified the search for suitable alternatives. Bone-substitute materials have increased in popularity as adjuncts to or replacements for autografts in bone augmentation procedures to overcome the limitations related to the use of autografts. Bone-substitute materials can be categorized in three groups: *(1)* allogenic, from another individual within the same species; *(2)* xenogenic, from another species; or *(3)* alloplastic, synthetically produced.

The osteogenic potential of bone defects may vary considerably depending on their extent and morphology. It may be too optimistic to expect that the material characteristics of a single grafting material will be suitable for all indications. In addition, the

[1]Consultant Oral and Maxillofacial Surgeon, Department of Oral and Maxillofacial Surgery, Copenhagen University Hospital Glostrup, Glostrup, Denmark; and Research Fellow, Department of Oral Surgery and Stomatology, School of Dental Medicine, University of Bern, Bern, Switzerland.
[2]Professor and Chairman, Department of Oral and Maxillofacial Surgery, Red Cross Hospital Kassel, Kassel, Germany.

The authors report no conflict of interest.

Correspondence to: Dr Simon Storgård Jensen, Department of Oral and Maxillofacial Surgery, Copenhagen University Hospital Glostrup, Ndr Ringvej 57, DK-2600 Glostrup, Denmark. Fax: +45 43 23 39 47. Email: simon.storgaard@jensen.mail.dk

This review paper is part of the Proceedings of the Fourth ITI Consensus Conference, sponsored by the International Team for Implantology (ITI) and held August 26–28, 2008, in Stuttgart, Germany.

osteogenic potential of the grafting material may influence the time needed for completion of the bone regeneration procedure.

This review was undertaken to evaluate the treatment outcomes following augmentation of localized bone defects, with special emphasis on comparing the clinical performance of different bone grafts and bone-substitute materials. A recent systematic review of bone augmentation procedures performed prior to or in conjunction with placement of dental implants revealed that only a limited number of studies passed the strict inclusion criteria for such a review.[3] Therefore, the inclusion criteria for the present review allowed evaluation of all levels of evidence, from case series up to the level of randomized controlled trials,[4] to gather as much clinical information as possible about clinical experience with different grafting protocols for augmentation of localized bone defects.

The hypothesis was that augmentation of localized alveolar ridge defects in the forms of dehiscence-type defects, fenestration-type defects, bone defects in the lateral and vertical dimensions, and inadequate initial bone height toward the sinus floor are predictable procedures with implant survival rates comparable to those of implants placed in pristine bone, using autogenous bone grafts, bone-substitute materials, or combinations of these. The results obtained with different grafting protocols were compared. Finally, the results with and without the use of barrier membranes were recorded for the individual clinical indications.

MATERIALS AND METHODS

Study Types

Any clinical evaluation of a bone augmentation procedure in humans associated with immediate or delayed placement of dental implants published in English and including 10 or more treated patients was evaluated.

Patient Selection

The review included patients intended for dental implant placement in the maxilla and/or mandible, presenting with localized bone defects that required bone augmentation procedures simultaneous with implant placement or to allow later implant placement.

Augmentation Procedures

Peri-implant defects in the form of dehiscence-type defects and fenestration-type defects were included if they were augmented at the time of implant placement. Two-stage augmentation procedures for localized defects in the alveolar ridge were also included. In these cases a distinction was made as to whether the alveolar ridge was augmented in the horizontal or vertical dimension. Finally, maxillary sinus floor elevation procedures, including the lateral window technique and the transalveolar approach, were included in the review.

Evaluation of Outcome

Implant survival is a straightforward outcome measure, but it shows little sensitivity to minor changes in bone volume and soft tissue levels. In this review, implant survival rate was only included if the mean observation period was 1 year or more after prosthetic loading. The implant survival rates are presented as ranges and median values. Implant success is defined in several different ways and was not included in the present review. In addition to implant survival, the following parameters were recorded for the different augmentation techniques and grafting protocols:

1. In dehiscence-type defects and fenestration-type defects, the primary parameter of evaluation was the degree of bone defect reduction. This parameter was most often presented as the relative reduction of defect area (mm^2 or %) or defect height (mm or %), or as the number of exposed implant threads pre- and postaugmentation. All results were recalculated and the defect reduction was recorded as a percentage of the original defect size. In addition, the proportion of cases that showed complete resolution of the former defect, ie, where the goal of the treatment was accomplished, was recorded. Finally, the frequency of complications was recorded.
2. In an alveolar ridge with insufficient height or width to accommodate an implant with the desired dimensions, a two-stage augmentation procedure is usually indicated. The first outcome parameter of interest in a two-stage bone augmentation procedure is the possibility of implant placement in an ideal position for the later prosthetic restoration. Gain in ridge width and height was recorded as an indirect measure of the efficiency of the different grafting protocols in providing sufficient alveolar ridge dimensions for implant placement. The percentage of cases in need of regrafting or additional grafting at the time of implant placement was also recorded as an indirect measure of the predictability of the grafting protocol. The long-term goal, for both one-stage and two-stage augmentation procedures, is the stability of the augmented bone volume, allowing unhindered masticatory function and optimal esthetics, as expressed by implant survival, bone stability, and soft tissue stability.
3. A study was categorized as a randomized controlled clinical trial (RCT), a controlled clinical trial (CCT), a prospective study (PS), or a retrospective study (RS).[4]

4. Grafting materials were categorized in one of the following groups:

- No graft (coagulum)
- Autograft block (extraoral or intraoral donor site)
- Autograft particulate
- Autograft from bone trap
- Membrane alone (nonresorbable or resorbable)
- Allograft (freeze-dried bone allograft [FDBA] or demineralized freeze-dried bone allograft [DFDBA])
- Xenograft (demineralized bovine bone mineral [DBBM], algae-derived, or coral-derived)
- Alloplast (hydroxyapatite [HA], β-tricalcium phosphate [TCP], bioglass, or calcium sulphate)
- Combinations (autograft + allograft, autograft + xenograft, autograft + alloplast, allograft + xenograft, or allograft + alloplast)

5. Whether the augmented site was covered with a resorbable membrane, a nonresorbable membrane, or no membrane was recorded. For maxillary sinus floor elevation procedures, it was only registered whether some kind of membrane was used to cover the lateral window, and if machined or rough-surfaced implants were placed in the augmented bone.

6. All healing times were recorded or calculated to be presented as mean values. For implant survival rates, ranges and median values were calculated.

7. The treatment result after augmentations in the orofacial dimension cannot be evaluated using traditional radiographs. Computed tomography (CT), conventional tomography, and digital volume tomography are only seldom used at control visits because of their high doses of radiation. Therefore, the outcome of augmentation of dehiscence-type defects, fenestration-type defects, and horizontal ridge augmentations could only be evaluated with clinical parameters. These included defect fill at reentry (%), gain in ridge width at reentry (mm), soft tissue stability (mm), and ultimate implant survival (%). Augmentations in the vertical dimension can be evaluated by traditional x-ray as marginal bone stability (mm) in vertical ridge augmentations and apical bone stability (mm) in maxillary sinus floor elevation procedures. However, since this information was only available from a very limited number of publications, the radiographic evaluation was excluded from the final evaluation.

8. Infectious complications are often related to the exposure of membranes. All membrane exposures were recorded as complications, although the consequence of exposure may differ when nonresorbable and resorbable membranes are compared. The type of membrane used was recorded; therefore, the outcome data should reveal whether exposure of nonresorbable membranes leads to a compromised healing result more often than exposure of resorbable membranes.

The background variables and outcome measures that were recorded for each defect type are listed in Table 1.

If data from different time points for the same pool of patients were presented in separate publications, the most recent paper was included for the evaluation of implant survival. However, additional clinical and radiographic data were included from all available observation times (if $n \geq 10$) to monitor healing dynamics from immediately postoperative to long-term healing results.

Exclusion Criteria

Studies were excluded if data covered:

- Grafting of bone defects caused by tumor resections, osteoradionecrosis, osteochemonecrosis, and bisphosphonate-associated osteonecrosis
- Grafting of bone defects in syndrome patients with craniofacial involvement and with congenital malformations, such as cleft patients
- Grafting of extraction sockets and intraalveolar defects simultaneously with immediate implant placements (presented in parallel reviews by Buser and Chen and Darby et al in this supplement)
- Treatment of defects caused by peri-implantitis
- Augmentations of the complete ridges in severely atrophied edentulous jaws, including the application of distraction osteogenesis (presented in a parallel review by Chiapasco et al in this supplement)
- Grafting protocols including the addition of growth factors or other bioactive molecules to the grafting materials
- Different augmentation procedures and/or grafting materials evaluated in the same paper, where the outcome measures could not be separated according to the individual protocols

Search Strategy

A search was performed in PubMed and the Cochrane library, combining the following terms: *clinical study, clinical trial, dental implant, preprosthetic surgery, bone transplantation, bone graft, autograft, allograft, xenograft, alloplast, bone substitute, bone filler, onlay bone graft, inlay bone graft, bone regeneration, bone augmentation, peri-implant defect, fenestration, dehiscence, atrophy, bone loss, guided bone regeneration, guided tissue regeneration, horizontal ridge augmentation, vertical ridge augmentation, block graft, sinus augmentation, sinus floor elevation, sinus lift*.

Table 1 Data Collected for the Individual Defect Types

Background and treatment variables	Dehiscence-type defects and fenestration-type defects	Horizontal ridge augmentation	Vertical ridge augmentation	Sinus augmentation
Study type	x	x	x	x
No. of patients	x	x	x	x
No. of augmentation procedures	x	x	x	x
No. of implants	x	x	x	x
Implant surface				x
Grafting material	x	x	x	x
Initial bone height				x
Membrane over augmented site	x	x	x	x
Staged/simultaneous implant placement		x	x	x
Healing time before implant placement, mean (mo)		x	x	x
Healing time before reentry/abutment, mean (mo)	x	x	x	x
Follow-up after augmentation, mean (mo)	x	x	x	x
Outcome measures				
Gain in ridge width (mm)		x		
Gain in ridge height (mm)			x	
Defect reduction (%)	x			
Cases with complete defect fill (%)	x	x	x	
Complication rate including membrane exposures (%)	x	x	x	x
Implant survival (%)	x	x	x	x

In addition, a manual search of the tables of contents of the following journals was performed: *British Journal of Oral & Maxillofacial Surgery; Clinical Implant Dentistry and Related Research; Clinical Oral Implants Research; Clinical Oral Investigations; Implant Dentistry; International Journal of Oral & Maxillofacial Implants; International Journal of Oral & Maxillofacial Surgery; International Journal of Periodontics & Restorative Dentistry; Journal of Clinical Periodontology; Journal of Craniofacial Surgery; Journal of Oral Implantology; Journal of Oral and Maxillofacial Surgery; Journal of Oral Rehabilitation; Journal of Periodontology; Journal of Prosthetic Dentistry;* and *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*.

Finally, reference lists of the included articles were checked for additional publications of relevance. Publications available in print or electronic form up to January 1, 2008, were considered.

RESULTS

A total of 2,006 abstracts and 424 full-text articles were evaluated. One hundred eight articles met the inclusion criteria. Data from the included studies are listed in Tables 2 to 6. Grafting protocols that are documented in three or more studies for the individual defect types are discussed in the following sections.

Dehiscence-type Defects and Fenestration-type Defects

Forty-six publications were evaluated as full text, of which 20 studies (4 RCTs, 1 CCT, 12 PS, 3 RS) were included (Table 2).[5–24] Sixteen studies described the augmentation of dehiscence-type defects,[5–10,12,14,15,17–21,23,24] four described fenestration-type defects,[7,11,16,22] and in one study the data set could not be separated for the two defect types.[13] In 627 patients, a total of 987 implants were inserted. Reentry was performed after a mean healing period of 5.8 months. A mean defect fill of 81.7% could be calculated based on 17 patient pools.[5,6,8,9,11–18,20,21,23,24] Complete defect fill was accomplished in 68.5% of the cases (data from 10 studies).[5,9,11,12,15–18,21,23] Seven studies followed the patients for 12 to 60 months after loading, reporting survival rates of 93% to 100% (median: 95.4%).[6,7,10,19,21–23]

Three different grafting protocols were documented in three or more studies. Three studies (114 patients, 155 implants) reported on the use of a nonresorbable membrane alone.[5,6,10] Membrane exposure was recorded in 13.8% of the cases, and the mean defect fill at reentry was 79.4%.[5,6] After 18 to 24 months of function, the implant survival rate was reported in two studies to be 93% and 100%, respectively.[5,6] Six studies (69 patients, 131 implants) described the use of autograft as augmentation material, which was harvested locally as chips,[9,11,12,18]

Table 2 Augmentation of Dehiscence-type Defects and Fenestration-type Defects

Study	Study type	Defect type	No. of patients	No. of augm	No. of implants	Grafting material	Membrane	Healing impl (mo)	Follow-up (mo)	Defect fill (%)	% Complete fill	Complication rate (%)	Implant survival (%)
Jovanovic et al (1992)[5]	PS	Deh	11	16	16	Membr alone	Nonres	5	-	89	69	25	-
Dahlin et al (1995)[6]	CCT	Deh	44	54	54	Membr alone	Nonres	4.5	24	77	ND	11	93
Fugazzotto (1997)[7]	RS	Deh	84	172	172	DFDBA+TCP	Nonres	7.5	24	ND	ND	ND	99
		Fen	25	77	77	DFDBA+TCP	Nonres	7.5	24	ND	ND	ND	100
Zitzmann et al (1997)[8]	RCT	Deh	25	41	41	DBBM	Nonres	5	-	78	ND	24	-
		Deh	25	43	43	DBBM	Res	5	-	92	ND	16	-
Schlegel et al (1998)[9]	RCT	Deh	11	20	20	AP	none	6	-	60	60	20	-
		Deh	11	20	20	AP	Res	6	-	95	85	35	-
Lorenzoni et al (1999)[10]	RS	Deh	59	85	85	Membr alone	Nonres	6	18	ND	ND	ND	100
Peleg et al (1999)[11]	PS	Fen	ND	17	17	AP	Res	5.6	-	87	76	0	-
von Arx and Kurt (1999)[12]	PS	Deh	11	16	16	AP	none	6.6	-	90	63	6	-
Carpio et al (2000)[13]	RCT	Deh & Fen	25	25	25	A+DBBM	Nonres	6	-	54	ND	46	-
		Deh & Fen	23	23	23	A+DBBM	Res	6	-	61	ND	48	-
Nemcovsky et al (2000)[14]	PS	Deh	21	28	28	DBBM	Res	7	-	97	ND	0	-
van Steenberghe et al (2000)[15]	PS	Deh	15	21	21	DBBM	none	6	-	71	48	19	-
Widmark and Ivanoff (2000)[16]	PS	Fen	12	12	12	ABT	none	6	-	82	58	ND	-
Hämmerle and Lang (2001)[17]	PS	Deh	10	10	10	DBBM	Res	6.5	-	86	80	20	-
Tawill et al (2001)[18]	PS	Deh	13	14	14	AP	Res	6	-	87	71	14	-
Zitzmann et al (2001)[19]	PS	Deh	75	112	112	DBBM	Res	5	59	ND	ND	ND	95.4
		Deh	25	41	41	DBBM	Nonres	5	59	ND	ND	ND	92.9
Nemcovsky et al (2002)[20]	PS	Deh	43	54	54	DBBM	Res	7	-	94	ND	9	-
De Boever and De Boever (2005)[21]	PS	Deh	13	16	16	DBBM	Nonres	4	42	97	81	6	94
Juodzbalys et al (2007)[22]	PS	Fen	17	20	20	DBBM	Res	5	60	ND	ND	5	100
Llambés et al (2007)[23]	RS	Deh	11	14	32	ABT	Res	4.4	12	83	66	27	94
Park et al (2008)[24]	RT	Deh	18	18	18	FDBA	Res	6	-	83	ND	0	-

RCT = randomized controlled trial; CCT = controlled clinical trial; PS = prospective study; RS = retrospective study; Deh = dehiscence-type defect; Fen = fenestration-type defect; No. of augm = number of augmentation procedures; ND = no data; Membr alone = membrane without grafting material; AP = autogenous particulate; A = autogenous bone; ABT = autogenous bone from bone trap; DBBM = deproteinized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft; FDBA = freeze-dried bone allograft; Res = resorbable; Nonres = nonresorbable; Healing impl = mean healing time from implant placement to loading; Follow-up = mean period of loading; Defect fill = percentage reduction of bone defect size from intraoperative condition to reentry; % Complete fill = percentage of cases with complete resolution of the bone defect at reentry; Implant survival = implant survival after at least 12 months of loading.

Table 3 Horizontal Ridge Augmentation

Study	Study type	No. of patients	No. of augm	No. of implants	Grafting material	Membrane	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Gain width (mm)	Complication rate (%)	Implant survival (%)
Buser et al (1996)[25]	PS	40	40	66	AB IO	Nonres	8.9	3.5	–	3.5	2.5	–
Raghoebar et al (1996)[26]	RS	23	23	27	AB IO	None	3	6	31	ND	13	100
Fugazzotto (1997)[7]	RS	99	ND	183	AG+ALP	Nonres	ND	7.5	24	ND	ND	97
von Arx et al (1998)[27]	PS	18	18	27	AB IO	None	5.2	7.2	12	ND	ND	100
Parodi et al (1998)[28]	RS	16	16	27	Membr alone	Nonres	9.5	ND	-	2.5	31	–
Chiapasco et al (1999)[29]	PS	15	15	30	AP	Nonres	7	6	22	2.7	13	100
		15	15	44	AB EO	None	7	6	22	4	0	100
Bedrossian and Tawfilis (2000)[30]	RS	63	87	187	AB IO	None	4	4.5	38	ND	ND	100
Kirkland et al (2000)[31]	RS	12	12	ND	AG+ALP	Res	12	ND	–	3.2	ND	–
Sethi and Kaus (2001)[32]	PS	60	ND	118	AB IO	ND	4.5	6	22	ND	0	98
Cordaro et al (2002)[33]	PS	15	18	40	AB IO	None	6	6	12	5	0	100
Friedmann et al (2002)[34]	RCT	14	14	ND	DBBM	Nonres	7	ND	–	ND	64	–
		14	14	ND	DBBM	Res	7	ND	–	ND	71	–
Buser et al (2002)[35]	PS	40	40	66	AB IO	Nonres	8.9	3.5	60	3.5	2.5	100
Hellem et al (2003)[36]	PS	27	29	74	A+DBBM	None	6	ND	36	ND	0	97
Knapp et al (2003)[37]	PS	12	12	ND	BG	Nonres	6	ND	–	1.1	50	–
Feuille et al (2003)[38]	PS	10	10	ND	FDBA	Nonres	6	ND	–	3.2	ND	–
Maiorana et al (2005)[39]	PS	14	14	ND	AB IO	None	5.4	5.4	–	5.7	14.3	–
		12	12	ND	AB+DBBM	None	5.4	5.4	–	5.3	8	–
von Arx and Buser (2006)[40]	PS	42	58	58	AB+DBBM	Res	5.8	ND	–	4.6	7	–
Strietzel et al (2007)[41]	PS	10	10	10	ALP HA	None	7	3.5	-	2	50	-
Levin et al (2007)[42]	RS	50	50	129	AB IO	Res	5.2	ND	24	ND	ND	96.9
Hämmerle et al (2008)[43]	PS	12	15	14	DBBM	Res	9.5	4	-	3.6	0	-

RCT = randomized controlled trial; PS = prospective study; RS = retrospective study; No. of augm = number of augmentation procedures; ND = no data; A = autogenous bone; AB = autogenous block; EO = extraoral donor site; IO = intraoral donor site; AP = autogenous particulate; AG = allograft; ALP = alloplast; DBBM = deproteinized bovine bone mineral; BG = bioglass; FDBA = freeze-dried bone allograft; HA = hydroxyapatite; Res = resorbable; Nonres = nonresorbable; Healing augm = mean healing time from augmentation to implant placement; Healing impl = mean healing time from implant placement to loading; Follow-up = mean period of loading; Gain width = gain in alveolar ridge width at reentry; Implant survival = implant survival after at least 12 months of loading.

Table 4 Vertical Ridge Augmentation

Study	Study type	No. of patients	No. of augm	No. of implants	Grafting material	Membrane	Simul/ staged	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Gain height (mm)	Complication rate (%)	Implant survival (%)
Corrente et al (1997)[44]	RS	11	11	22	Coral	None	Simul	ND	6	–	2.1	0	–
Simion et al (1998)[45]	PS	10	10	22	DFDBA	Nonres	Simul	ND	9.3	–	3.1	20	–
		10	12	30	AP	Nonres	ND	ND	7	–	5	20	–
Sethi and Kaus (2001)[32]	PS	60	ND	118	AB IO	ND	Staged	4.5	6	22	ND	0	98
Simion et al (2001)[46]	RS	11	11	24	DFDBA	Nonres	Simul	ND	10	39.3	ND	18	100
		32	34	79	AP	Nonres	Simul	ND	10.4	30.4	ND	19	100
Artzi et al (2003)[47]	PS	10	10	20	DBBM	None	Staged	9	ND	–	5.2	20	–
Roccuzzo et al (2004)[48]	PS	18	18	37	AB IO	None	Staged	4.6	ND	–	4.8	22	–
Chiapasco et al (2004)[49]	RCT	11	11	25	AB IO	Nonres	ND	6.5	4	35.5	4.8	27	100
Proussaefs and Lozada (2005)[50]	PS	12	12	ND	AB+DBBM	None	Staged	5	5	–	5.8	25	–
Smolka et al (2006)[51]	PS	10	10	20	AB EO	ND	Staged	6	3	21.3	11.8	30	95
Merli et al (2006)[52]	RS	11	11	18	AP	Nonres	Simul	ND	6.2	–	ND	8	–
Verhoeven et al (2006)[53]	PS	13	13	30	AB EO	ND	Simul	ND	ND	105.6	7.2	23	100
Levin et al (2007)[42]	RS	50	50	129	AB IO	Res	Staged	5.2	ND	24	ND	ND	96.9
Merli et al (2007)[54]	RCT	11	11	11	AP	Nonres	Simul	ND	4.6	–	2.8	45	–
		11	11	11	AP	Res	Simul	ND	4.6	–	2.1	36	–
Roccuzzo et al (2007)[55]	RCT	12	12	ND	AB IO	None	Staged	4.7	ND	–	3.6	50	–
		12	12	ND	AB IO	None	Staged	4.6	ND	–	4.8	33	–

RCT = randomized controlled trial; PS = prospective study; RS = retrospective study; No. of augm = number of augmentation procedures; ND = no data; AB = autogenous block; EO = extraoral donor site; IO = intraoral donor site; AP = autogenous particulate; Coral = xenograft of coralline origin; DFDBA = demineralized freeze-dried bone allograft; Res = resorbable; Nonres = nonresorbable; Simul = implant placed simultaneously with augmentation; Staged = implant placed in a second stage; Healing augm = mean healing time from augmentation to implant placement; Healing impl = mean healing time from implant placement to loading; Follow-up = mean period of loading; Gain height = gain in alveolar ridge height at reentry; Implant survival = implant survival after at least 12 months of loading.

Table 5 Sinus Augmentation Lateral Window Technique

Study	Study type	No. of patients	No. of augm	No. of implants	Implant surface	Grafting material	Membrane	Simul/ staged	Initial bone height (mm)	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Complication rate (%)	Implant survival (%)
Small et al (1993)[56]	CS	27	45	111	R	DFDBA+coral	+	Simul	ND	NR	9	37.6	7	100
Blomqvist et al (1996)[57]	RS	49	93	171	M	AB EO	–	Simul	ND	NR	9	30.0	ND	82.5
Lundgren et al (1996)[58]	CS	10	10	30	M	AP	–	Sta	ND	6	6	26.0	ND	100
Daelemans et al (1997)[59]	CS	33	44	121	M	AB EO	–	Simul	ND	NR	5.5	40.2	2.2	92.2
Lundgren et al (1997)[60]	CS	10	20	26	M	AB EO	–	Sta	ND	6	6	16.0	ND	76.9
Valentini and Abensur (1997)[61]	CS	10	12	28	R	DFDBA+DBBM	–	Simul	ND	NR	9.4	25.0	ND	92.8
	CS	10	16	32	R	DFDBA+DBBM	–	Sta	ND	6.4	6	29.0	ND	96.8
Blomqvist et al (1998)[62]	PS	50	97	202	M	AB EO	–	Sta	ND	5.3	6	16.0	ND	84.2
Peleg et al (1998)[63]	CS	20	20	55	R	A+DFDBA	+	Simul	ND	NR	9	26.4	ND	100
van den Bergh et al (1998)[64]	RS	42	62	161	R	AP	–	Sta	ND	4	4	34.0	5	100
Zitzmann and Schärer (1998)[65]	CS	10	ND	20	M	DBBM	+	ND	3.2	ND	ND	16.5	0	100
Johansson et al (1999)[66]	PS	39	78	131	M	AB EO	ND	Simul	ND	NR	6	36.0	20.5	75.3
Keller et al (1999)[67]	RS	37	58	139	M	AB EO	ND	Simul	ND	NR	ND	41.0	0	85.6
Mazor et al (1999)[68]	CS	10	10	10	R	A+DFDBA	+	Simul	5.4	NR	9	36.0	0	100
Peleg et al (1999)[69]	CS	63	63	160	R	A+DFDBA	–	Simul	4.0	NR	9	31.0	0	100
Valentini et al (2000)[70]	CS	15	20	57	ND	DBBM	+	Sta	1.8	6	9	48.0	6.6	98.2
van den Bergh et al (2000)[71]	CS	24	30	69	R	DFDBA	–	Sta	ND	6	4	30.6	13	100
Wannfors et al (2000)[72]	RCT	20	40	76	M	AB EO	ND	Simul	ND	NR	6	12.0	ND	79
	RCT	20	40	74	M	AP	ND	Sta	ND	6	6	12.0	ND	89
Cordioli et al (2001)[73]	CS	12	ND	27	R	A+DFDBA	+	Simul	4.4	NR	10.8	12.0	0	96
Hallman et al (2001)[74]	PS	20	30	79	M	A+DBBM	–	Sta	2.7	6.7	3	36.0	10	89
Kahnberg et al (2001)[75]	PS	26	39	93	M	AB EO	–	Simul	2.5	ND	6	47.4	ND	61.2
Raghoebar et al (2001)[76]	RS	99	182	392	M	AB EO	–	ND	3.0	ND	6	58.0	18	91.8
Tawil and Mawla (2001)[77]	RCT	29	30	61	M	DBBM	+/-	ND	ND	NR	ND	22.4	ND	85.0
Hallman et al (2002)[78]	PS	20	30	79	M	A+DBBM	–	Sta	2.7	6	6.7	12.0	10	92.4
Hallman et al (2002)[79]	RCT	11	11	33	M	AP	–	Sta	ND	6.5	6	12.0	ND	82.4
	RCT	11	11	35	M	A+DBBM	–	Sta	ND	6.5	6	12.0	ND	94.4
	CS	10	14	43	M	DBBM	+	Sta	ND	8.5	6	12.0	ND	96
Kan et al (2002)[80]	RS	ND	73	195	R	DFDBA+DBBM	ND	ND	ND	NR	ND	41.6	ND	88.6
	RS	ND	11	33	R	A+DFDBA	ND	ND	ND	NR	ND	41.6	ND	100
Pejrone et al (2002)[81]	CS	13	26	87	M	AB EO	ND	Sta	ND	6	6	12.0	0	94
Mangano et al (2003)[82]	CS	12	12	28	R	Allopl HA	–	Simul	4.5	NR	5.5	12.0	0	100
Reinert et al (2003)[83]	RS	30	58	200	ND	AB EO	–	Sta	3.7	5	6	24.0	7	95
Stricker et al (2003)[84]	PS	41	66	183	R	AP	–	ND	ND	ND	4.1	17.2	ND	99.5
Valentini and Abensur (2003)[85]	CS	10	12	28	ND	DFDBA+DBBM	–	Simul	ND	NR	9	106.8	0	82.1
	CS	11	13	32	ND	DBBM	–	Simul	ND	NR	9	56.4	0	92.6
	CS	28	37	100	ND	DBBM	–	Sta	ND	6	6	68.4	3.6	98
Hallman and Nordin (2004)[86]	RS	50	71	196	R	DBBM	ND	Sta	ND	8	2.5	20.0	3	96
Hallman and Zetterqvist (2004)[87]	PS	20	30	79	M	A+DBBM	–	Sta	2.7	6	6.7	60.0	10	88.6
Hatano et al (2004)[88]	RS	191	294	361	M	A+DBBM	–	Simul	ND	NR	7.5	20.5	ND	94
Lundgren et al (2004)[89]	CS	10	12	19	R	Coagulum	–	Simul	ND	NR	6	12.0	0	100
Shlomi et al (2004)[90]	CS	63	73	253	ND	A+DBBM	+	ND	5.0	ND	6	18.0	ND	91

Table 5 continued Sinus Augmentation Lateral Window Technique

Study	Study type	No. of patients	No. of augm	No. of implants	Implant surface	Grafting material	Membrane	Simul/ staged	Initial bone height (mm)	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Complication rate (%)	Implant survival (%)
Hallman et al (2005)[91]	PS	20	30	79	M	A+DBBM	ND	Sta	2.7	6	6.7	36.0	10	89
Rodoni et al (2005)[92]	CS	13	13	13	M	DBBM	+	ND	ND	ND	ND	31.1	0	100
Wiltfang et al (2005)[93]	RS	61	ND	349	ND	AP	ND	Sta	ND	4	6	54.0	4	94.6
Mangano et al (2006)[94]	CS	24	29	57	R	Allopl HA	–	ND	ND	ND	4.4	36.0	0	100
Orsini et al (2006)[95]	CS	10	10	10	R	DBBM	+	Sta	ND	5	6	12.0	0	100
Becktor et al (2007)[96]	CS	12	ND	36	M	AB EO	–	ND	ND	ND	7.4	45.7	ND	94.4
Chen et al (2007)[97]	RS	33	33	47	R	Coagulum	–	ND	ND	ND	9	24.0	ND	100
Krennmair et al (2007)[98]	RS	25	25	28	R	A+DBBM	+	Simul	7.8	NR	6	44.5	ND	100
	RS	12	12	12	R	A+DBBM	+	Sta	3.5	ND	9	44.5	ND	100
Mangano et al (2007)[99]	RCT	20	ND	50	R	DBBM	–	Simul	4.5	NR	6	12.0	0	96
	RCT	20	ND	50	R	Allopl HA	–	Simul	4.5	NR	6	12.0	0	96
Marchetti et al (2007)[100]	CS	30	48	140	ND	A+DBBM	–	ND	3.2	5	5	12.0	13	94.9
Mardinger et al (2007)[101]	PS	25	30	88	R	DBBM	+	Simul	2.0	NR	6.6	34.5	4	92
	PS	30	30	76	R	DBBM	+	Simul	ND	NR	6.1	39.1	7	98.7
Thor et al (2007)[102]	CS	20	27	44	R	Coagulum	–	Simul	4.6	NR	6	27.5	ND	97.7

RCT = randomized controlled trial; CCT = controlled clinical trial; PS = prospective study; RS = retrospective study; CS = case series; No. of augm = number of sinus augmentation procedures; ND = no data or data cannot be separated; Impl surf = implant surface; R = rough; M= machined; A = autogenous bone; AB = autogenous block; EO = extraoral donor site; AP = autogenous particulate; DFDBA = demineralized freeze-dried bone allograft; Allopl HA = Alloplastic hydroxyapatite; Simul = implant placed simultaneously with augmentation; Sta = implant placed in a second stage; + = membrane was used; – = membrane was not used. Initial bone height = Initial subantral bone height; Healing augm = mean healing time from augmentation to implant placement for staged procedures; NR = not relevant due to the study design; Healing impl = mean healing time from implant placement to loading; Follow-up = mean follow-up period after loading; Implant survival = implant survival after at least 12 months in function.

or with a suction device during preparation of the implant bed.[16,23] A resorbable membrane was applied in four groups of patients,[9,11,18,23] while no membrane was used in another three.[9,12,16] Data on defect fill and the percentage of cases with complete regeneration of the defects could be extracted from all the studies, and averaged 83.8% and 68.8%, respectively. Membrane or graft dehiscence was reported in 15.5% of the cases. There was only one study using autografts (11 patients with 32 implants) presenting data on implant survival, which was reported to be 94% after 12 months of loading.[23] Eight studies (269 patients with 386 implants) evaluated the use of DBBM with[8,14,17,19–22] or without[15] the use of a membrane. A mean defect fill at reentry of 88.9% (based on six studies) and a percentage of cases with complete defect fill of 67.7% (based on 3 studies) was found. The rate of dehiscences was 12%. Four studies (145 patients with 210 implants) with follow-up periods of 42 to 60 months after prosthetic loading reported implant survival rates of 93% to 100% (median 95.4%).[15,19,21,22]

When the data set was divided according to the use of nonresorbable membranes,[5,6,13,21] resorbable membranes,[9,11,13,14,17,18,20,23,24] or no membrane,[9,12,15,16] the percentages of defect fill were 75.7%, 87%, and 75.5%; the percentage of cases with complete defect fill were 75.5%, 75.4%, and 56.4%; the rates of membrane/graft dehiscences were 26.3%, 14.5%, and 15.4%; and the implant survival rates were 92.9% to 100% (median 96.5%) with nonresorbable membranes and 94% to 100% (median 95.4%) with resorbable membranes. None of the included studies contained data on implant survival after at least 12 months of loading without the use of a membrane.

Analyzing augmentation of dehiscence-type defects alone, 525 patients received 813 implants showing buccal dehiscences. Five hundred twelve of the implants were followed for 12 to 59 months after loading and had survival rates of 92.6% to 100% (median 94%).[6,7,10,19,21,23] The augmentation procedures provided on average a defect fill of 85.5%,[5,6,8,9,12–15,17,18,20,21,23,24] and complete regeneration was accomplished in 68.5% of the cases.[5,9,12,15,17,18,21,23] Infectious complications were recorded in 13.7% of the cases.[5,6,8,9,12–15,17,18,20,21,23,24]

Grafting of fenestration-type defects was documented in four studies (54 patients, 126 implants).[7,11,16,22] In two studies, the mean defect fill and percentage of cases with complete bone fill at reentry were 84.9% and 68.6%, respectively.[11,16] The two other studies showed implant survival rates of 100% after 24 to 60 months of functional loading.[7,22] The mean complication rate was 2.5%.[11,22]

Table 6 Transalveolar Sinus Floor Elevation

Study	Study type	No. of patients	No. of augm	No. of implants	Grafting material	Simul/ Staged	Initial bone height (mm)	Follow-up (mo)	Implant survival (%)
Zitzmann and Schärer (1998)[65]	PS	20	ND	59	DBBM	Simul	8.8	16.5	95
Fugazzotto and De Paoli (2002)[103]	RS	150	167	167	A	Sta	ND	20.1	97.8
Winter et al (2002)[104]	RS	34	58	58	Coagulum	Simul	2.9	22	91.4
Brägger et al (2004)[105]	PS	19	25	25	A+DBBM	Simul	7	12	96
Deporter et al (2005)[106]	RS	70	104	104	DBBM	Simul	4.2	37.7	98
Leblebicioglu et al (2005)[107]	PS	40	54	75	Coagulum	Simul	8.8	25	97.3
Rodoni et al (2005)[92]	RS	18	18	18	DBBM	Simul	ND	42.6	100
Ferrigno et al (2006)[108]	PS	323	588	588	AP	Simul	7.7	53.7	94.8
Stavropoulos et al (2007)[109]	RCT	26	26	35	A+BG	Sta	6.4	12	83
Krennmair et al (2007)[98]	RS	14	14	14	DBBM	Simul	9.6	44.5	100
Fermergård and Åstrand (2008)[110]	RS	36	ND	53	Coagulum	Simul	6.3	12	96

RCT = randomized controlled trial; PS = prospective study; RS = retrospective study; No. of augm = number of sinus augmentation procedures; Simul = implant placed simultaneously with augmentation; Sta = implant placed in a second stage; Initial bone height = initial subantral bone height; Follow-up = mean follow-up period after loading; Implant survival = implant survival after at least 12 months of loading; ND = no data; A = autogenous bone; AP = autogenous particulate; DBBM = deproteinized bovine bone mineral; BG = Bioglass.

Four of the included studies were RCTs, and all randomizations were related to the use of membranes.[8,9,13,24] Schlegel and coworkers[9] randomized 40 implant sites with exposed implant threads to be augmented with autogenous bone chips with or without a resorbable membrane. The authors stated that the use of a membrane increased the defect fill, but presented no statistics to support the conclusion. Another RCT compared two different resorbable membranes versus no membrane over an allogenic grafting material.[24] No differences in defect fill could be demonstrated using a membrane, but a significantly increased width of the augmented volume was shown. No difference was found between the two resorbable membranes tested. Two RCTs evaluated the use of a resorbable versus a nonresorbable membrane to cover DBBM particles.[8,13] Both studies showed similar amounts of defect fill with the two membrane types, but the use of nonresorbable membranes was accompanied by more wound healing complications.

Horizontal Ridge Augmentation

Two categories of studies on horizontal ridge augmentations were included: *(1)* studies that reported on the augmentation procedure itself, where the successful outcome was the possibility to place implants of the desired dimensions in the ideal positions for the later suprastructure, without the need for additional grafting, and *(2)* studies that evaluated implant survival in horizontally augmented alveolar ridges.

A total of 107 studies were screened as full text, and 20 of these were included, reporting data on 593 patients with 1,034 implants (Table 3).[7,25–43] Twelve of these studies contained specific data on the horizontal ridge augmentation.[25,28,29,31,33,35,37–41,43] A total of 225 patients underwent 247 horizontal ridge augmentation procedures. After a mean healing period of 7.3 months, an average gain in ridge width of 3.6 mm could be recorded. The mean complication rate was 12.2%. However, when the complication rate was calculated for studies with the use of nonresorbable membranes, resorbable membranes, or no membranes, the corresponding rates were 23.6%, 18.9%, and 9.4%. Six studies reported data on the percentage of sites where additional grafting was needed in conjunction with implant placement.[28,29,36,40,41,43] This was the case in 11.1% of the cases.

Implant survival after a minimum of 12 months of loading was calculated based on 10 studies including 425 patients and 925 implants.[7,26,27,29,30,32,33,35,36,42] The horizontal ridge augmentations had been performed on average 6.3 months prior to implant placement. In total, 97% to 100% (median 100%) of the implants were still present after 12 to 60 months of function.

When the augmented sites were covered with nonresorbable membranes, the mean gain in ridge width was 2.9 mm,[7,25,28,29,34,35,37,38] the percentage of cases that did not need additional grafting was 80.8%,[28,29] and the complication rate was 23.6%.[25,28,29,34,35,37] The corresponding figures for the use of resorbable membranes were 4.2 mm, 95.9%, and 18.9%.[31,34,40,43] When no membrane was used, the results were 4.5 mm, 86.1%, and 9.4%.[26,29,33,36,39,41]

The results after horizontal ridge augmentation may also be divided according to whether a space-maintaining autogenous bone block is used as opposed to a particulated bone graft or a granular bone-substitute material. In studies utilizing autogenous bone blocks alone or in combination with a membrane and/or a bone-substitute material,[25–27,29,30,32,33,35,36,39,40,42]

the mean gain in ridge width was 4.4 mm, the percentage of cases that needed no additional grafting was 97.2%, and the complication rate was 3.8%. When no autogenous block graft was used, the corresponding figures were 2.6 mm, 75.6%, and 39.6%.[7,28,29,31,34,37,38,41,43]

Only one grafting protocol for augmenting localized bone defects in the horizontal dimension was documented in three or more studies. Autogenous block grafts from intraoral donor sites were used in nine studies comprising 283 patients with 594 implants.[25–27,30,32,33,35,39,42] Four studies contained data on width gain at reentry,[25,33,35,39] two of which reported on the same group of patients.[25,35] The average gain in ridge width was 4.3 mm after a mean healing period of 6.8 months, with a complication rate of 3.9%. Seven studies reported implant survival rates of 96.9% to 100% (median 100%) after 12 to 60 months of loading.[26,27,30,32,33,35,42]

One RCT compared the use of a resorbable versus a nonresorbable membrane to cover DBBM for horizontal ridge augmentation.[34] Both groups experienced high frequencies of membrane exposures (64% and 71%). General improvement of the volume and shape of the alveolar ridges was reported, but no measurements were presented to support this statement.

Vertical Ridge Augmentation

Seventy-six studies were evaluated as full text. Of these, 14 were found to contain data on implant survival after at least 12 months of loading and/or on the efficiency of the augmentation procedure (Table 4).[32,42,44–55] A total of 596 implants were placed in 315 patients. In 6 studies, 187 patients with 425 implants were followed for 22 to 105 months of function. Implant survival rates ranged from 95% to 100% (median 100%).[32,42,46,49,51,53] The efficacy of the augmentation protocols to allow later implant placement was documented in 10 studies including 162 patients with 226 implants.[44,45,47–51,53–55] The mean gain in ridge height at reentry was 4.8 mm and the average percentage of cases that allowed implant placement in the planned position without the need for additional grafting was 73.6%. Exposure of the augmentation material was reported in 18.8% of the cases.

Comparing the data when a membrane was used,[42,45,46,49,52,54] or no membrane was used,[44,47,48,55] the gain in ridge height was 3.5 mm vs 4.2 mm, the percentage of cases that required no regrafting was 67.2% vs 80%, and the complication rate was 23.2% vs 25.3%. When cases treated with an autogenous block graft[42,48,50,52,53,55] were compared to cases treated with a particulated autograft or a bone-substitute material,[44–47,49,52,54] the corresponding figures were 3.7 mm vs 3.6 mm (gain in ridge height), 83.1% vs 67.4% (cases not needing regrafting), and 29.8% vs 21.0% (complication rate).

Only intraorally harvested autogenous block grafts and autogenous particulate were documented in three studies or more. A total of 152 patients had 284 implants placed in alveolar ridges vertically augmented with block grafts harvested from the mandibular chin or body/ascending ramus.[32,42,48,55] Roccuzzo and coworkers[48,55] reported an average gain in ridge height of 4.5 mm at reentry 4.6 months after augmentation without the use of barrier membranes. Additional grafting or regrafting was necessary in 24% of the cases. After loading times of 22 and 24 months, two studies reported implant survival rates of 96.9% and 98%, respectively.[32,42] Five studies described the use of autogenous bone chips harvested intraorally and covered with a titanium-reinforced nonresorbable membrane [45,46,49,52,54] or with a resorbable membrane supported by miniplates.[54] One hundred seventy-four implants were placed in 86 patients. Three studies reported a mean gain in ridge height of 3.6 mm.[45,49,54] Additional grafting at reentry was necessary in 35% of the cases.[45,52,54] Complication rates were reported in all five studies, averaging 24.2%. Only two of the five studies contained data on implant survival.[46,49] Forty-three patients with 104 implants were followed for 30 and 36 months of loading, respectively, and reported 100% survival rates.

Two RCTs compared different grafting protocols for vertical ridge augmentation. Merli and coworkers[54] compared particulated autografts covered either by osteosynthesis miniplates in combination with a resorbable collagen membrane or by a titanium-reinforced nonresorbable membrane in a total of 22 patients. No differences in augmented bone height (2.8 mm vs 2.1 mm) or in complication rate (45% vs 36%) could be demonstrated. The effect of covering an autogenous bone block harvested intraorally with a titanium mesh was evaluated in the other RCT.[55] A statistically significantly larger gain in ridge height was obtained by covering the block graft with a titanium mesh than when no mesh was used (4.8 mm vs 3.6 mm). A third RCT compared vertical ridge augmentation using distraction osteogenesis with the results obtained by using autogenous particulate in combination with titanium-reinforced nonresorbable membranes.[49] Distraction osteogenesis is evaluated in a parallel review in this supplement (Chiapasco et al). In the 11 patients augmented with autograft and a membrane, the survival rate of the 25 placed implants was 100% after 35.5 months of loading, but one-third of the implants showed progressive marginal bone loss.

Maxillary Sinus Floor Elevation—Lateral Window Technique

A total of 179 studies were evaluated as full text, 47 of which were included (Table 5).

In 1,571 patients, 5,388 implants were inserted in 2,180 augmented sinuses.[56–107] From 19 studies, the mean initial subantral bone height before grafting was calculated to be 3.8 mm.[65,68–70,73–76,78,82,83,87,90,91,98–102] For simultaneous implant placements and two-stage placements, the mean heights were 4.4 mm and 2.9 mm, respectively. In two-stage procedures, the mean healing time from grafting to implantation was 5.9 months. Infectious complications were reported in 4.7% of the cases.[56,59,64–71,73,74,76,78,81–83,85–87,89,91–95,99–101] The average healing time from implant placement until loading was 6.5 months. Implant survival ranged from 61.2% to 100% (median 95.5%) after 12 to 107 months of prosthetic loading.[56–107] When the material was divided according to the surface of the implants used, the corresponding figures were 61.2% to 100% (median 89%) after 12 to 60 months for machined-surface implants[57–60,62,65–67,72,74–79,81,87,88,91,92,96] and 88.6% to 100% (median 100%) after 12 to 45 months of loading for rough-surfaced implants.[56,61,63,64,68,69,71,73,80,82,84,86,89,94,95,97–99,101,102]

A barrier membrane was used to cover the lateral window in 12 studies (282 patients, 803 implants).[56,63,65,68,70,73,79,90,92,95,98,101] No membrane was used in 27 studies (1,000 patients, 3,165 implants).[57–62,64,69,71,74–76,78,79,82–85,87–89,94,96,97,99,100,102] The implant survival rates with and without the use of a membrane were 92% to 100% (median 100%) and 61.2% to 100% (median 94.7%) after loading periods of up to 48 and 107 months, respectively. Excluding studies using smooth-surfaced implants, the survival rates ranged from 92% to 100% (median 100%) with the use of a barrier membrane after up to 45 months of loading, compared to 93% to 100% (median 100%) without the use of a membrane after up to 36 months of loading.

A bone-substitute material was used alone in 16 studies (388 patients, 1,344 implants),[56,61,65,70,71,77,79,80,82,85,86,92,94,95,99,101] whereas 30 studies used autografts alone or a combination of autografts and a bone-substitute material (1,183 patients, 4,044 implants).[57–60,62–64,66–69,72–76,78–81,83,84,87,88,90,91,93,96,98,100] The mean initial bone height for the two groups was 3.4 mm and 3.9 mm, respectively. For two-stage procedures, the mean healing time before implant placement was 6.6 months and 5.6 months, respectively. In the "bone-substitute group," the implant survival rates after up to 107 months of loading ranged from 82% to 100% (median 96.8%). In comparison, the survival rates in the "autograft group" ranged from 61.2% to 100% (median 94.2%) after up to 60 months of loading. Excluding studies using smooth-surfaced implants, the survival rates ranged from 88.6% to 100% (median 96.8%) with the use of a bone-substitute material alone[56,61,71,80,82,86,94,95,99,101] after up to 42 months of loading, compared to 96% to 100% (median 100%) after up to 45 months of loading when particulated autograft was included in the grafting material.[63,64,68,69,73,80,84,98]

Eight grafting protocols for maxillary sinus floor elevation procedures were documented in three or more studies.

Three case series (63 patients, 110 implants) presented data on maxillary sinus floor elevation procedures without the use of a grafting material. Instead, the simultaneously placed implants acted as tent poles for the elevated sinus membrane, allowing a coagulum to occupy the created space.[89,97,102] After an average of 12 to 27.5 months of loading, the survival rate ranged from 97.7% to 100% (median 100%).

A total of 10 studies used autogenous block grafts for augmenting the maxillary sinus, all of which were harvested from the iliac crest.[59,60,62,66,67,72,75,76,81,96] In 5 studies (155 patients),[59,66,67,72,75] 560 implants were placed simultaneously with the grafting procedure, whereas 4 studies (85 patients, 351 implants)[60,62,72,81] used a staged approach (2 studies did not separate staged and simultaneous implant placements[76,96]). The overall implant survival rate after a period of function up to 58 months ranged from 61.2% to 94.4% (median 84.9%). For simultaneous and staged implant placements in autogenous bone blocks, the corresponding survival rates were 61.2% to 92.2% (median 79%) and 76.9% to 94.4% (median 89.1%), respectively.

Six studies (185 patients, 830 implants) presented data on maxillary sinus floor elevations using particulated autografts from different donor sites.[58,64,72,79,84,93] Most of the studies (five) used a staged approach,[58,64,72,79,93] where the mean healing time before implant placement was 5.3 months. The survival rate after 12 to 54 months of loading was 82.4% to 100% (median 97.1%).

DBBM alone was used for maxillary sinus floor elevation in 10 studies (338 patients, 874 implants).[65,70,77,79,85,86,92,95,99,101] The initial bone height was reported in 4 of the studies, with an average of 2.8 mm. Three studies contained data on implant placement at the time of the augmentation procedure,[85,99,101] whereas 5 studies delayed implant placement for an average of 6.7 months.[70,79,85,86,95] Implant survival after up to 68 months in function ranged from 85% to 100% (median 97%).

Alloplastic particulate in the form of hydroxyapatite was used as a grafting material for maxillary sinus floor elevations and presented in 3 studies from

the same group (56 patients, 135 implants).[82,94,99] After a period of function up to 36 months, the survival rate was 96% to 100% (median: 100%).

Four studies presented the use of a composite graft consisting of particulated autograft and allograft in 94 patients with 338 implants (two studies did not report the number of patients).[63,68,69,80] All four studies reported 100% implant survival after loading periods of up to 42 months.

Autografts were combined with DBBM in nine studies.[74,78,79,87,88,90,91,98,100] However, four studies reported on the same pool of patients at different time points.[74,78,87,91] Therefore, only clinical data from the latest follow-up were included.[87] A total of 908 implants were placed in 352 patients. The height of the initial ridge was presented for five patient pools with an average of 4.4 mm.[79,87,90,98,100] The implant survival rate was 89% to 100% (median 94.3%) with a follow-up of 12 to 60 months after loading.

A combination of DFDBA and DBBM was used in three studies[61,80,85] comprising the augmentation of 113 maxillary sinuses (the number of patients was not reported by Kan et al[80]) and the placement of 283 implants. After a period of function of up to 107 months, the implant survival rate ranged from 82.1% to 96.8% (median 90.7%).

Three studies included randomization of two different grafting protocols.[72,79,99] Wannfors and coworkers[72] randomized 40 patients with edentulous maxillae to have bilateral maxillary sinus floor elevation performed with either autogenous bone blocks from the iliac crest in combination with immediate implant placement (76 implants) or particulated autogenous bone (also from the iliac crest) in a two-stage procedure (74 implants placed after 6 months of graft healing). The implant survival rate after 12 months of function was 79% in the block graft group and 89% in the particulate group. The difference was not statistically significant.

Eleven patients in whom bilateral augmentation of the maxillary sinus was indicated were randomized in a split-mouth design to be grafted with particulated autogenous bone harvested from the mandibular ramus or a mixture of 80% DBBM and 20% particulated autograft.[79] After a healing period of 6.5 months, 33 implants were placed in the autograft side and 35 implants were placed in the composite side. After 12 months of loading, the survival rate for the implants placed in 100% autograft was 82.4%, versus 94.4% for the implants placed in 80% DBBM and 20% autograft. This difference was also not statistically significant.

Mangano and coworkers[99] compared the use of DBBM versus an alloplastic HA for maxillary sinus floor elevation. Forty patients were randomized to receive one of the two augmentation materials. A total of 100 implants were placed simultaneously with the augmentation procedure—50 in each group. Both groups had an implant survival rate of 96% after 12 months of loading.

Transalveolar Sinus Floor Elevation

A total of 16 studies were screened as full text. Data from 11 studies were included (Table 6).[65,92,98,103–110] One thousand and fifty-four sinus floor elevations using the transalveolar approach (2 studies did not report the number of augmentation procedures[65,110]) were performed in 750 patients with a mean initial subantral bone height of 6.9 mm (2 studies did not present data on initial bone height[92,103]). A total of 1,196 implants were followed for a period of up to 64 months after prosthetic loading, with an implant survival rate ranging from 83% to 100% (median 96%).

Three studies reported results after elevating the sinus floor without the introduction of a grafting material in 110 patients (186 implants) with a mean initial bone height of 6 mm.[104,107,110] The mean implant survival was 91.4% to 97.3% (median 96%) after up to 25 months of loading. The highest number of patients (473) were grafted with autogenous bone, with 755 implants placed in a mean initial ridge height of 6.6 mm and followed for up to 54 months of loading.[103,108] The implant survival rates were 97.8% and 94.8%, respectively. DBBM alone was used as grafting material in four studies reporting on 122 patients with a mean initial bone height of 7.5 mm, in which 195 implants were placed.[65,92,98,106] The survival rate was 95% to 100% (median 99%) after a follow-up period of 12 to 45 months after loading.

The only RCT describing the transalveolar approach in maxillary sinus floor elevations was not randomized regarding the grafting protocol but had two different implant designs.[109]

No studies compared the lateral window technique with the transalveolar approach for similar indications.

DISCUSSION

Survival rates of implants placed in conjunction with augmentation of dehiscence-type defects or fenestration-type defects (median 95.4%), implants placed in bone augmented in the horizontal and vertical dimensions (medians both 100%), and implants placed in augmented sinuses, using the lateral window technique (median 95.5%) or a transalveolar approach (median 96%), are comparable to survival rates of implants placed in pristine bone. This is in accordance with a previous systematic review.[111] However, these high survival rates are almost exclusively based on observational, nonrandomized, uncontrolled studies.

Augmentation of dehiscence-type defects and fenestration-type defects resulted in 54% to 97% resolution of the former defects (mean 81.7%), and complete defect fill was reported in 68.5% of the cases. In contrast, very limited resolution of the defects could be observed when no augmentation was performed in an RCT by Dahlin and coworkers[112] (this specific RCT could not be included in the present review, since only seven patients were treated). Irrespective of the grafting protocol employed, complete defect fill could not be predictably accomplished. Augmentation of fenestration-type defects was accompanied by fewer membrane exposures and infectious complications than augmentation of dehiscence-type defects (2.5% vs 13.7%). When fenestration-type defects are augmented, the augmentation material can, most often, be placed with a safe distance to the incision line. This is not the case when dehiscence-type defects are augmented. Any minor opening in the suture line may, therefore, lead to exposure of the membrane or grafting material.

It seems to make no difference whether a resorbable or a nonresorbable membrane is used to cover the defect area.[8,13] However, the use of a membrane may increase the augmented volume as compared to when no membrane is used.[24] Comparable results were obtained with regard to implant survival and amount of defect fill when a nonresorbable membrane alone, autogenous particulate, or DBBM was used to cover dehiscence-type defects and fenestration-type defects.

In horizontal ridge augmentations, the use of nonresorbable membranes seems to provide less gain in ridge width, increased need for additional grafting procedures, and higher complication rates as compared to the use of resorbable membranes or no membrane at all. However, a confounding factor may be that nonresorbable membranes were mainly utilized to cover granular grafting materials,[7,28,29,34,37,38] and only seldom autogenous bone blocks.[25,35] Based on these findings, the most predictable horizontal ridge augmentation seems to involve an autogenous block graft alone or in combination with a particulated bone graft or bone-substitute material, with or without the concomitant use of a resorbable membrane. The included studies did not provide conclusive evidence as to whether or not barrier membranes protect autogenous bone grafts against resorption. The same conclusion was drawn by a recent review of animal and human studies.[113] There are some clinical and experimental data to support the premise that resorption of autogenous block grafts may be reduced by combining the block graft with a bone-substitute material with a low substitution rate.[39,114] However, no RCTs have tested this hypothesis.

Implants placed in vertical ridge augmentations showed very high survival rates (median 100%) after an average loading time of more than 3 years. The only RCT contributing to this high implant survival rate revealed that 32% of the implants did not meet the success criteria by Albrektsson et al[115] after 3 years of function because of crestal bone loss.[49] In addition, a loss of the augmented height of 50% after 10 to 11 years of function was observed in another long-term study, despite a 100% implant survival rate.[53] Only one study has reported positive results using a granular grafting material without any space-keeping mechanisms other than the tenting effect of the simultaneously placed implants.[44] Otherwise, whenever a granular or particulated grafting material was utilized for a vertical ridge augmentation procedure, a titanium mesh, a titanium-reinforced membrane, or miniplates were used to protect the augmented volume. The use of block grafts seemed to yield more gain in ridge height and a greater reduction in the need for additional grafting procedures than the use of granular grafts. However, in contrast to horizontal ridge augmentations, the rate of dehiscences also seemed to increase with the use of block grafts. This may be caused by the increased stretching of the covering soft tissues elicited by the larger blocks, which may compromise tension-free primary closure.

Maxillary sinus floor elevation using the lateral window technique is a predictable treatment procedure with a low complication rate of 4.7% and a median implant survival rate of 95.5%. It has been debated whether the use of a barrier membrane to cover the lateral window increases the implant survival rate. There seemed to be a tendency toward better prognosis when a membrane was used (98% vs 92.7%). If the studies using implants with machined surfaces were excluded, the survival rates with and without the use of a barrier membrane were almost identical. However, it should be noted that by eliminating smooth-surfaced implants, the cases treated with implants placed simultaneously with transplanted autogenous bone blocks from the iliac crest were also eliminated. The block grafts seem to reduce the survival rate of implants compared to particulated autografts, and hence might be an important confounding factor. Therefore, when particulated autografts or bone-substitute materials are utilized, it cannot be assumed that the use of a barrier membrane to cover the lateral window will improve the implant survival rate dramatically.

An arbitrary initial ridge height of 5 mm has often been mentioned as a threshold for the possibility of simultaneous implant placement and maxillary sinus floor elevation. However, several of the included

studies present favorable results from simultaneous procedures in initial ridges of 2 to 4 mm.[69,73,99,101] Therefore, the decision whether to use a simultaneous or a staged approach should be based on an individual evaluation of bone quantity and quality, and thus the possibility of achieving primary implant stability.

Whether autografts improve the prognosis of maxillary sinus floor elevation procedures is an ongoing discussion. A Cochrane review concluded that bone-substitute materials may replace autografts in this indication.[3] Data from the present review support this conclusion. No tendency was observed toward a lower implant survival rate in sinuses augmented with bone-substitute materials alone (96.1%) versus augmentation protocols including particulated autogenous bone (95.8%). Another matter of discussion is whether autografts accelerate the bone healing within the augmented volume. With the transplantation of autogenous bone, osteogenic cells and osteogenic growth factors are brought to the augmented site.[116] This is not the case with bone-substitute materials. It may, therefore, be anticipated that the ingrowth of newly formed bone is delayed with bone-substitute materials compared to autografts, and that implant placement (in two-stage procedures) and loading therefore will have to be postponed. In the included studies reporting on two-stage procedures, the average healing time from augmentation to implantation was 6.6 months in the bone-substitute studies and 5.6 months in the studies where autografts were included. The healing periods between implant placement and loading were almost identical (6.5 vs 6.6 months).

Several grafting protocols using autogenous bone from intraoral donor sites and/or bone-substitute materials are well documented, with low complication rates and high implant survival rates. However, data from maxillary sinus floor elevations with autogenous bone blocks from the iliac crest showed a tendency toward lower survival rates (83.5%), especially when implants were placed simultaneously (78.7%). In addition, the surgical procedure is more complicated and the morbidity is higher.

Maxillary sinus floor elevation using the transalveolar approach may be a valid and less invasive supplement to the lateral window technique. A prerequisite for using this technique is that primary implant stability can be achieved. In cases where primary stability cannot be reached, where perforations of the sinus membrane arise, or where other complications are observed, the surgeon must be able to switch to the lateral window technique in order not to be forced to abort the surgery. In principle, there is no evidence to recommend a minimum initial bone height above which a maxillary sinus floor elevation using the transalveolar approach is feasible. Winter and coworkers[104] presented a mean initial bone height of 2.9 mm. However, the mean initial bone height was 6.9 mm as opposed to 3.8 mm in the studies on the lateral window technique. At present, it is not clear whether the introduction of a grafting material improves the prognosis. Maxillary sinus floor elevation procedures using the transalveolar approach have been endoscopically controlled.[117] Perforations of the sinus membrane were observed which could not be recognized clinically, and grafting material was displaced into the sinus cavity. From a clinical point of view, it may, therefore, be advantageous to use an autogenous material to prevent foreign body–related sinus infections.

CONCLUSIONS

A large but heterogeneous body of literature was available regarding augmentation of localized bone defects in the alveolar ridges after including all levels of clinical evidence except expert opinions. Based on these data it was possible to accept the hypothesis that survival rates of implants placed in augmented bone are comparable to those of implants in pristine bone. The overall level of evidence supporting the hypothesis lies between level A and level B.

In dehiscence-type defects and fenestration-type defects, the best documented augmentation protocols are DBBM covered with a membrane, particulated autograft with or without a resorbable membrane, and a nonresorbable membrane alone.

In horizontal ridge augmentations, the best documented grafting protocol includes an intraorally harvested autogenous bone block alone or in combination with DBBM and with or without coverage of a barrier membrane.

Augmentations in the vertical dimension have mainly been performed using autogenous bone grafts, either as intraorally harvested blocks or as particulate supported by a space-keeping device.

In maxillary sinus floor elevations using the lateral window technique, the following grafting protocols may be considered well-documented: coagulum (in combination with immediate implant placements), autogenous particulate alone or in combination with DBBM or DFDBA, DBBM alone or in combination with DFDBA, and an alloplastic HA alone.

The best documented sinus grafting materials using the transalveolar approach are coagulum, particulated autograft, and DBBM.

ACKNOWLEDGMENTS

The efforts of Mrs K. Birkefoss and Mrs L. Madsen, Medical Library, Copenhagen University Hospital Glostrup, in procuring additional articles from several university libraries around Europe were highly appreciated.

REFERENCES

1. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: Anatomic and surgical considerations. Int J Oral Maxillofac Implants 2004;19(suppl): 43–61.
2. Hjørting-Hansen E. Bone grafting to the jaws with special reference to reconstructive preprosthetic surgery. A historical review [in German]. Mund Kiefer Gesichtschir 2002;6:6–14.
3. Esposito M, Grusovin MG, Coulthard P, Worthington HT. The efficacy of various bone augmentation procedures for dental implants: A Cochrane systematic review of randomized controlled clinical trials. Int J Oral Maxillofac Implants 2006;21: 696–710.
4. Esposito M, Worthington HT, Coulthard P. In search of the truth: The role of systematic reviews and meta-analyses for assessing the effectiveness of rehabilitation with oral implants. Clin Implant Dent Relat Res 2001;3:62–78.
5. Jovanovic SA, Spiekermann H, Richter EJ. Bone regeneration around titanium dental implants in dehisced defect sites: A clinical study. Int J Oral Maxillofac Implants 1992;7:233–245.
6. Dahlin C, Lekholm U, Becker W, et al. Treatment of fenestration and dehiscence bone defects around oral implants using the guided tissue regeneration technique: A prospective multicenter study. Int J Oral Maxillofac Implants 1995;10:312–318.
7. Fugazzotto PA. Success and failure rates of osseointegrated implants in function in regenerated bone for 6 to 51 months. Int J Oral Maxillofac Implants 1997;12:17–24.
8. Zitzmann NU, Naef R, Schärer P. Resorbable versus nonresorbable membranes in combination with Bio-Oss for guided bone regeneration. Int J Oral Maxillofac Implants 1997;12: 844–852.
9. Schlegel AK, Donath K, Weida S. Histological findings in guided bone regeneration (GBR) around titanium dental implants with autogenous bone chips using a new resorbable membrane. J Long Term Eff Med Implants 1998;8:211–224.
10. Lorenzoni M, Pertl C, Polansky RA, Wegscheider WA. Guided bone regeneration with barrier membranes—A clinical and radiographic follow-up study after 24 months. Clin Oral Implants Res 1999;10:16–23.
11. Peleg M, Chaushu G, Blinder D, Taicher S. Use of lyodura for bone augmentation of osseous defects around dental implants. J Periodontol 1999;70:853–860.
12. von Arx T, Kurt B. Implant placement and simultaneous ridge augmentation using autogenous bone and a micro titanium mesh: A prospective clinical study with 20 implants. Clin Oral Implants Res 1999;10:24–33.
13. Carpio L, Loza J, Lynch S, Genco R. Guided bone regeneration around endosseous implants with anorganic bovine bone mineral. A randomized controlled trial comparing bioabsorbable versus non-resorbable barriers. J Periodontol 2000;71:1743–1749.
14. Nemcovsky CE, Artzi Z, Moses O, Gelernter I. Healing of dehiscence defects at delayed-immediate implant sites primarily closed by a rotated palatal flap following extraction. Int J Oral Maxillofac Implants 2000;15:550–558.
15. van Steenberghe D, Callens A, Geers L, Jacobs R. The clinical use of deproteinized bovine bone mineral on bone regeneration in conjunction with immediate implant installation. Clin Oral Implants Res 2000;11:210–216.
16. Widmark G, Ivanoff CJ. Augmentation of exposed implant threads with autogenous bone chips: Prospective clinical study. Clin Implant Dent Relat Res 2000;2:178–183.
17. Hämmerle CHF, Lang NP. Single stage surgery combining transmucosal implant placement with guided bone regeneration and bioresorbable materials. Clin Oral Implants Res 2001;12:9–18.
18. Tawil G, El-Ghoule G, Mawla M. Clinical evaluation of a bilayered collagen membrane (Bio-Gide) supported by autografts in the treatment of bone defects around implants. Int J Oral Maxillofac Implants 2001;16:857–863.
19. Zitzmann NU, Schärer P, Marinello CP. Long-term results of implants treated with guided bone regeneration: A 5-year prospective study. Int J Oral Maxillofac Implants 2001;16: 355–366.
20. Nemcovsky CE, Artzi Z, Moses O, Gelernter I. Healing of marginal defects at implants placed in fresh extraction sockets or after 4-6 weeks of healing. A comparative study. Clin Oral Implants Res 2002;13:410–419.
21. De Boever AL, De Boever JA. Guided bone regeneration around non-submerged implants in narrow alveolar ridges: A prospective long-term clinical study. Clin Oral Implants Res 2005;16:549–556.
22. Juodzbalys G, Raustia AM, Kubilius R. A 5-year follow-up study on one-stage implants inserted concomitantly with localized alveolar ridge augmentation. J Oral Rehabil 2007;34:781–789.
23. Llambés F, Silvestre FJ, Caffesse R. Vertical guided bone regeneration with bioabsorbable barriers. J Periodontol 2007;78: 2036–2042.
24. Park SH, Lee KW, Oh TJ, Misch CE, Shotwell J, Wang HL. Effect of absorbable membranes on sandwich bone augmentation. Clin Oral Implants Res 2008;19:32–41.
25. Buser D, Dula K, Hirt HP, Schenk RS. Lateral ridge augmentation using autografts and barrier membranes: A clinical study with 40 partially edentulous patients. J Oral Maxillofac Surg 1996;54:420–432.
26. Raghoebar GM, Batenburg RHK, Vissink A, Reintsema H. Augmentation of localized defects of the anterior maxillary ridge with autogenous bone before insertion of implants. J Oral Maxillofac Surg 1996;54:1180–1185.
27. von Arx T, Wallkamm B, Hardt N. Localized ridge augmentation using a micro titanium mesh: A report on 27 implants followed from 1 to 3 years after functional loading. Clin Oral Implants Res 1998;9:123–130.
28. Parodi R, Carusi G, Santarelli G, Nanni F. Implant placement in large edentulous ridges expanded by GBR using a bioresorbable collagen membrane. Int J Periodontics Restorative Dent 1998;18:267–275.
29. Chiapasco M, Abati S, Romeo E, Vogel G. Clinical outcome of autogenous bone blocks or guided bone regeneration with e-PTFE membranes for the reconstruction of narrow edentulous ridges. Clin Oral Implants Res 1999;10:278–288.
30. Bedrossian E, Tawfilis A. Veneer grafting: A technique for augmentation of the resorbed alveolus prior to implant placement. A clinical report. Int J Oral Maxillofac Implants 2000; 15:853–858.
31. Kirkland G, Greenwell H, Drisko C, Wittwer JW, Yancey J, Rebitski G. Hard tissue ridge augmentation using a resorbable membrane and a particulate graft without complete flap closure. Int J Periodontics Restorative Dent 2000;20:383–389.

32. Sethi A, Kaus T. Ridge augmentation using mandibular block bone grafts: Preliminary results of an ongoing prospective study. Int J Oral Maxillofac Implants 2001;16:378–388.
33. Cordaro L, Amadé DS, Cordaro M. Clinical results of alveolar ridge augmentation with mandibular block bone grafts in partially edentulous patients prior to implant placement. Clin Oral Implants Res 2002;13:103–111.
34. Friedmann A, Strietzel AP, Maretzki B, Pitaru S, Bernimoulin JP. Histological assessment of augmented jaw bone utilizing a new collagen barrier membrane compared to a standard barrier membrane to protect a granular bone substitute material. A randomized clinical trial. Clin Oral Implants Res 2002;13: 587–594.
35. Buser D, Ingimarsson S, Dula K, Lussi A, Hirt HP, Belser UC. Long-term stability of osseointegrated implants in augmented bone: A 5-year prospective study in partially edentulous patients. Int J Periodontics Restorative Dent 2002;22:108–117.
36. Hellem S, Åstrand P, Stenström B, Engquist B, Bengtsson M, Dahlgren S. Implant treatment in combination with lateral augmentation of the alveolar process: A 3-year prospective study. Clin Implant Dent Relat Res 2003;5:233–240.
37. Knapp CI, Feuille F, Cochran DL, Mellonig JT. Clinical and histologic evaluation of bone-replacement grafts in the treatment of localized alveolar ridge defects. Part 2: Bioactive glass particulate. Int J Periodontics Restorative Dent 2003;23:129–137.
38. Feuille F, Knapp CI, Brunsvold MA, Mellonig JT. Clinical and histologic evaluation of bone-replacement grafts in the treatment of localized alveolar ridge defects. Part 1: Mineralized freeze-dried bone allograft. Int J Periodontics Restorative Dent 2003;23:29–35.
39. Maiorana C, Beretta M, Salina S, Santoro F. Reduction of autogenous bone graft resorption by means of Bio-Oss coverage: A prospective study. Int J Periodontics Restorative Dent 2005;25:19–25.
40. von Arx T, Buser D. Horizontal ridge augmentation using autogenous block grafts and the guided bone regeneration technique with collagen membranes: A clinical study with 42 patients. Clin Oral Implants Res 2006;17:359–366.
41. Strietzel FP, Reichart PA, Graf HL. Lateral alveolar ridge augmentation using synthetic nano-crystalline hydroxyapatite bone substitution material (Ostim). Preliminary clinical and histological results. Clin Oral Implants Res 2007;18:743–751.
42. Levin L, Nitzan D, Schwartz-Arad D. Success of dental implants placed in intraoral block bone grafts. J Periodontol 2007;78: 18–21.
43. Hämmerle CHF, Jung RE, Yaman D, Lang NP. Ridge augmentation by applying bioresorbable membranes and deproteinized bovine bone mineral: Report of twelve consecutive cases. Clin Oral Implants Res 2008;19:19–25.
44. Corrente G, Abundo R, Cardaropoli G, Martuscelli G, Trisi P. Supracrestal bone regeneration around dental implants using a calcium carbonate and a fibrin-fibronectin sealing system: Clinical and histologic evidence. Int J Periodontics Restorative Dent 1997;17:171–181.
45. Simion M, Jovanovic SA, Trisi P, Scarano A, Piattelli A. Vertical ridge augmentation around dental implants using a membrane technique and autogenous bone or allografts in humans. Int J Periodontics Restorative Dent 1998;18:9–23.
46. Simion M, Jovanovic SA, Tinti C, Benfenati SP. Long-term evaluation of osseointegrated implants inserted at the time or after vertical ridge augmentation. A retrospective study on 123 implants with 1-5 years follow-up. Clin Oral Implants Res 2001;12:35–45.
47. Artzi Z, Dayan D, Alpern Y, Nemcovsky CE. Vertical ridge augmentation using xenogenic material supported by a configured titanium mesh: Clinicohistopathologic and histochemical study. Int J Oral Maxillofac Implants 2003;18:440–446.
48. Roccuzzo M, Ramieri G, Spada MC, Bianchi SD, Berrone S. Vertical alveolar ridge augmentation by means of a titanium mesh and autogenous bone grafts. Clin Oral Implants Res 2004;15: 73–81.
49. Chiapasco M, Romeo E, Casentini P, Rimondini L. Alveolar distraction osteogenesis vs. vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: A 1–3-year prospective study on humans. Clin Oral Implants Res 2004;15:82–95.
50. Proussaefs P, Lozada J. The use of intraorally harvested autogenous block grafts for vertical alveolar ridge augmentation: A human study. Int J Periodontics Restorative Dent 2005;25: 351–363.
51. Smolka W, Bosshardt DD, Mericske-Stern R, Iizuka T. Reconstruction of the severely atrophic mandible using calvarial split bone grafts for implant-supported oral rehabilitation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:35–42.
52. Merli M, Migani M, Bernadelli F, Esposito M. Vertical bone augmentation with dental implant placement: Efficacy and complications associated with 2 different techniques. A retrospective cohort study. Int J Oral Maxillofac Implants 2006;21:600–606.
53. Verhoeven JW, Cune MS, Ruijter J. Permucosal implants combined with iliac crest onlay grafts used in extreme atrophy of the mandible: Long-term results of a prospective study. Clin Oral Implants Res 2006;17:58–66.
54. Merli M, Migani M, Esposito M. Vertical ridge augmentation with autogenous bone grafts: Resorbable barriers supported by osteosynthesis plates versus titanium-reinforced barriers. A preliminary report of a blinded, randomized controlled clinical trial. Int J Oral Maxillofac Implants 2007;22:373–382.
55. Roccuzzo M, Ramieri G, Bunino M, Berrone S. Autogenous bone graft alone or associated with a titanium mesh for vertical alveolar ridge augmentation: A controlled clinical trial. Clin Oral Implants Res 2007;18:286–294.
56. Small SA, Zinner ID, Panno FV, Shapiro HJ, Stein JI. Augmenting the maxillary sinus for implants: Report of 27 patients. Int J Oral Maxillofac Implants 1993;8:523–528.
57. Blomqvist JE, Alberius P, Isaksson S. Retrospective analysis of one-stage maxillary sinus augmentation with endosseous implants. Int J Oral Maxillofac Implants 1996;11:512–521.
58. Lundgren S, Moy P, Johansson C, Nilson H. Augmentation of the maxillary sinus floor with particulated mandible: A histologic and histomorphometric study. Int J Oral Maxillofac Implants 1996;11:760–766.
59. Daelemans P, Hermans M, Godet F, Malavez C. Autologous bone graft to augment the maxillary sinus in conjunction with immediate endosseous implants: A retrospective study up to 5 years. Int J Periodontics Restorative Dent 1997;17:27–39.
60. Lundgren S, Nyström E, Nilson H, Gunne J, Lindhagen O. Bone grafting to the maxillary sinuses, nasal floor and anterior maxilla in the atrophic edentulous maxilla. A two-stage technique. Int J Oral Maxillofac Surg 1997;26:428–434.
61. Valentini P, Abensur DJ. Maxillary sinus floor elevation for implant placement with demineralized freeze-dried bone and bovine bone (Bio-Oss): A clinical study of 20 patients. Int J Periodontics Restorative Dent 1997;17:233–241.
62. Blomqvist JE, Alberius P, Isaksson S. Two-stage maxillary sinus reconstruction with endosseous implants: A prospective study. Int J Oral Maxillofac Implants 1998;13:758–766.

63. Peleg M, Mazor Z, Chaushu G, Garg AK. Sinus floor augmentation with simultaneous implant placement in the severely atrophic maxilla. J Periodontol 1998;69:1397–1403.
64. van den Bergh JP, ten Bruggenkate CM, Krekeler G, Tuinzing DB. Sinus floor elevation and grafting with autogenous iliac crest bone. Clin Oral Implants Res 1998;9:429–435.
65. Zitzmann NU, Schärer P. Sinus elevation procedures in the resorbed posterior maxilla. Comparison of the crestal and lateral approaches. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;85:8–17.
66. Johansson B, Wannfors K, Ekenbäck J, Smedberg JI, Hirsch J. Implants and sinus-inlay bone grafts in a 1-stage procedure on severely atrophied maxillae: Surgical aspects of a 3-year follow-up study. Int J Oral Maxillofac Implants 1999;14: 811–818.
67. Keller EE, Tolman DE, Eckert SE. Maxillary antral-nasal inlay autogenous bone graft reconstruction of compromised maxilla: A 12-year retrospective study. Int J Oral Maxillofac Implants 1999;14:707–721.
68. Mazor Z, Peleg M, Gross M. Sinus augmentation for single-tooth replacement in the posterior maxilla: A 3-year follow-up clinical report. Int J Oral Maxillofac Implants 1999;14:55–60.
69. Peleg M, Mazor Z, Garg AK. Augmentation grafting of the maxillary sinus and simultaneous implant placement in patients with 3 to 5 mm of residual alveolar bone height. Int J Oral Maxillofac Implants 1999;14:549–556.
70. Valentini P, Abensur D, Wenz B, Peetz M, Schenk R. Sinus grafting with porous bone mineral (Bio-Oss) for implant placement: A 5-year study on 15 patients. Int J Periodontics Restorative Dent 2000;20:245–253.
71. van den Bergh JP, ten Bruggenkate CM, Krekeler G, Tuinzing DB. Maxillary sinus floor elevation and grafting with human demineralised freeze dried bone. Clin Oral Implants Res 2000;11:487–493.
72. Wannfors K, Johansson B, Hallman M, Strandkvist T. A prospective randomized study of 1- and 2-stage sinus inlay bone grafts: 1-year follow-up. Int J Oral Maxillofac Implants 2000; 15:625–632.
73. Cordioli G, Mazzocco C, Schepers E, Brugnolo E, Majzoub Z. Maxillary sinus floor augmentation using bioactive glass granules and autogenous bone with simultaneous implant placement. Clinical and histological findings. Clin Oral Implants Res 2001;12:270–278.
74. Hallman M, Cederlund A, Lindskog S, Lundgren S, Sennerby L. A clinical histologic study of bovine hydroxyapatite in combination with autogenous bone and fibrin glue for maxillary sinus floor augmentation. Clin Oral Implants Res 2001;12: 135–143.
75. Kahnberg KE, Ekestubbe A, Grondahl K, Nilsson P, Hirsch JM. Sinus lifting procedure. I. One-stage surgery with bone transplant and implants. Clin Oral Implants Res 2001;12:479–487.
76. Raghoebar GM, Timmenga NM, Reintsema H, Stegenga B, Vissink A. Maxillary bone grafting for insertion of endosseous implants: Results after 12-124 months. Clin Oral Implants Res 2001;12:279–286.
77. Tawil G, Mawla M. Sinus floor elevation using a bovine bone mineral (Bio-Oss) with or without the concomitant use of a bilayered collagen barrier (Bio-Gide): A clinical report of immediate and delayed implant placement. Int J Oral Maxillofac Implants 2001;16:713–721.
78. Hallman M, Hedin M, Sennerby L, Lundgren S. A prospective 1-year clinical and radiographic study of implants placed after maxillary sinus floor augmentation with bovine hydroxyapatite and autogenous bone. J Oral Maxillofac Surg 2002;60: 277–286.
79. Hallman M, Sennerby L, Lundgren S. A clinical and histologic evaluation of implant integration in the posterior maxilla after sinus floor augmentation with autogenous bone, bovine hydroxyapatite, or a 20:80 mixture. Int J Oral Maxillofac Implants 2002;17:635–643.
80. Kan JYK, Rungcharassaeng K, Kim J, Lozada JL, Goodacre CJ. Factors affecting the survival of implants in grafted maxillary sinuses: A clinical report. J Prosthet Dent 2002;87:485–489.
81. Pejrone G, Lorenzetti M, Mozzati M, Valente G, Schierano GM. Sinus floor augmentation with autogenous iliac bone block grafts: A histological and histomorphometrical report on the two-step surgical technique. Int J Oral Maxillofac Surg 2002; 31:383–388.
82. Mangano C, Bartolucci EG, Mazzocco C. A new porous hydroxyapatite for promotion of bone regeneration in maxillary sinus augmentation: Clinical and histologic study in humans. Int J Oral Maxillofac Implants 2003;18:23–30.
83. Reinert S, König S, Bremerich A, Eufinger H, Krimmel M. Stability of bone grafting and placement of implants in the severely atrophic maxilla. Br J Oral Maxillofac Surg 2003;41:249–255.
84. Stricker A, Voss PJ, Gutwald R, Schramm A, Schmelzeisen R. Maxillary sinus floor augmentation with autogenous bone grafts to enable placement of SLA-surfaced implants: Preliminary results after 15–40 months. Clin Oral Implants Res 2003;14:207–212.
85. Valentini P, Abensur DJ. Maxillary sinus grafting with anorganic bovine bone: A clinical report of long-term results. Int J Oral Maxillofac Implants 2003;18:556–560.
86. Hallman M, Nordin, T. Sinus floor augmentation with bovine hydroxyapatite mixed with fibrin glue and later placement of nonsubmerged implants: A retrospective study in 50 patients. Int J Oral Maxillofac Implants 2004;19:222–227.
87. Hallman M, Zetterqvist L. A 5-year prospective follow-up study of implant-supported fixed prostheses in patients subjected to maxillary sinus floor augmentation with an 80:20 mixture of bovine hydroxyapatite and autogenous bone. Clin Implant Dent Relat Res 2004;6:82–89.
88. Hatano N, Shimizu Y, Ooya K. A clinical long-term radiographic evaluation of graft height changes after maxillary sinus floor augmentation with 2:1 autogenous bone/xenograft mixture and simultaneous placement of dental implants. Clin Oral Implants Res 2004;15:339–345.
89. Lundgren S, Andersson S, Gualini F, Sennerby L. Bone reformation with sinus membrane elevation: A new surgical technique for maxillary sinus floor augmentation. Clin Implant Dent Relat Res 2004;6:165–173.
90. Shlomi B, Horowitz I, Kahn A, Dobriyan A, Chaushu G. The effect of sinus membrane perforation and repair with Lambone on the outcome of maxillary sinus floor augmentation: A radiographic assessment. Int J Oral Maxillofac Implants 2004;19:559–562.
91. Hallman M, Sennerby L, Zetterqvist L, Lundgren S. A 3-year prospective follow-up study of implant-supported fixed prostheses in patients subjected to maxillary sinus floor augmentation with an 80:20 mixture of deproteinized bovine bone and autogenous bone. Clinical, radiographic and resonance frequency analysis. Int J Oral Maxillofac Surg 2005;34:273–280.
92. Rodoni LR, Glauser R, Feloutzis A, Hämmerle CH. Implants in the posterior maxilla: A comparative clinical and radiologic study. Int J Oral Maxillofac Implants 2005;20:231–237.
93. Wiltfang J, Schultze-Mosgau S, Nkenke E, Thorwarth M, Neukam FW, Schlegel KA. Onlay augmentation versus sinus lift procedure in the treatment of the severely resorbed maxilla: A 5-year comparative longitudinal study. Int J Oral Maxillofac Surg 2005;34:885–889.

94. Mangano C, Scarano A, Iezzi G, et al. Maxillary sinus augmentation using an engineered porous hydroxyapatite: A clinical, histological, and transmission electron microscopy study in man. J Oral Implantol 2006;22:122–131.
95. Orsini G, Scarano A, Piattelli M, Piccirilli M, Caputi S, Piattelli A. Histologic and ultrastructural analysis of regenerated bone in maxillary sinus augmentation using a porcine bone-derived biomaterial. J Periodontol 2006;77:1984–1990.
96. Becktor J, Isaksson S, Sennerby L. Endosseous implants and bone augmentation in the partially dentate maxilla: An analysis of 17 patients with a follow-up of 29 to 101 months. Int J Oral Maxillofac Implants 2007;22:603–608.
97. Chen TW, Chang HS, Leung KW, Lai YL, Kao SY. Implant placement after the lateral approach of the trap door window procedure to create a maxillary sinus lift without bone grafting: A 2-year retrospective evaluation of 47 implants in 33 patients. J Oral Maxillofac Surg 2007;65:2324–2328.
98. Krennmair G, Krainhöfner M, Schmid-Schwap M, Piehslinger E. Maxillary sinus lift for single implant-supported restorations: A clinical study. Int J Oral Maxillofac Implants 2007;22:351–358.
99. Mangano C, Scarano A, Perrotti V, Iezzi G, Piattelli A. Maxillary sinus augmentation with a porous hydroxyapatite and bovine-derived hydroxyapatite: A comparative clinical and histologic study. Int J Oral Maxillofac Implants 2007;22:980–986.
100. Marchetti C, Pieri F, Trasarti S, Corinaldesi G, Degidi M. Impact of implant surface and grafting protocol on clinical outcomes of endosseous implants. Int J Oral Maxillofac Implants 2007;22:399–407.
101. Mardinger O, Nissan J, Chaushu G. Sinus floor augmentation with simultaneous implant placement in the severely atrophic maxilla: Technical problems and complications. J Periodontol 2007;78:1872–1877.
102. Thor A, Sennerby L, Hirsch JM, Rasmusson L. Bone formation at the maxillary sinus floor following simultaneous elevation of the mucosal lining and implant installation without graft material: An evaluation of 20 patients treated with 44 Astra Tech implants. J Oral Maxillofac Surg 2007;65(suppl 1):64–72.
103. Fugazzotto PA, De Paoli S. Sinus floor augmentation at the time of maxillary molar extraction: Success and failure rates of 137 implants in function for up to 3 years. J Periodontol 2002;73:39–44.
104. Winter AA, Pollack AS, Odrich RB. Placement of implants in the severely atrophic posterior maxilla using localized management of the sinus floor: A preliminary study. Int J Oral Maxillofac Implants 2002;17:687–695.
105. Brägger U, Gerber C, Joss A, et al. Patterns of tissue remodelling after placement of ITI dental implants using an osteotome technique: A longitudinal radiographic case cohort study. Clin Oral Implants Res 2004;15:158–166.
106. Deporter DA, Caudry S, Kermalli J, et al. Further data on the predictability of the indirect sinus elevation procedure used with short, sintered, porous-surfaced dental implants. Int J Periodontics Restorative Dent 2005;25:585–593.
107. Leblebicioglu B, Ersanli S, Karabuda C, Tosun T, Gokdeniz H. Radiographic evaluation of dental implants placed using an osteotome technique. J Periodontol 2005;76:385–390.
108. Ferrigno N, Laureti M, Fanali S. Dental implants placement in conjunction with osteotome sinus floor elevation: A 12-year life-table analysis from a prospective study on 588 ITI implants. Clin Oral Implants Res 2006;17:194–205.
109. Stavropoulos A, Karring T, Kostopoulos L. Fully vs. partially rough implants in maxillary sinus floor augmentation: A randomized-controlled clinical trial. Clin Oral Implants Res 2007;18:95–102.
110. Fermergård R, Åstrand P. Osteotome sinus floor elevation and simultaneous placement of implants—A 1-year retrospective study with Astra Tech implants. Clin Implant Dent Relat Res 2008;10:62–69.
111. Hämmerle CHF, Jung RE, Feloutzis A. A systematic review of the survival of implants in bone sites augmented with barrier membranes (guided bone regeneration) in partially edentulous patients. J Clin Periodontol 2002;29:226–231.
112. Dahlin C, Andersson L, Linde A. Bone augmentation at fenestrated implants by an osteopromotive membrane technique. A controlled clinical study. Clin Oral Implants Res 1991;2:159–165.
113. Gielkens PFM, Bos RRM, Raghoebar GM, Stegenga B. Is there evidence that barrier membranes prevent bone resorption in autologous bone grafts during the healing period? A systematic review. Int J Oral Maxillofac Implants 2007;22:390–398.
114. Adeyemo WL, Reuther T, Bloch W, et al. Healing of onlay mandibular bone grafts covered with collagen membrane or bovine bone substitutes: A microscopic and immunohistochemical study in the sheep. Int J Oral Maxillofac Surg 2008;37:651–659.
115. Albrektsson T, Zarb G, Worthington PMD, Eriksson AR. The long term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.
116. Burchardt H. The biology of bone graft repair. Clin Orthop Relat Res 1983;174:28–42.
117. Nkenke N, Schlegel A, Schultze-Mosgau S, Neukam F, Wiltfang J. The endoscopically controlled osteotome sinus floor elevation: A preliminary prospective study. Int J Oral Maxillofac Implants 2002;17:557–566.