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Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants

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Abstract

Objectives: To analyze publications related to augmentation procedures and to evaluate the success of different surgical techniques for ridge reconstruction and the survival/success rates of implants placed in the augmented areas.

Material and methods: Clinical investigations published in English involving at least 5 patients and with a minimum follow-up of 6 months were included. The following procedures were considered: a) Guided bone regeneration (GBR); 2) Onlay bone grafts; 3) Inlay grafts; 4) Bone splitting for ridge expansion (RE); 5) Distraction osteogenesis (DO); and 6) Revascularized flaps. Success rates of augmentation procedures and related morbidity, as well as survival and success rates of implants placed in the augmented sites were analyzed.

Results: Success rates of surgical procedures ranged from 60% to 100% for GBR, from 92% to 100% for onlay bone grafts, from 98% to 100% for ridge expansion techniques, from 96,7% to 100% for DO, and was 87.5% for revascularized flaps, whereas survival rates of implants ranged from 92% to 100% for GBR, from 60% to 100% for onlay bone grafts, from 91% to 97.3% for RE, from 90.4% to 100% for DO, and, finally, was 88.2% for revascularized flaps.

Conclusion: On the basis of available data it was shown that it was difficult to demonstrate that a particular surgical procedure offered better outcome as compared to another. The main limit encountered in this review has been the overall poor methodological quality of the published articles. Therefore larger well-designed long term trials are needed.

Dental rehabilitation of partially or totally edentulous patients with oral implants has become common practice in the last decades, with reliable long-term results (Albrektsson et al. 1986; van Steenberghe et al. 1989, 1990; Lindquist et al. 1996; Buser et al. 1997; Arvidson et al. 1998; Lekholm et al. 1999a; Weber et al. 2000; Leonhardt et al. 2002). However, unfavorable local conditions of the alveolar ridge, due to atrophy, periodontal disease and trauma sequelae, may provide insufficient bone volume or unfavorable vertical, transverse, and sagittal interarch relationship, which may render implant placement impossible or incorrect from a functional and esthetic viewpoint.

Five main methods have been described to augment the local bone volume of deficient sites: (a) osteoinduction by the use of appropriate growth factors (Urist 1965; Reddi et al. 1987); (b) osteoconduction where a grafting material serves as a scaffold for new bone formation (Burchardt 1983; Reddi et al. 1987); (c) distraction osteogenesis (DO), by which a fracture is

surgically induced and the two bone fragments are then slowly pulled apart (Ilizarov 1989a, 1989b); (d) guided bone regeneration (GBR), which allows spaces maintained by barrier membranes to be filled with bone (Dahlin et al. 1988, 1989, 1991; Kostopoulos & Karring 1994; Kostopoulos et al. 1994; Nyman & Lang 1994; Hämmerle et al. 1996, 2002); and (e) revascularized bone grafts, where a vital bone segment is transferred to its recipient bed with its vascular pedicle, thus permitting immediate survival of the bone and no need of a remodeling/substitution process (Taylor 1982; Soutar & McGregor 1986; Swartz et al. 1986; Hidalgo 1989).

While osteoinduction with growth factors such as bone morphogenetic proteins (BMPs) is still in an experimental phase, inlay or onlay bone grafts, GBR, bone splitting for ridge expansion, and alveolar DO represent commonly applied methods to recreate correct intermaxillary relationship and adequate bone morphology and volume for implant placement. Yet, despite an increasing number of publications related to the correction of deficient edentulous ridges, much controversy still exists as far as the choice of the more suitable and reliable technique is concerned. This is frequently because the publications are of insufficient methodological quality (insufficient follow-up, inadequate sample size, absence of randomization, lack of well-defined exclusion and inclusion criteria, lack of well-defined success criteria, etc.).

The objective of this review was to analyze publications related to augmentation procedures and to evaluate: (a) the success of different surgical techniques for the reconstruction of the deficient alveolar bone and (b) the survival/success rates of implants placed in the reconstructed areas.

Criteria for considering studies for this review

Types of studies

The basis of this review was represented by the systematic reviews published by Hämmerle et al. (2002) and Esposito et al. (2006). To expand these reviews and not to limit the literature search to randomized clinical trials, any clinical investigation published in English language involving more than five consecutively treated patients and with a minimum follow-up of 6 months after the start of prosthetic loading were included. Publications in which the same data were reported in later publications by the same groups of authors were not considered.

Types of participants

Only patients presenting with deficient edentulous ridges following atrophy, periodontal disease, and trauma have been taken into consideration. Patients affected by bone defects following ablation for tumors or osteoradionecrosis as well as bone defects related to congenital malformations (such as cleft lip and palate or major craniofacial malformations) were excluded from this analysis, because the initial clinical situation is very different and not comparable to defects following atrophy, periodontal disease, or trauma).

Types of interventions

Only articles related to endosseous root-form titanium implants were considered. The following surgical procedures were considered: (1) GBR; (2) onlay bone grafts; (3) inlay grafts (sinus floor elevation, nasal lift, mandibular inlay grafts, Le Fort I osteotomy with interpositional grafts); (4) bone splitting for ridge expansion; (5) DO; and (6) revascularized flaps.

Outcome measures

Success rates of augmentation procedures and related morbidity, as well as survival and success rates of implants placed in the augmented sites were analyzed.

Search method

Full-text articles published in English were found with a computerized search by key words (Medline) from 1966 to 2005. Key words used in the search included the following: atrophy, alveolar bone loss, mandible, maxilla, edentulous jaw, edentulous maxilla, edentulous mandible, preprosthetic surgery, oral surgical procedure, alveolar ridge augmentation, oral implant, osseointegrated implant, dental, endosteal, endosseous, dental implantation, implant-supported, dental prosthesis, implant-supported dental prosthesis, guided bone regeneration, guided tissue regeneration, bone transplantation, graft, bone graft, onlay bone graft, calvarium, iliac crest, ilium, distraction osteogenesis, expansion, Le Fort I, maxillary sinus, sinus lift, sinus floor elevation, oral sagittal osteotomy, split crest, ridge expansion, humans, follow-up study, retrospective study, prospective study, comparative study, randomized clinical trials, free flap, revascularized free flap, fibula, iliac free flap, morbidity, donor, distraction osteogenesis, alveolar distraction osteogenesis, inlay bone graft, allograft, xenografts, and alloplastic.

To expand this, a manual search of journal issues from 1966 through 2005 was undertaken on the following journals: *Clinical Oral Implants Research, The International Journal of Oral & Maxillofacial Implants, Journal of Oral and Maxillofacial Surgery, International Journal of Oral and Maxillofacial Surgery, Journal of Cranio-Maxillo-Facial Surgery, Journal of Prosthetic Dentistry, Scandinavian Journal of Plastic and Reconstructive Surgery, Dental Clinics of North America, Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics, Clinical Implant Dentistry and Related Research, British Journal of Oral and Maxillofacial Surgery, International Journal of Periodontics and Restorative Dentistry, Journal of Periodontology, European Journal of Prosthodontics and Restorative Dentistry, Journal of Oral Surgery, and Plastic Reconstructive Surgery*.

Other articles were identified from the reference lists of the articles found.

Selection criteria and data extraction

The titles and abstracts (when available) of all reports identified were analyzed by the first author of this review. For studies appearing to meet the inclusion criteria, or for which there were sufficient data in the title and the abstract to make a clear decision, the full report was obtained. Data obtained were recorded on flow sheets including: (a) year of publication; (b) type of study; (c) details of participants including criteria of inclusion/exclusion; (d) details of the type of intervention; and (e) details of the outcomes reported.

GBR

Patients and methods

Only articles related to horizontal and vertical GBR have been analyzed, whereas bone regeneration around implants placed

Table 1. **Guided bone regeneration (GBR) – characteristics of included studies**

Author and year	Study type	No. pts	Defect site	Type defect	Membrane	Grafting material	GBR succ %	No. implants (timing)	Follow-up (months)	Imp surv %	Imp succ %
Dahlin et al. (1991)	RCT	7	Max	Hor/FE	e-PTFE	None	100	7 (imm)	24	100	ND
Buser et al. (1996)	RCS	9	Max/mand	Hor	e-PTFE	BC	67	12 (del)	60	100	ND
Nevins et al. (1998)	RMCS	352	Max/mand	Hor/DE	e-PTFE	AB FDBA DFDBA	ND	526 (imm/del)	6–74	ND	97.5
Mayfield et al. (1998)	PCCT	7	Max	DE-FE	PL PG	None	ND	21 (imm)	24–30	100	ND
von Arx et al. (1998)	RCS	18	ND	Hor/vert	TB	AB	ND	27 (del)	12–36	100	100
Becker et al. (1999)	PMCS	26	ND	PO DE-FE	ND	ND	ND	33 (imm/del)	12–60	76.8–83.8	ND
Chiapasco et al. (1999)	PCCS	15	Max/mand	Hor	e-PTFE	AB	87	30 (del)	18–36	100	93.3
Lorenzoni et al. (1999)	RCT	59	Max/mand	Hor/vert	e-PTFE	AB	ND	85 (imm)	12–24	100	100
Brunel et al. (2001)	RCS	14	Max/mand	Hor PO	COL	HA	ND	14 (del)	12–84	100	86
Simion et al. (2001)	RMCS	49	Max/mand	Vert	e-PTFE	BC AB DFDBA	82	123 (imm/del)	12–60	99.2	97.5
Zitzmann et al. (2001)	RCT	75	ND	ND	e-PTFE COL	BBM	ND	265 (imm)	55–70	92.6–97.3	ND
Buser et al. (2002)	RCS	40	Max/mand	Hor	e-PTFE	AB	97.5	61 (del)	12–60	100	98.3
Lorenzoni et al. (2002)	RMCS	41	Max/mand	Hor/vert	e-PTFE PL-PG	AB	ND	72 (imm)	36–60	100	ND
Christensen et al. (2003)	PCCT	45	Max/mand	Hor	e-PTFE PL-COL	BBM-AB None	ND	55 (imm/del)	12–24	100	ND
van Steenberghe et al. (2003)	RCS	10	Max	Hor/vert	TB	None	60	39 (del)	9–84	92	ND
Chiapasco et al. (2004a, 2004b)	RCT	11	Max/mand	Vert	e-PTFE	AB	73	25 (imm/del)	18–48	100	61.5–75
Fugazzotto (2005)	RCS	319	Max/mand	Hor/vert	e-PTFE	DFDBA TCP	78	607 (imm)	68–133	ND	97.3–97.4
Total		1097						2002			

RCS, retrospective case series; PCS, prospective clinical series; PCCS, prospective comparative clinical series; RMCS, retrospective multicenter clinical series; PCCT, prospective controlled clinical trial; RCT, randomized clinical trial; no. pts, number of patients treated; max, maxilla; mand, mandible; hor, horizontal defect; vert, vertical defect; AB, autogenous bone; BC, blood clot; BBM, bovine bone mineral; TCP, tricalcium-phosphate; FDBA, freeze-dried bone allograft; DFDBA, demineralized freeze-dried bone allograft; HA, hydroxylapatite; polylac, polylactic acid membrane; polyglyc, polyglycolic acid membrane; TB, titanium barrier; GBR succ, success rate of the GBR procedure; imm, immediate placement; del, delayed placement; PL, polylactic; PG, polyglycolic; COL, collagen; DE-FE, dehiscence/fenestration; PO, post-extraction socket; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

in post-extractive sockets to close the bone-implant gap, as well as bone regeneration around implants presenting with defects following peri-implantitis, have not been reported in this review, because they were not considered a 'true' augmentation procedure.

The search provided 376 articles, of which 112 were screened as full text. Among these, 17 publications were included (Table 1). The number of patients presenting with horizontal and/or vertical defects treated with GBR was 1097. Both non-resorbable and resorbable membranes were used. Bone regeneration was obtained either by membranes alone, or with the aid of various grafting materials, such as autogenous bone (AB), demineralized or mineralized freeze-dried bone allografts (DFDBA, FDBA), hydroxylapatite (HA), bovine bone mineral (BBM), tri-calcium-phosphate (TCP), or mixtures of different materials. However, it was often impossible to obtain separate data according to different grafting materials (see Table 1 for details). Although it was not always possible to differentiate bone regeneration according to type of initial defect, because some publications reported a combination of defects without specifying the distribution, the majority of bone augmentation procedures were related to fenestrations, dehiscences, and localized horizontal defects. Only 70 patients were treated for true vertical defects.

A total of 2002 implants were placed: of these, 1057 were inserted in conjunction with the bone augmentation procedure, and 183 in a second stage. For 762 implants, it was not possible to separate immediate and delayed placement. Patients were rehabilitated with both fixed and removable implant-supported prostheses. Prosthetic rehabilitation was started on average 6 months after implant placement (range: 3–13 months). Follow-up after the start of prosthetic loading of implants ranged from 6 to 133 months (Table 1).

Results

The overall success rate of the regenerative procedures with resorbable and non-resorbable membranes (including titanium meshes) ranged from 67% to 100%. However, it is worth noting that only eight out of 17 articles reported data on the clinical outcome of the regenerative procedure, whereas the other articles reported only data regarding the survival rates of implants (see Table 1).

For vertical GBR, bone augmentation ranged from 2 to 7 mm, and from 2 to 4.5 mm for horizontal GBR. However, it must be underlined that only a few articles reported data of bone gain obtained after surgery (Chiapasco et al. 1999, 2004a; Simion et al. 2001; Buser et al. 2002).

As far as non-resorbable (expanded polytetrafluoroethylene (e-PTFE)) membranes are concerned, the success rate ranged from 60% to 97.5% (887 patients treated). Conversely, it was difficult or impossible to retrieve these data as far as resorbable membranes (200 patients treated) are concerned (see Table 1).

Failures of GBR were mainly related to membrane exposure, which may lead to infection and eventually to partial or total loss of the regenerated tissue. The survival rate of implants placed in the augmented sites varied between 76.8% and 100%, with the majority of studies indicating more than 90% survival after at least 1 year of function, with no significant differences between GBR with resorbable or non-resorbable membranes (including titanium meshes). However, no conclusions can be drawn either because some articles (Zitzmann et al. 2001; Lorenzoni et al. 2002; Christensen et al. 2003) did not separate implant failures according to type of membrane or because the number of patients of the two groups was very different (the sample of patients treated with non-resorbable membranes was approximately seven times higher than the sample of patients treated with resorbable membranes).

For obtaining more information, survival rates of implants according to (a) type of GBR (horizontal or vertical); (b) type of membrane; and (c) type of graft (autogenous or non-autogenous) were analyzed. However, this analysis was limited by the fact that not always publications separated data concerning these issues. In 512 out of 1097 patients, it was not specified whether defects were horizontal or vertical.

The overall survival rate of implants placed in horizontally augmented sites (fenestrations and dehiscences with immediate implants, horizontal augmentation with delayed implant placement) was 98% (range: 76.8–100%) (see Table 1 for details).

Success rates ranged from 86% to 98.3%; however, only four articles reported well-defined success criteria (Nevins et al. 1998; Chiapasco et al. 1999; Brunel et al. 2001; Buser et al. 2002).

The overall survival rate of implants placed in sites augmented with vertical GBR was 99.3% (range: 99–100%), whereas the overall success rate of implants according to well-defined criteria was 92.6% (range: 61.5–97.5%) (see Table 1 for references).

Survival rates of implants placed in augmented sites with resorbable membranes ranged from 95% to 100%, while the success rate was 91%, but it was reported only in one article (Brunel et al. 2001). Survival of implants placed in augmented sites with non-resorbable barriers ranged from 92% to 100%, while success rates ranged from 61.5% to 100% (Table 1).

In two articles (Lorenzoni et al. 2002; Christensen et al. 2003), in which both resorbable and non-resorbable membranes were used, it was not possible to separate data.

It was difficult to correlate the survival/success rate of implants with the type of grafting materials used in association with membranes, because different materials or their mixtures were frequently used in the same article. It was also difficult to compare the clinical outcomes because: (a) the range of initial defects was extremely wide; (b) many authors did not separate outcomes of patients treated with resorbable and non-resorbable membranes; and (c) there is a paucity of comparative, controlled, split-mouth studies comparing different grafting materials and different membranes (see Table 1).

Discussion

Data reported in the literature seem to demonstrate that GBR procedures are a reliable means for augmenting bone in case of vertical and/or horizontal defects of partially edentulous patients. Survival rates of implants placed in the augmented areas with GBR are similar to those reported for implants placed into sites not necessitating bone augmentation procedures (Albrektsson et al. 1986; van Steenberghe et al. 1989, 1990; Adell et al. 1990a; Lekholm et al. 1994, 1999a; Lindquist et al. 1996; Buser et al. 1997; Arvidson et al. 1998; Weber et al. 2000; Leonhardt et al. 2002).

However, the analysis of available publications demonstrated, on average, a poor methodological quality, in particular with regard to: (a) stability over time of the augmented bone according to type of regeneration (vertical and horizontal); (b) implant outcome according to well-defined success criteria; and (c) well-defined indications for GBR procedures (in particular in case of limited defects). Therefore, the following issues should need a more accurate evaluation in future publications. Out of 17 publications included in this review, only four were randomized clinical trials, while the majority of the remaining articles were represented by prospective (4) or retrospective (9) clinical series.

Stability over time of the augmented bone

GBR techniques should be ideally evaluated not only as far as the outcome of implants placed in the augmented bone is concerned but also with regard to stability over time of the augmented bone. For vertical GBR, peri-implant bone resorption is a good means for this evaluation. Retrieved data from two publications (Simion et al. 2001; Chiapasco et al. 2004a) demonstrated an acceptable stability over time of the augmentation obtained after GBR (1–2.9 mm peri-implant bone resorption, after a follow-up ranging from 1 to 7 years).

Conversely, with regard to horizontal augmentation, peri-implant bone resorption is a valuable means to evaluate the success rate of implants placed in the regenerated areas, but it may not give information concerning modifications of the horizontal bone augmentation. In fact, conventional radiographs do not provide any direct measurement of this parameter. This also means that the total loss of the regenerated tissue cannot be detected with panoramic or intraoral radiographs. Unfortunately, the majority of studies analyzed in this review reported only vertical peri-implant bone resorption, but no data on horizontal resorption (Dahlin et al. 1991; Buser et al. 1996; Mayfield et al. 1998; Becker et al. 1999; Lorenzoni et al. 1999, 2002; Zitzmann et al. 2001; Christensen et al. 2003). Only one study evaluated the stability over time of the horizontal augmentation obtained with GBR (Chiapasco et al. 1999). It was demonstrated that the initial bone gain undergoes contraction over time (40% of the initial bone gain). These results have also been reported in experimental studies. Rasmusson et al. (1999) demonstrated, on a rabbit model, that the bone volume obtained at the end of GBR procedures showed extensive resorption after membrane removal, with a rate

similar to that reported in case of bone grafts without membranes. Therefore, it should be recommendable to evaluate long-term stability of the regenerated tissue with computed tomography (CT) scans or, to avoid the high biologic costs of CT, with simpler methods such as surgical calipers, as already suggested by some authors (Chiapasco et al. 1999).

Success rates of implants

While survival rates of implants placed in augmented sites with GBR techniques are reported in all the retrieved articles, only nine out of 17 articles reported well-defined success criteria. This may represent a limit in evaluating the reliability of GBR techniques, because a high survival rate may not correspond to a high success rate (i.e. an implant can remain stable and osseointegrated even if the total amount of regenerated tissue has been resorbed sometime after the GBR procedure).

Indications for GBR procedures

The necessity of using membranes to obtain adequate peri-implant coverage in case of limited horizontal/vertical defects is still questionable. Only two studies that provided internal controlled data were identified in this review (Mayfield et al. 1998; Zitzmann et al. 2001). It was demonstrated that survival and success rates for implants placed in regenerated bone were not significantly different from those of implants placed in native non-regenerated bone. One may assume that moderate resorption of the alveolar crest, which can reduce only partially the bone to implant contact, will not necessarily lead to implant failure or to a worse performance regarding function and esthetics of that particular implant. Therefore, questions that should be addressed should be how much exposed implant surface should be considered the limit to avoid osseointegration jeopardy (Hämmerle et al. 2002).

Implant placement timing

Another aspect that should be analyzed is the timing of implant placement. The review of the literature showed that both placement of implants in conjunction with the GBR procedure or after the consolidation of the augmented bone have been used. However, no clear indications regarding the choice between these two approaches have been defined. Only one prospective, cohort study (Christensen et al. 2003) evaluated this topic. It was concluded that a staged approach may have a lower risk for greater amount of crestal bone loss as compared with a simultaneous approach, although no differences in treatment outcome were seen between the groups who received implants either simultaneously or with a staged approach.

Choice of grafting material

Successful outcome of GBR procedures and implants placed in the augmented area was obtained with a wide range of filling materials, such as blood clot, AB, allografts, xenografts and/or alloplastic materials, and HA. However, no conclusive recommendations can be given to clinicians due to the paucity of controlled comparative studies using different materials. Only one study (Christensen et al. 2003) reported data on GBR procedures with the use of AB or BBM as filling material. The authors concluded that the use of autogenous and non-autogenous filling materials yielded a similar outcome. However, as the quantity of initial available bone before the augmentation procedure is very rarely specified, it is difficult to assert whether the success of implants relies on the augmented tissue or on the residual native bone.

Choice of membrane

Successful outcome has been obtained with both resorbable and non-resorbable membranes. However, it must be underlined that quite frequently different membranes were used in the same studies without correlating success rate according to the type of membrane. It is therefore difficult to draw any significant conclusion as far as a correlation between type of membrane and success rate is concerned. Only one article (Christensen et al. 2003), in a prospective, comparative, cohort study, reported outcomes of bioresorbable and non-resorbable membranes, and concluded that no significant differences were found between the two. Yet, these results should be interpreted with caution, because they are related to small initial defects, such as fenestrations and dehiscences. These conclusions might be not applicable to large defects (in particular in case of vertical GBR).

Autogenous onlay bone grafts

Patients and methods

The search provided 305 studies, of which 117 were screened as full text. Of these publications, only 29 were included (see Table 2).

Overall, 875 patients presenting with alveolar defects of the jaws, which did not allow the placement of implants of adequate dimensions and/or in a correct position from a functional and esthetic viewpoint, were treated by means of AB grafts taken from intraoral or extraoral sites. One hundred and ninety-eight defects were localized in the mandible and 593 in the maxilla. Owing to insufficient data, it was not possible to attribute the location of atrophy to 99 defects. The number of defects and grafts does not correspond to the number of patients because in some cases bilateral defects as well as defects involving both the maxilla and mandible were present in the same patient. One hundred and forty-seven grafts were harvested from intraoral sites (mental symphisis and/or mandibular body/ramus), 44 from the calvarium, 700 from the iliac crest, and 10 from non-specified donor sites. The harvested bone was used as a block in the majority of cases. Particulated bone was associated with bone blocks in case of simultaneous sinus grafting procedures or as a filling material around/between bone blocks. The bone was used alone in 814 patients, or mixed with allografts or alloplastic materials (HA, TCP) in 61 patients. Of these defects, 300 had limited extension (one to four teeth missing, on average) and 628 were extended (subtotal or total edentulism of one or both jaws). A total of 4445 implants were placed: of these, 415 were placed in reconstructed mandibles, 2547 in reconstructed maxillae, while for 1483 implants it was not possible to determine the site of placement (publications reporting both mandibular and maxillary reconstructions). Out of 4445 implants, 2229 were placed at the same time of reconstruction, and 1573 implants were inserted on average 4–6 months after the reconstructive procedure (once consolidation of the graft occurred). For the remaining 643 implants, it was not possible to determine the timing of insertion.

Patients were rehabilitated with both fixed and removable implant-supported

prostheses. Prosthetic rehabilitation was started on average 5–6 months (range: 3–26 months) after implant placement. Early loading (2 months after implant placement) of implants placed in the reconstructed areas has been reported in one publication (Raghoebar et al. 2003). Immediate loading of implants placed in reconstructed jaws has been described in one publication (Chiapasco et al. 2006a). Follow-up of patients after the start of prosthetic loading of implants ranged from 6 to 144 months (Table 2).

Results

Postoperative morbidity related to bone harvesting from intraoral sites was mainly represented by temporary neural disturbances involving branches of the inferior alveolar nerve. In particular, neural disturbances related to bone harvesting from the

Table 2. **Onlay bone grafts (maxilla and mandible) – characteristics of included studies**

Author and year	Study type	No. pts	Defect site (type of atr)	Donor site	Graft succ %	No. implants (timing)	Follow-up (months)	Imp surv %	Imp succ %
Adell et al. (1990a, 1990b)	RCS	23	Maxilla (hor–vert)	Ilium	ND	124 (imm)	12–120	73.8	ND
Jensen & Sindet-Pedersen (1991)	RCS	15	Maxilla (hor–vert)	Ilium/chin	ND	74 (imm)	6–26	90.2–92.3	ND
Lew et al. (1991)	RCS	9	Mandible (hor–vert)	Ilium	100	39 (imm)	12–36	93	ND
Isaksson & Alberius (1992)	RCS	8	Maxilla (hor–vert)	Ilium	100	46 (imm)	32–64	87	ND
Donovan et al. (1994)	RCS	24	Max + mand (hor–vert)	Calvarium	100	43 (imm) 50 (del)	6–45	86–98	ND
Keller (1995)	RCS	9	Mandible (hor–vert)	Ilium	ND	43 (imm)	8–72	91.7	ND
McGrath et al. (1996)	RCS	18	Mandible (hor–vert)	Ilium	100	36 (imm)	12–32	91.6	91.6
Åstrand et al. (1996)	RCS	17	Maxilla (hor–vert)	Ilium	100	92 (imm)	36–60	75	ND
Vermeeren et al. (1996)	RCS	31	Mandible (hor–vert)	Ilium	100	78 (imm)	12–60	90	ND
Triplett & Schow (1996)	RCS	99	Max + mand (hor–vert)	Ilium/calvarium/ chin	90–100	65 (imm) 154 (del)	12	ND	90.7
Schliephake et al. (1997)	RCS	137	Max + mand (hor–vert)	Ilium/chin	ND	550 (imm) 321 (del)	12–120	83.4 (1 year) 67.8 (5 years)	ND
Neyt et al. (1997)	RCS	17	Maxilla (hor–vert)	Ilium	ND	123 (del)	6	97.5	92.7
van Steenberghe et al. (1997)	RCS	13	Maxilla (hor–vert)	Ilium	92	72 (imm)	12–120	ND	85
Verhoeven et al. (1997)	PCS	13	Mandible (hor–vert)	Ilium	92	30 (imm)	6–36	100	ND
Lundgren et al. (1997)	RCS	10	Maxilla (hor–vert)	Ilium	ND	70 (del)	12–32	80	ND
Widmark et al. (1998)	PCS	16	Maxilla (hor–vert)	Ilium	ND	81 (imm) 20 (del)	12	83	83
Keller et al. (1999a, 1999b)	RCS	32	Maxilla (hor–vert)	Ilium/calvarium	96	183 (imm) 21 (del)	7–144	86.3	ND
Chiapasco et al. (1999)	PCCT	15	Max + mand (hor)	Ilium/calvarium/ chin	100	44 (del)	18–36	100	90.9
Lekholm et al. (1999a, 1999b)	RMCS	56	Maxilla (hor–vert)	Intraoral/ilium	ND	181 (imm) 75 (del)	36	60–84	ND
Raghoebar et al. (2000)	RCS	7	Mandible	Chin + ramus	100	18 (del)	14–68	100	95
Bahat & Fontanessi (2001)	RCS	62	Max + mand	Ilium/ramus allograft	92	21 (imm) 310 (del)	12–96	93	93
Bell et al. (2002)	RCS	14	Mandible	Ilium	100	70 (del)	24–48	100	ND
Becktor et al. (2002)	RCS	90	Maxilla (hor–vert)	Ilium	ND	643 (imm/del)	22–105	71.6	ND
Raghoebar et al. (2003)	PCS	10	Maxilla (hor–vert)	Ilium	100	68 (del)	12	95.6	95.6
Jemt & Lekholm (2003)	PCS	10	Maxilla	Chin	100	10 (del)	24	100	100
Becktor et al. (2004)	RCS	64	Maxilla (hor–vert)	Ilium	ND	260 (imm) 177 (del)	27–100	75.1	ND
Iizuka et al. (2004)	RCS	13	Max + mand (hor–vert)	Calvarium	100	42 (del)	6–42	100	97.6
Nyström et al. (2004)	RCS	30	Maxilla (hor–vert)	Ilium	ND	177 (imm)	36–60	72.8–82.5	ND
van der Meij et al. (2005)	RCS	13	Mandible	Ilium + HA	92	34 (imm)	6–90	88.2	88.2
Total		875				4445			

RCS, retrospective case series; PCS, prospective clinical series; RMCS, retrospective multicenter clinical series; PCCT, prospective controlled clinical trial; RCT, randomized clinical trial; no. pts, number of patients treated; type of atr, type of atrophy; max, maxilla; mand, mandible; hor, horizontal defect; vert, vertical defect; TCP, tricalcium-phosphate; FDBA, freeze-dried bone allograft; HA, hydroxylapatite; graft succ, success rate of the grafting procedure; imm, immediate placement; del, delayed placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

chin ranged from 10% to 50% (Chiapasco et al. 1999; Nkenke et al. 2001; Raghoebar et al. 2001b; Clavero & Lundgren 2003), whereas those related to bone harvesting from the mandibular ramus ranged from 0% to 5% (Chiapasco et al. 1999; Nkenke et al. 2001; Clavero & Lundgren 2003). For this reason, chin grafts should be considered with more caution, whereas the mandibular ramus is gaining more and more popularity due to its advantages as compared with the mental symphisis: the quality of bone is similar, the quantity may be higher, and the risk of neural damages lower.

In case of bone harvesting from the iliac crest, temporary pain/gait disturbances were the most frequent complaints, but only 13 out of 25 articles dealing with iliac grafts reported data on this topic. Long-standing pain/gait disturbances were reported only in 2% of the cases (Adell et al. 1990b; Jensen & Sindet-Pedersen 1991; Lew et al. 1991; Isaksson & Alberius 1992; Keller 1995; Åstrand et al. 1996; Vermeeren et al. 1996; Lundgren et al. 1997; Neyt et al. 1997; van Steenberghe et al. 1997; Chiapasco et al. 1999; Raghoebar et al. 2000; Bell et al. 2002).

In case of bone harvesting from the calvarium, morbidity was extremely low (0% in the reviewed articles), but only three out of five articles dealing with calvarial grafts reported pertinent data (Donovan et al. 1994; Chiapasco et al. 1999; Iizuka et al. 2004).

An uneventful healing/consolidation of both intraoral and extraoral grafts occurred in the majority of patients (range: 90–100%). Partial loss of the graft, due to wound dehiscence/infection, occurred in 3.3% of the cases, while total loss of the graft occurred in 1.4% of the cases (Triplett & Schow 1996; van Steenberghe et al. 1997), and the majority were related to extensive reconstructions of atrophic maxillae with iliac grafts. However, it is worth noting that only 18 out of 29 articles reported data on this topic.

Overall, the survival rate of implants placed in reconstructed maxillae and mandibles ranged from 60% to 100% (mean: 87%). The majority of articles reported survival rates >90%.

For obtaining more information, the survival rates of implants according to (a) site of atrophy (maxilla or mandible); (b) timing of implant placement (in conjunction with the reconstructive procedure or after the consolidation of the graft); and (c) type of graft (intraoral, calvarial, iliac) were analyzed. However, this analysis was limited by the fact that not always publications separated data concerning these issues.

The overall survival rate of implants placed in reconstructed maxillae (both with a one-stage and a two-stage placement) was 81.7% (range: 60–100%) (follow-up: 6–120 months).

The mean survival rate of implants placed in conjunction with maxillary reconstructions was 79.3% (range: 72.8–92.3%). However, it was possible to retrieve pertinent data only from six out of 14 articles (Adell et al. 1990b; Jensen & Sindet-Pedersen 1991; Isaksson & Alberius 1992; Åstrand et al. 1996; van Steenberghe et al. 1997; Nyström et al. 2004). Other articles reported failure of implants, but did not separate maxillary from mandibular implants and/or immediate and delayed implant placement.

The mean survival rate of implants placed in reconstructed maxillae with a staged approach was 93.4% (range: 80–100%). However, it was possible to retrieve pertinent data only from four out of 15 articles (Lundgren et al. 1997; Neyt et al. 1997; Jemt & Lekholm 2003; Raghoebar et al. 2003).

The overall survival rate of implants placed in reconstructed mandibles (both with a one-stage and a two-stage placement) was 94.5% (range: 88.2–100%) (follow-up: 6–120 months) (see Table 2 for details).

The survival rate of implants was 92.7% (range: 88.2–100%) for those placed in conjunction with mandibular reconstruction, and 100% for those placed in a staged approach. All implant losses occurred in patients receiving implants at the same time of reconstruction (see Table 2 for details).

As far as the relationship between survival rate and donor site is concerned, the retrieved data demonstrated that the majority of implant failures occurred in patients reconstructed with iliac grafts (failure rate: 17.5%). The failure rate for implants placed in calvarial grafts was 5.1% and that for implants placed in intraoral grafts was 2.9% (see Table 2).

However, it is worth noting that these percentages should be evaluated with caution, because some publications in which different donor sites were used did not separate implant failures according to donor site distribution.

Even more insufficient data were found as far as the success rate of implants according to well-defined criteria is concerned: only 12 out of 29 publications specified the criteria for implant success evaluation (see Table 2). The success rate ranged from 83% to 100%, with the majority of articles reporting success rates >90%, but it is worth noting that the number of implants reported in the over-mentioned publications represented only one-fourth of the total number of implants placed in the grafted jaws (Table 2).

Discussion

The analysis of available publications demonstrated, on average, a poor methodological quality with regard to: (a) bone resorption pattern of the grafted bone; (b) timing of implant placement; (c) success criteria of implants according to well-defined criteria; (d) success rate of implants according to type of graft and implant location; and (e) completeness of follow-up. Out of 29 publications included in this review, 24 were retrospective clinical series, and five prospective studies, but no randomized clinical trials, were found.

However, within the limits determined by the lack of these data, some considerations can be drawn on the following topics.

Bone resorption pattern of the grafted bone

In the past and before the advent of osseointegrated implants, the reconstruction of atrophic edentulous ridges with onlay bone grafts has been criticized because of the relevant resorption that followed prosthetic loading (Shelton 1977). However, it is worth noting that these results were mainly due to the use of completely removable dentures, which adversely affected not only the grafted jaws but also the non-grafted edentulous ridges (Cawood & Howell 1988). The use of onlay grafts has been re-evaluated after the advent of osseointegrated screw-type implants, which seem to inhibit bone resorption of the residual as well as of the transplanted bone, as demonstrated by a number of publications (Adell et al. 1990b; Lew

et al. 1991; Isaksson & Alberius 1992; Donovan et al. 1994; Lundgren et al. 1997; Nyström et al. 1997, 2004; Schliephake et al. 1997; van Steenberghe et al. 1997; Chiapasco et al. 1999; Lekholm et al. 1999b; Becktor et al. 2002, 2004; Jemt & Lekholm 2003). However, the capacity of bone grafts in maintaining the original bone volume is variable, and results reported in the literature contradictory, due to relevant differences in observation periods, type and site of reconstruction, timing of implant loading, use or non-use of provisional dentures on reconstructed sites, and, last but not the least, the site of bone harvesting. On average, there is a paucity of information as far as bone resorption of grafts is concerned. This is because many papers reported only survival rates of implants placed in grafts, with no measurement of modifications of graft dimensions, in particular as far as horizontal bone resorption is concerned.

As far as vertical bone resorption of onlay grafts is concerned, the following considerations can be drawn, despite the limits caused by the paucity of available data:

(a) Bone resorption is higher in the first year after the reconstruction and in the first year post-loading of implants, with a significant reduction in the following years (Verhoeven et al. 2000).
(b) Relevant differences in bone resorption were found according to donor sites. In case of iliac grafts, resorption rates of the initial graft height, 1–5 years post-loading of implants, ranged from 12% to 60% (Adell et al. 1990b; Åstrand et al. 1996; Vermeeren et al. 1996; Lundgren et al. 1997; Schliephake et al. 1997; Verhoeven et al. 1997; Widmark et al. 1998; Lekholm et al. 1999b; Nyström et al. 2004; van der Meij et al. 2005). In case of intraoral grafts, there are insufficient data to draw any meaningful conclusion. The best results were found in case of vertical reconstruction with calvarial grafts, where resorption rates ranged from 0% to 15% of the initial graft height (Donovan et al. 1994; Iizuka et al. 2004; Chiapasco et al. 2006a). This seems to indicate that cortical thickness and density of donor bone are factors that might influence the resorption pattern.
(c) Oversized grafts should be harvested to maintain enough graft volume after the initial resorption phase.
(d) If AB grafts are used, it is highly suggested to use cortico-cancellous bone blocks. Cancellous bone alone or particulated bone, if not associated with membranes of titanium meshes, do not provide sufficient rigidity to withstand tension from the overlying soft tissues or from the compression by provisional removable dentures and may undergo almost complete resorption (Brånemark et al. 1975; Breine & Brånemark 1980).

Even less data are available as far as resorption of horizontal bone grafts is concerned, due to the higher difficulty in measuring this parameter (need for computed tomography or calipers instead of simpler methods such as intraoral radiographs). Only three articles reported data on horizontal bone resorption of the graft, which ranged from 10% to 50% (Chiapasco et al. 1999; Raghoebar et al. 2000; Jemt & Lekholm 2003).

This review seems to demonstrate that, despite the limits mentioned above, reconstruction of atrophic partially or totally edentulous jaws with AB grafts is an acceptable modality in restoring dentition with implant-supported prostheses. However, the pros and cons of bone transplantation must be carefully weighed, as far as economic and biologic costs (morbidity) are concerned. In particular, the extension and the site (maxilla or mandible) of the defect must be carefully evaluated.

In case of moderate/severe atrophy of partially edentulous patients, other surgical options such as DO, GBR, and sagittal osteotomies, which may present less morbidity, should be taken into consideration.

In case of severely atrophied edentulous maxillae, relevant resorption of the alveolar process and the presence of nasal and paranasal cavities (maxillary sinuses) leads to a clinical situation that is not compatible with implant placement, because of insufficient quantity and low quality of the residual bone. In these cases, onlay grafts (with/without associated nasal/sinus grafts – see next sections for more details) are one of the few options that permits the recreation of a more favorable environement for implant placement. Other surgical options, such as Le Fort I osteotomy with interpositional bone grafts and microvascular free flaps, present even more morbidity and should be limited to extreme atrophy or severe intermaxillary discrepancy not susceptible to be treated with onlay grafts (see next sections for further details). Conversely, the edentulous mandible, although severely atrophied, may present local conditions that are compatible with a safe implant placement also without complex, technically, and biologically demanding procedures. It has been demonstrated that, also in case of severe atrophy, the dense highly corticalized bone of the mandibular symphisis is able to support the functional demands of removable or fixed implant-supported prostheses, also when short implants (<10 mm) are used (Keller 1995; Stellingsma et al. 2004). According to the protocol proposed by Keller (1995), short implants can be placed in severely atrophic mandibles without reconstruction when the anterior mandible (intraforaminal area) is more than 5 mm in height and at least 6 mm in width. Fifty-seven patients presenting with such conditions received 260 implants loaded with removable or fixed implant-supported prostheses. The survival rate of implants was 93.1%, after a mean follow-up of 59 months, with no significant differences as compared with the survival rate of implants placed in atrophic non-reconstructed mandibles. Therefore, reconstruction of the atrophic mandible should be limited only to cases where the mandibular bone height and width are <5 and 6 mm, respectively. In this situation, the residual available bone is insufficient for harboring implants of adequate dimensions, and there is a risk of 'fatigue' fractures of the mandible. However, if reconstruction of the mandible is the chosen option, calvarial grafts should be preferred to iliac grafts, due to the very limited resorption (Donovan et al. 1994; Iizuka et al. 2004; Chiapasco et al. 2006a). In contrast, it has been shown that iliac onlay grafts for the reconstruction of edentulous mandibles are exposed to relevant resorption (up to 50%) (Vermeeren et al. 1996; Verhoeven et al. 1997), and therefore are questionable nowadays.

Timing of implant placement

Both immediate implant placement in conjunction with bone grafting and delayed

implant placement, after the consolidation of the graft has occurred, have been proposed. For those who advocate immediate implant placement (Adell et al. 1990b; Jensen & Sindet-Pedersen 1991; Lew et al. 1991; Isaksson & Alberius 1992; Keller 1995; Åstrand et al. 1996; Mc Grath et al. 1996; Vermeeren et al. 1996; van Steenberghe et al. 1997; Verhoeven et al. 1997; Keller et al. 1999a, 1999b; Lekholm et al. 1999b; Nyström et al. 2004; van der Meij et al. 2005), the reason is that resorption of an onlay graft over time is not a linear process but most pronounced soon after its transplantation (Verhoeven et al. 1997, 2000). Immediate implant placement will shorten the waiting time before rehabilitation, thus potentially reducing the risk of bone resorption.

Those who advocate delayed placement (Triplett & Schow 1996; Lundgren et al. 1997; Neyt et al. 1997; Chiapasco et al. 1999; Raghoebar et al. 2000, 2003; Bahat & Fontanessi 2001; Bell et al. 2002; Jemt & Lekholm 2003; Iizuka et al. 2004) think that immediate placement of implants exposes to some risks, which can be summarized as follows: (1) in case of wound dehiscence, exposure and infection/necrosis of the bone graft may occur and lead to partial or total loss of the graft; and (2) immediate implants are placed into avascular bone, which increases the risk of non-integration. Conversely, when a delayed protocol is performed, it will be possible to place implants in a revascularized (albeit partly) graft. As the regenerative capacity of bone is determined by the presence of vessels, bone marrow, and vital bone surfaces, a delayed approach will permit a better integration of implants (higher values of bone–implant contact) and stability of implants, as compared with immediate implant placement (Shirota et al. 1991; Lundgren et al. 1997; Rasmusson et al. 1999). Despite these considerations, much controversy still exists as far as the timing of implant placement in grafted areas is concerned, and no conclusions can be drawn.

Loading time of implants placed in grafted areas

Initial reports suggested longer waiting times (6–12 months) between implant placement and subsequent abutment connection and prosthetic loading. The rationale was to allow some extra time for graft incorporation but not too long to neglect the theoretical advantage of implants to provide a bone-preserving stimulus in the same manner as the presence of healthy teeth preserves the alveolar bone (Adell et al. 1990b; Isaksson & Alberius 1992). However, a recent clinical study (Sjoström et al. 2005), using resonance frequency measurements, demonstrated that 24 weeks after implant placement, implants placed in grafted bone achieved a stability similar to that of implants placed in native bone. Therefore, longer waiting periods appear to be fruitless.

Although no conclusive recommendations can be given, due to the wide range of waiting times proposed and the different characteristics of macro-, micro-, and nano-geometry of different implant systems (which may influence osseointegration times), the majority of authors suggested waiting times similar to those proposed for implants placed in non-reconstructed bone (3–6 months). Only one article (Raghoebar et al. 2003) reported data on early loading (2 months after implant placement) of implants placed in edentulous maxillae augmented with onlay iliac grafts. Out of 68 implant placed in 10 patients, 65 survived (95.6%) after 1 year of functional loading. Only one article (Chiapasco et al. 2006a) reported data on immediate loading (within 48 h after implant placement) of implants placed in reconstructed edentulous mandibles with calvarial onlay grafts. Out of 23 implants placed in six patients, 23 survived (100%), after a follow-up of 12–36 months post-loading.

Survival and success rate of implants

Survival and success rates of implants placed in reconstructed jaws are, on average, lower than those related to implants placed in native bone, in particular in cases where extensive reconstructions were performed. However, as already underlined, only a few publications reported data according to well-defined criteria. In particular, only two studies (Schliephake et al. 1997; Becktor et al. 2002) applied thorough statistical means for the evaluation of clinical outcomes, with the objective to correlate implant survival/success with factors such as: (a) type and dimension of implants; (b) type of opposing arch dentition; (c) type of augmentation technique; (d) patients' gender; and (e) site of reconstruction. The conclusions were as follows: (1) the cumulative survival rate of implants demonstrated a progressive decline from 1 to 5 years following the start of prosthetic loading; (2) implants placed in edentulous reconstructed maxillae were associated with lower survival rates, as compared with implants placed in reconstructed mandibles. Conversely, the difference between partially edentulous maxillae and mandibles lacked statistical significance; (3) onlay grafts from the iliac crest were associated with lower survival rates, as compared with grafts harvested from the mandible; (4) the time at which implants were inserted into the bone grafts showed no significant effect on the survival rate; (5) implant survival rate tended to improve with increasing implant length; (6) the patients' age had no significant impact on implant survival; (7) a higher failure rate was found in female patients; (8) many implant failures in the maxilla occurred in only a few patients; (9) implants opposing unilateral occlusal support showed the highest rate of implant failure; and (10) implants that opposed a mandibular implant-supported fixed prosthesis or a removable mandibular denture presented the lowest failure rate.

Non-autogenous grafting materials'

Patients and methods

The search allowed to retrieve 18 articles, of which only one was included (Block & Degen 2004). Eleven patients presenting with localized, horizontal defects of the mandible were treated with particulated FDBA, which was injected after a tunnel elevation of the overlying mucoperiosteum. After a consolidation period of 4 months, 35 implants were placed in the reconstructed area. The mean follow-up period after the start of prosthetic rehabilitation was 12 months.

Results

Bone augmentation ranging from 5 to 8 mm was obtained, but at the time of implant placement a bone resorption rate up to 50% was observed. The survival rate of implants was 97% (one implant removed), but no data were available with regard to success rate.

Discussion

The use of non-autogenous grafting materials for onlay grafting procedures lacks sufficient data to draw any meaningful conclusion.

Inlay bone grafts

Inlay bone grafts have been proposed for the correction of both mandibular and maxillary defects. Owing to the differences in surgical techniques and clinical aspects, mandibular and maxillary inlay grafts will be considered separately.

Mandible

Patients and methods

The search provided 80 studies, of which seven were screened as full-text articles. However, only two publications were included (Satow et al. 1997; Stellingsma et al. 2004). Overall, 50 patients presenting with severely atrophied edentulous mandibles were treated by means of a horizontal osteotomy of the anterior mandible (intraforaminal area), which permitted the elevation of the most cranial segment in association with interpositional grafts taken from the anterior iliac crest. The posterior mandible was augmented with an onlay graft formed by autogenous particulated bone from the ilium in association with hydroxyapatite granules. After a consolidation period of the graft ranging from 3 to 5 months, 153 implants were placed in the intraforaminal area of the reconstructed mandibles (two to four implants per patient). After a further healing period to obtain osseointegration, prosthetic loading was started. All patients were rehabilitated with implant-supported overdentures. Patients were followed for 12 to 84 months after the start of prosthetic loading (Table 3).

Results

Postoperative recovery after the reconstructive procedure was uneventful in 47 out of 50 patients. Minor complications such as uneventful dehiscences occurred in two patients. Only one patient presented a relevant lingual dislocation of the reconstructed area and a second graft was necessary to permit implant placement. The overall success rate of the procedure was therefore 98%. A very limited reduction of the initial bone gain was observed at the time of implant placement (10–15%).

The overall survival rate of implants ranged from 90% to 95%, while the success rate of implants (95%) was reported only in one article (Satow et al. 1997) (Table 3).

Discussion

The implant and patients' sample is too small to draw relevant conclusions. However, data reported seem to show that bone augmentation of atrophic edentulous mandibles with interpositional bone grafts is an acceptable procedure that may allow to maintain the initial bone gain (10–15% reduction rate over time) more predictably than with onlay iliac grafts (15–50% reduction rate over time). Survival rates of implants are comparable to those of implants placed in non-reconstructed mandibles. However, in a randomized clinical study where the clinical and radiographic outcome of implants placed in inlay grafted mandibles was compared with that of implants placed in non-reconstructed severely atrophic mandibles, it was demonstrated that the success rate of implants placed in the inlay graft group was significantly lower as compared with the non-grafted group (Stellingsma et al. 2004). It was concluded that patients with severely atrophic mandibles could be treated with short implants without complex reconstructive procedures. Therefore, indications of this technique seem to be very limited.

Maxilla

Inlay grafts for the correction of maxillary bone defects are represented by three procedures:

- sinus floor augmentation;
- nasal lift; and
- Le Fort I osteotomy with interpositional bone grafts.

The clinical outcome of these three procedures will be analyzed separately.

Sinus floor augmentation

Patients and methods

The search provided 983 studies, of which 470 were screened as full-text articles. Of these publications, only 62 were included. Some publications, although fulfilling our inclusion criteria, were not considered in this review in the case the same data were reported in later publications where the same authors reported the same patient sample with longer follow-ups. Fifty-seven studies were related to sinus floor elevation with lateral approach; five were related to transalveolar elevation. Of these, two reported data related to both trans-alveolar and lateral approaches (Zitzmann & Schärer 1998; Rodoni et al. 2005) (see Tables 4 and 5 for further details).

Overall, 3558 patients were treated by means of 4503 maxillary sinus augmentation procedures. However, it is worth noting that some articles reported only the number of patients without specifying the number of sinus grafting procedures. Patients received a total of 10,449 implants: of these, 9369 were placed in the elevated maxillary sinuses, and 1080 in the anterior maxilla.

Data related to trans-alveolar and lateral approach for sinus floor elevation were analyzed separately, because the two procedures differ significantly.

Trans-alveolar approach

The five selected studies reported data on 395 patients and 556 trans-alveolar sinus floor elevation procedures. A total of 588 implants were placed in the augmented sinuses, of which 451 were placed at the same time of the elevation procedure and

Table 3. **Mandibular interpositional bone grafts–characteristics of included studies**

Author and year	Study type	No. pts	Grafting material	Surg succ %	No. implants (timing)	Follow-up (months)	Imp surv %	Imp succ %
Satow et al. (1997)	RCS	30	AB (ilium) + HA	97	73 (del)	12–84	95	95
Stellingsma et al. (2004)	RCT	20	AB (ilium)	100	80 (del)	24	90	ND
Total		50			153			

RCS, retrospective case series; RCT, randomized clinical trial; no. pts, number of patients treated; AB, autogenous bone; HA, hydroxylapatite; surg succ, success rate of the surgical procedure; del, delayed placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

Table 4. **Sinus lifting procedure (crestal approach) – characteristics of included studies**

Author and year	Study type	No. pts	No. SL	Grafting material	No. implants (timing)	Follow-up (months)	Imp surv %	Imp succ %
Zitzmann & Schärer (1998)	PCS	20	59	BBM	59 (imm)	6–24	94.9	ND
Fugazzotto & De Paoli (2002)	RCS	150	167	AB	137 (del)	36	98.5	97.8
Toffler (2004)	RCS	167	276	BBM + AB	276 (imm)	6–84	94.9	93.5
Rodoni et al. (2005)	PCS	18	ND	BBM	41 (imm)	40–93	100	ND
Leblebicioglu et al. (2005)	RCS	40	54	None	75 (imm)	25	97.3	ND
Total		395			588			

RCS, retrospective case series; PCS, prospective clinical series; no. pts, number of patients treated; no. sl, number of sinus lifting procedures; AB, autogenous bone; BBM, bovine bone mineral; imm, immediate placement; del, delayed placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

137 at a second stage. The grafting materials used were as follows: (a) AB; (b) xenografts (BBM); (c) a mixture of AB and BBM; (d) AB + TCP; and (e) no grafting materials (see Table 4 for further details).

Patients were rehabilitated with both fixed and removable implant-supported prostheses. Prosthetic rehabilitation was started 4–8 months after implant placement. The follow-up period after the start of prosthetic loading ranged from 6 to 93 months (Table 4).

Lateral approach

The 57 selected studies reported data on 3163 patients and 3947 sinus floor elevation procedures with the lateral approach. A total of 9861 implants were placed, of which 8781 were in the augmented sinuses. Of these, 3760 were placed at the same time of the augmentation procedure and 3503 at a second stage, while for 1518 implants the timing of implant placement was not specified.

In 22 out of 57 studies, one grafting material (AB, BBM, calcium sulfate, HA, or allograft) was used alone. In the remaining studies, mixtures of different grafting materials such as AB + BBM, AB + HA or TCP, AB + allograft; HA + allograft, BBM + allograft, AB + PRP, allograft + PRP, and BBM + PRP were used.

Patients were rehabilitated with both fixed and removable implant-supported prostheses. Prosthetic rehabilitation was started 1–13 months after implant placement (on average 6 months later). The follow-up period after the start of prosthetic loading ranged from 6 to 134 months (Table 5).

Results

Trans-alveolar sinus augmentation

Data related to healing of the augmentation procedure were reported only in three out of five articles. In two articles, an uneventful healing was observed (Zitzmann & Schärer 1998; Leblebicioglu et al. 2005). Twenty-one out of 588 implants were removed, with an overall survival rate of 96.4% (range: 94.9–100%). The survival rate of implants placed in conjunction with the augmentation procedure (451 implants) ranged from 94.9% to 100%, while the survival of implants placed in a staged approach (137 implants) was 98.5%.

Available data did not demonstrate significant differences in survival rates of implants according to different grafting materials. Success rates of implants ranged from 93.5% to 97.8%. However, it is worth noting that only two out of five articles reported success rates according to well-defined criteria (Table 4).

Lateral approach sinus elevation

Data related to intra-operative and postoperative complications were reported in 34 out of 57 articles. An uneventful healing of the augmentation procedure occurred in 87% of the patients. The most frequent intra-operative complication was sinus membrane perforation, which occurred in approximately 10% of the cases (range: 4.8–40%). In the vast majority of patients, sinus grafting was, however, completed either by closing the perforation with resorbable materials, such as collagen sponge, resorbable membranes, allograft sheets, or simply increasing sinus floor mucosa elevation, with no further complications. Only in an extremely limited number of patients (<1%) the grafting procedure had to be stopped, due to large tears of the membrane.

Postoperative complications occurred in approximately 3% of the patients. The most frequent was represented by graft infection and/or postoperative maxillary sinusitis. Partial or total graft loss occurred in approximately 0.1% of the patients, whereas the incidence of sinusitis ranged from 0% to 27% (average: 2.3%). However, these data must be interpreted with caution, because only 38 out of 57 articles reported these data.

The overall survival rate of implants placed in grafted sinuses was 92.6% (range: 60% to 100%), with the majority of articles reporting values higher than 90%.

Success rates of implants placed in grafted sinuses ranged from 74.7% to 100% (Table 5). However, it is worth noting that only 18 out of 57 articles reported data according to well-defined criteria. Therefore, these data should be interpreted with caution.

To obtain more information, the survival rates of implants according to: (a) type of graft (autografts, allografts, xenografts, alloplastic materials, or mixtures of these materials); (b) timing of implant placement (in conjunction with the reconstructive procedure or after the consolidation of the graft); and (c) the quantity and quality of residual bone before grafting procedures should be analyzed. However, meaningful comparisons were rarely possible, because: (a) the number of patients treated with different materials differ greatly; (b) many publications in which different combinations of grafting materials were used reported data without separating them according to grafting material; and (c) the quantity and quality of residual bone in the posterior maxilla were not always reported, but these latter parameters may greatly influence the final outcome of implants.

Survival rates of implants according to grafting material

The mean survival rates of implants placed in augmented sinuses with AB grafts, allografts, xenografts, alloplastic materials, and

Table 5. **Sinus lifting procedure (lateral approach) – characteristics of included studies**

Author and year	Study type	No. pts	No. SFE	Grafting material	No. implants (timing)	Follow-up (months)	Imp surv %	Imp succ %
Kent & Block (1989)	RCS	11	18	AB	54 (imm)	12–48	100	ND
Tidwell et al. (1992)	RCS	48	83	AB + HA	203 (del)	12–32	93.6	ND
Raghoebar et al. (1993)	RCS	25	47	AB	93 (NS)	6–36	94.6	ND
Block & Kent (1993)	RCS	32	51	AB/AB + AG/AG	173 (NS)	24–120	75	ND
Chiapasco & Ronchi (1994)	RCS	30	43	AB + BBM	41 (imm) 83 (del)	12–24	93.5	93.5
Hurzeler et al. (1996)	RCS	133	ND	Various	235 (imm) 105 (del)	12–60	98.8	90.3
Triplett & Schow (1996)	RCS	99	70	AB	69 (imm) 76 (del)	>12	90.8	ND
Wheeler et al. (1996)	RCS	24	36	HA/BBM/AB/AB + HA	66 (NS)	6–66	92.4	92.4
Raghoebar et al. (1997)	RCS	43	81	AB	171 (NS)	8–62	94.7	ND
Block & Kent (1997)	RCS	33	53	AB/AG	173 (NS)	36–134	88.4	ND
Watzek et al. (1998)	RCS	20	40	BBM/AB + BBM/AB + HA/AB	155 (del)	12–70	95.2	74.7
Peleg et al. (1998)	PCS	20	20	AG + AB	45 (imm)	15–39	100	100
Van den Bergh et al. (1998)	RCS	42	62	AB	161 (del)	12–72	100	ND
Zitzmann & Schärer (1998)	RCS	10	ND	BBM	7 (imm) 13 (del)	6–24	100	ND
Fugazzotto & Vlassis (1998)	RCS	181	194	BBM/AG/TCP	181 (imm) 252 (del)	6–73	97	97
Blomqvist et al. (1998)	PCS	50	97	AB	202 (del)	9–48	84	ND
Block et al. (1998a)	RCS	16	27	AB/AB + AG	73 (imm)	63–126	95.9	ND
Peleg et al. (1999a)	PCS	21	24	AG + AB	57 (imm)	36	100	ND
Mazor et al. (1999)	PCS	10	10	AG + AB	10 (imm)	36	100	100
Peleg et al. (1999b)	RCS	63	63	AG + AB	160 (imm)	24–48	100	ND
Keller et al. (1999a, 1999b)	RCS	37	58	AB	127 (imm) 12 (del)	12–144	85.6	ND
Khoury (1999)	RCS	216	216	AB/AB + HA	467 (imm)	24–72	94	94
Lekholm et al. (1999a, 1999b)	RMCS	68	ND	AB	330 (NS)	36	77.9	ND
De Leonardis & Pecora (1999)	PCCT	57	65	CS	56 (imm) 74 (del)	12	98.5	ND
Olson et al. (2000)	RCT	29	45	AG + AB/AB/HA + AG/HA/AG	120 (NS)	6–71	97.5	ND
Mazor et al. (2000)	PCS	10	10	HA	26 (imm)	12–24	100	ND
Valentini et al. (2000)	PCS	15	20	BBM	57 (del)	36–60	98.2	98.2
Lorenzoni et al. (2000)	RCS	67	ND	AB/BBM	73 (imm) 25 (del) 78 (NS)	6–60	95	94
Wannfors et al. (2000)	RCT	40	80	AB	76 (imm) 74 (del)	12	84	ND
Kassolis et al. (2000)	PCS	14	14	AG + PRP	36 (del)	12	88.9	ND
Raghoebar et al. (2001a)	RCS	99	182	AB	86 (imm) 306 (del)	12–124	91.8	90.8
Kahnberg et al. (2001)	PCS	26	39	AB	91 (imm)	12–72	61.2	ND
Mayfield et al. (2001)	RCS	6	6	AB + BBM	14 (NS)	48–72	80	ND
Karabuda et al. (2001)	PCCS	9	9	AG/HA	10 (imm) 9 (del)	9–24	100	ND
Tawil & Mawla (2001)	PCCS	29	30	BBM	41 (imm) 20 (del)	12–40	85.2	ND
Hallman et al. (2002a)	PCS	20	30	BBM + AB	79 (del)	18	90.7	ND
Hallman et al. (2002b)	PCCS	21	36	BBM/BBM + AB/ AB	111 (del)	12	91	ND
Engelke et al. (2003)	RCS	83	118	TCP + AB	175 (imm) 36 (del)	6–60	94.8	ND
Cordaro (2003)	PCS	8	16	AB	44 (imm)	8–24	100	ND
Stricker et al. (2003)	RCS	41	66	AB	48 (imm) 135 (del)	15–40	99.5	97.8
Rodriguez et al. (2003)	PCS	15	24	BBM + PRP	70 (imm)	6–36	92.9	ND
Valentini & Abensur (2003)	RCS	59	78	BBM/BBM + AG	55 (imm) 128 (del)	38–113	94.5	ND
McCarthy et al. (2003)	RCS	19	27	AB + BBM/ AB + PRP/AB	27 (imm) 49 (del)	19–72	78.9	ND
Philippart et al. (2003)	RCS	18	25	AB + PRP	58 (del)	12–48	91.4	ND
Pinholt (2003)	RCS	22	39	AB	104 (del)	20–67	86.5	ND
Hatano et al. (2004)	RCS	191	361	BBM + AB	361 (imm)	6–108	94.2	ND
Hallman & Zetterqvist (2004)	PCS	20	30	AB + BBM	79 (del)	36	88.6	88.6
Peleg et al. (2004)	RCS	156	194	AB + BBM/AB	436 (imm)	8–24	99.3	99.3
Shlomi et al. (2004)	RCS	63	73	AB + BBM/AB	253 (NS)	24	90.9	ND
Simion et al. (2004)	RCS	14	16	AB + BBM/AB	16 (imm) 22 (del)	12–84	92.1	76.3
Hallman & Nordin (2004)	RCS	50	71	BBM	196 (del)	6–42	96	96
Iturriaga & Ruiz (2004)	RCS	58	79	AB	223 (del)	24–96	100	ND
Velich et al. (2004)	RCS	624	810	AB + AG/ AB	485 (imm) 325 (del)	60	94.5	ND
Zijderveld et al. (2005)	PCCS	10	16	AB/TCP	67 (del)	6–19	100	ND
Raghoebar et al. (2005)	RCT	5	10	AB + PRP/AB	30 (del)	20	96.7	ND
Rodoni et al. (2005)	PCS	13	13	BBM	47 (NS)	37–62	100	100
Butz & Huys (2005)	RCS	20	22	AP + AB	48 (imm) 8 (del)	84	100	100

RCS, retrospective case series; PCS, prospective clinical series; RMCS, retrospective multicenter clinical series; PCCT, prospective controlled clinical trial; RCT, randomized clinical trial; no. pts, number of patients treated; no. SFE, number of sinus floor elevation procedures; AB, autogenous bone; AG, allograft; AP, alloplastic material; BBM, bovine bone mineral; PRP, platelet-rich plasma; TCP, tricalcium-phosphate; CS, calcium sulfate; HA, hydroxylapatite; imm, immediate placement; del, delayed placement; NS, implant placement timing not specified; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

Table 6. **Maxillary inlay (nasal) bone grafts –characteristics of included studies**

Author and year	Study type	No. pts	Donor site	Graft succ %	No. impl (timing)	Follow-up (months)	Imp surv %	Imp succ %
Keller et al. (1999a, 1999b)	RCS	15	Ilium	100	56 (imm)	12–120	93	ND
Becktor et al. (2002)	RCS	7	Ilium	ND	24 (imm)	22–105	83.3	ND
Total		22			80			

RCS, retrospective clinical series; no. pts, number of patients treated; graft succ, success rate of the grafting procedure; no. impl, number of implants placed; imm, immediate placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

mixtures of these materials were 89%, 93.4%, 95.5%, 98.4%, and 93.8%, respectively. On average, the use of different filling materials apparently did not significantly influence survival rates of implants (see Tables 5 and 6). However, comparisons are difficult to be made, due to relevant differences in patients' samples and number of implants placed. Moreover, it was frequently difficult or impossible to retrieve pertinent data related to survival of implants because in many articles different materials or different mixtures were used without separating results.

Only four studies compared prospectively the clinical outcome of implants according to different grafting materials: (1) Fugazzotto & Vlassis (1998) – Bio-oss® vs. allografts and TCP; (2) Hallman et al. (2002b) – AB vs. Bio-oss® and mixture of autogenous and BBM; (3) Velich et al. (2004) – AB vs. calcium carbonate, AB + HA, AB + TCP, HA alone, TCP alone, TCP + PRP; and (4) Valentini & Abensur (2003) – allograft + BBM vs. BBM alone). No relevant differences were found, but again survival rates are difficult to compare because both immediate and delayed implant placements were performed, thus introducing a bias that may influence the results.

Survival rate of implants according to the timing of implant placement

As far as the timing of implant placement is concerned, the survival rate of implants placed in conjunction with the grafting procedure ranged from 61% to 100%, and from 72.7% to 100% in case of a staged approach. However, many articles, in which both an immediate or delayed implant placements were performed, did not separate implant failures according to the timing of implant placement. It was therefore difficult to obtain reliable information concerning this topic. A staged approach was generally suggested when the residual bone height might be insufficient to guarantee primary stability of implants (on average, when the residual bone height of the alveolar crest is <4 mm), while an immediate approach was suggested when enough bone volume to allow adequate primary stability of implants was present (>5 mm). Only one article reported successful outcome of implants placed in conjunction with the grafting procedure with a very limited residual bone height (1–2 mm) (Peleg et al. 1998). Therefore, no clear indications concerning the timing of implant placement were found in the literature.

Only one randomized clinical trial (Wannfors et al. 2000) compared 20 patients treated with sinus grafting by means of iliac bone blocks and immediate implant placement with 20 patients treated with particulated iliac bone and delayed implants. The authors concluded that the failure rate of implants placed in conjunction with the grafting procedure was two times higher as compared with implants placed in a staged approach.

Survival rates of implants according to quantity and quality of residual bone

The quantity and quality of residual bone in the posterior maxilla may influence survival rates of implants, independent of the type of grafting procedure. Yet, only 41 out of 57 articles reported data on initial residual bone height, and practically no articles reported data on residual bone width. It is therefore difficult to know whether survival of implants is related to the residual bone volume or to the grafting material. Another parameter that might influence the outcome of implants is the quality of residual bone, but only six out of 57 articles reported data on bone quality according to well-defined criteria (Zitzmann & Schärer 1998; Lekholm et al. 1999a, 1999b; Tawil & Mawla 2001; Pinholt 2003; Rodriguez et al. 2003; Raghoebar et al. 2005).

Discussion

The analysis of the literature seems to demonstrate that sinus grafting procedures, either with a trans-alveolar or a lateral approach, are reliable surgical techniques that permit to place implants in the atrophic posterior maxilla with an excellent long-term prognosis. Similar results have been obtained with different grafting materials, such as AB, allografts, xenografts, alloplastic materials, and mixtures of these materials.

Survival rates of implants placed in grafted sinuses are consistent with those related to implants placed in non-grafted edentulous maxillae (Albrektsson et al. 1986; Adell et al. 1990a; van Steenberghe et al. 1990; Buser et al. 1997; Weber et al. 2000).

However, these results should be interpreted with caution because the analysis of available publications demonstrated, on average, a poor methodological quality with regard to: (a) type of study (out of 62 articles, 40 were retrospective clinical series, 19 were prospective, and only three were randomized clinical trials); (b) description of initial clinical situation (quality and quantity of posterior maxilla residual bone); (c) success of implants according to well-defined criteria; and (d) duration of follow-up. Moreover, it was frequently difficult or impossible to retrieve pertinent data related to survival of implants because in many articles different materials or different mixtures were used without separating results. All these factors may introduce relevant bias and make statistically significant comparisons difficult. In particular, precise data concerning the initial clinical situation of the edentulous posterior maxilla (i.e, residual bone volume and interarch relationship) should always be reported in publications. This

aspect is deemed to be very important by the author, because different amounts of residual bone before sinus grafting procedures may influence the final outcome of implants placed in the grafted areas. In particular, if the residual volume of the posterior maxilla is not described in terms of volume, it is difficult to evaluate whether the survival rate of implants placed in the grafted area is related to the support offered by the grafted material or to the residual bone. It is also worth noting that atrophy of the edentulous maxilla develops tridimensionally, and it is not only dependent on sinus pneumatization. Therefore, an insufficient bone height may also be related to vertical resorption of the alveolar ridge or a combination of both factors. In the first situation, a sinus grafting procedure may be indicated, whereas in the second one (vertical atrophy) it may happen that the sinus does not need to be grafted. Instead, a vertical reconstruction to recreate an adequate interarch distance may be the treatment of choice. Moreover, bone resorption of the edentulous ridge may lead to a horizontal discrepancy between the maxilla and the mandible. If the sinus grafting procedure is the only one performed, it may happen that implants will be placed in a palatal position, with a less than ideal prosthetic rehabilitation, from an esthetic and functional viewpoint. Therefore, the atrophic posterior maxilla should be evaluated and classified not only as far as the residual bone height and width is concerned but also as far as the residual vertical and horizontal intermaxillary relationships are concerned. Consequently, sinus grafting may represent only a part of the reconstructive procedure necessary to re-establish adequate bone volumes and intermaxillary relationships, in order to optimize implant placement and the final prosthetic results from a functional and esthetic point of view. Classifications that consider these parameters should be used when reporting data, in order to obtain more homogeneous samples of patients, thus simplifying comparisons of clinical outcomes according to different procedures and/or different grafting materials, such as the classifications proposed by Chiapasco (Misch et al. 2006), Misch (Misch et al. 2006), and Simion (Simion et al. 2004). However, within the limits determined by the lack of some data, some considerations can be drawn on the following topics.

Safety of sinus grafting procedures

Grafting of maxillary sinuses is followed by a very low complication rate. It has been demonstrated that the volume reduction of the maxillary sinus following sinus elevation does not interfere with sinus functions (Timmenga et al. 1997). Intraoperative complications, which are mainly represented by sinus mucosa perforations, are well tolerated and followed by normal recovery in the vast majority of cases. The sinus mucosa will usually regenerate across the immobilized bone graft postoperatively. The majority of authors suggest to treat perforations either by simply folding the sinus mucosa after a more extended elevation or with resorbable barriers, such as collagen, fibrin adhesive, or resorbable membranes (van den Bergh et al. 1998; Khoury 1999; Mazor et al. 1999; Karabuda et al. 2001; Raghoebar et al. 2001a; Tawil & Mawla 2001; Engelke et al. 2003; Stricker et al. 2003; Valentini & Abensur 2003; Hallman & Nordin 2004; Shlomi et al. 2004; Zijderveld et al. 2005).

Complications such as sinusitis tend to occur in previously unhealthy sinuses (Timmenga et al. 1997). Therefore, a thorough preoperative screening of maxillary sinus status is mandatory (i.e. CT scans).

Choice of grafting material

Non-autogenous grafting materials appeared to be reliable for sinus floor elevation, with no significant differences in clinical outcomes and implant survival. AB presents similar results, but it has advantages and disadvantages, which can be summarized as follows:

1. AB must be harvested from intraoral or extraoral (typically from the anterior iliac crest) sites, with higher morbidity (i.e. risk of neural disturbances in case of intraoral grafts due to possible lesions of the inferior alveolar nerve branches, and gait disturbances in case of harvesting from the iliac crest) as compared with non-autogenous grafting materials.
2. AB is the material of choice when sinus grafting procedures must be associated with onlay grafting of the maxilla in case of severe atrophy (Jensen et al. 1994; Lundgren et al. 1997; van Steenberghe et al. 1997; Keller et al. 1999a; Lekholm et al. 1999b; Nyström et al. 2004). Conversely, there is a lack of information regarding such reconstructions with non-autogenous materials.

Type of sinus elevation procedure

Sinus floor elevation with a trans-alveolar approach seems to be indicated in case of residual bone height >4–5 mm (Zitzmann & Schärer 1998; Fugazzotto & De Paoli 2002; Toffler 2004; Leblebicioglu et al. 2005; Rodoni et al. 2005), whereas the lateral approach can also be applied in case of extreme pneumatization of the sinus (Tidwell et al. 1992; Chiapasco & Ronchi 1994; Block & Kent 1997; Keller et al. 1999a, 1999b; Kahnberg et al. 2001).

Resorption of grafts over time

It has been demonstrated that grafted sinuses may undergo re-pneumatization over time, in particular in the first 2–3 years after the grafting procedure (Hatano et al. 2004). The use of non-resorbable or slowly resorbable grafting materials should prevent this phenomenon. In the case where particulated AB is used, a mixture with xenografts or alloplastic materials such as BBM or HA should reduce the risk of bone resorption and sinus re-pneumatization (Tidwell et al. 1992; Chiapasco & Ronchi 1994; Neyt et al. 1997; Mayfield et al. 2001; Hallman et al. 2002a, 2002b; Halmann & Zetterqvist 2004; Hallman & Nordin 2004; Hatano et al. 2004).

Timing of implant placement

Both immediate implant placement (in conjunction with grafting procedures) and delayed implant placement (after consolidation of the graft has occurred) have been proposed. Although it is impossible to determine a clear indication for immediate or delayed implant placement, the majority of authors agree in suggesting immediate implant placement when the residual alveolar bone present adequate quality and quantity to allow primary stability of implants. On average, immediate placement is not indicated when the residual height is <4–5 mm, and in case of poor bone quality. Tawil & Mawla (2001) demonstrated that immediate implant placement with <5 mm residual bone height is followed

by a significantly lower survival rate of implants as compared with implants placed in more than 5 mm residual bone (56% vs. 100%). A previous review of the literature concerning this topic (Jensen et al. 1998) showed lower survivals of implants when placed in conjunction with the grafting procedure. Only one article reported successful outcome of implants placed in conjunction with the grafting procedure with a very limited residual bone height (1–2 mm) (Peleg et al. 1998). However, no clear indications were found in the literature.

Loading time of implants placed in grafted areas

Implants placed in grafted sinuses were loaded 2–13 months afterwards (on average 5–6 months after). It is, however, difficult to give clear indications, because osseointegration and implant capability to withstand the functional demands of loading are influenced by a large number of factors, to include: residual bone volume before grafting procedure, quality of residual bone, type of grafting material, implant dimensions, implant macro- and microgeometry, type of implant surface, type of prosthesis, and type of opposing arch dentition. These considerations were already made by Jensen et al. (1998), in their review on sinus grafting procedures. Since then, no significant improvement of information has been carried out. Therefore, studies related to these topics are needed. One of the few aspects that seems to be clarified is that screw-shaped implants with rough surfaces present a better prognosis as compared with implants with machined surfaces (Jensen et al. 1998), but data have been retrieved mainly from retrospective studies and not from prospective, comparative studies.

Nasal lift

Patients and methods

The search provided 27 articles, of which 11 were screened as full text. Of these publications, two were selected (Keller et al. 1999b; Becktor et al. 2002).

Overall, 22 patients were treated with autogenous nasal inlay grafts harvested from the iliac crest. All patients received at the same time maxillary sinus augmentation. A total of 80 implants were placed at the same time of the reconstruction. Five to 12 months afterwards, abutments were connected and the prosthetic rehabilitation was started. Patients were followed for 12 to 120 months after the start of prosthetic loading (Table 6).

Results

Postoperative recovery after the reconstruction was uneventful in all patients. Therefore, the overall success rate of the grafting procedure was 100%. The survival rate of implants ranged from 83.3% to 93% (eight out of 80 implants removed), but no data are available as far as success rate is concerned (Table 6).

Discussion

Data retrieved from these articles seem to demonstrate that nasal inlay grafts are a reliable means in restoring insufficient bone volume of the anterior edentulous maxilla, with a high survival rate of implants placed in the reconstructed area. However, the patient sample is too limited to draw any meaningful conclusion.

Le Fort I osteotomy with interpositional bone grafts

Patients and methods

The search allowed to retrieve 660 articles: among these, 25 were screened as full text, and 12 were selected (see Table 7).

A total of 239 patients, affected by extreme atrophy of the edentulous maxilla (class VI according to Cawood & Howell (1988) classification), were treated with Le Fort I osteotomy and inlay bone grafts taken from the anterior iliac crest to correct not only alveolar bone deficiency but also severe intermaxillary discrepancy. One hundred and twenty-four patients received 881 implants placed during the same surgical session (six to nine implants per patient), while 115 patients received 758 implants in a second stage, after consolidation of the graft occurred (3–10 months after reconstruction). A total of 1639 implants were placed in the reconstructed maxillae. Prosthetic rehabilitation was started 4–12 months after implant placement. Both fixed and removable implant-supported prostheses were used, but only nine out of 12 articles reported data about prosthetic rehabilitation. Follow-up after the start of prosthetic loading ranged from 6 to 140 months (Table 7).

Results

Postoperative recovery after Le Fort I osteotomy was uneventful in the majority of

Table 7. **Le Fort I osteotomy with inlay grafts – characteristics of included studies**

Author and year	Study type	No. pts	Donor site	Succ proc %	No. impl (timing)	Follow-up (months)	Imp surv %	Imp succ %
Isaksson et al. (1993)	RCS	12	Ilium	100	59 (imm)	12–24	79	ND
Cawood et al. (1994)	RCS	12	Ilium + HA	92	64 (del)	12–36	67–95	ND
Krekmanov (1995)	RCS	35	Ilium	95	225 (imm)	12–48	87	ND
Li et al. (1996)	RCS	20	Ilium	100	139 (imm)	13–62	82	ND
Watzinger et al. (1996b)	RCS	11	Ilium	91	41 (imm) 35 (del)	30	88	81
Nyström et al. (1997)	RCS	10	Ilium	100	60 (del)	15–39	95	ND
Keller et al. (1999a, 1999b)	RCS	10	Ilium	100	8 (imm) 45 (del)	6–139	83	ND
Kahnberg et al. (1999)	RCS	25	Ilium	100	181 (del)	60	83	ND
Lekholm et al. (1999a, 1999b)	RCS	20	Ilium	ND	133 (imm)	12–36	80	ND
Stoelinga et al. (2000)	RCS	15	Ilium + HA	100	92 (del)	12–144	91	91
Yerit et al. (2004)	RCS	30	Ilium	90	276 (imm)	12–120	87–91	ND
Chiapasco et al. (2006b)	PMCS	39	Ilium	97.5	281 (del)	12–108	94.5	82.9
Total		239			1639			

RCS, retrospective clinical series; PMCS, prospective multicenter clinical series; no. pts, number of patients treated; no. impl, number of implants placed; HA, hydroxylapatite; imm, immediate placement; del, delayed placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

Table 8. **Sagittal osteotomy – characteristics of included studies**

Author and year	Study type	No. pts	Defect site	Grafting material	Surg succ %	No.impl (timing)	Follow-up (months)	Imp surv %	Imp succ %
Engelke et al. (1997)	RCS	44	Max	HA + e-PTFE	100	124 (imm)	6–68	91	86.2
Bruschi et al. (1998)	RCS	303	Max	CLS	100	499 (imm)	25–0	ND	97.5
Chiapasco et al. (2006c)	PMCS	45	Max/mand	None	98	110 (imm)	12–6	97.3	95.4
Total		392				733			

RCS, retrospective clinical series; PMCS, prospective multicenter clinical study; no. pts, number of patients treated; max, maxilla; mand, mandible; HA, hydroxylapatite; CLS, collagen sponge; surg succ, success rate of the surgical procedure; no. impl, number of implants placed; imm, immediate placement; del, delayed placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

patients (211/239). In four patients, intraoperative fracture of the palate occurred, but with no consequences on the final outcome. In seven patients, postoperative sinusitis occurred, but was successfully treated with antibiotics. In eight patients, minor dehiscence with moderate bone graft fragments esfoliation was reported, with no consequences on the subsequent rehabilitation phases. In eight patients, dehiscence with partial bone loss/infection occurred but prosthetic rehabilitation, despite having to be modified, was concluded successfully. A total failure of the procedure was reported only in two patients. The overall success rate of this surgical procedure was 95.8% (229/239 patients).

Out of 1639 implants placed, 202 were removed (overall survival rate: 87.7%). Of these, 125 out of 881 implants were lost in the group where implants were placed in conjunction with Le Fort I osteotomy, while 68 out of 758 implants were lost in the group in which implants were placed at a second stage. An additional nine implants were lost in one publication where both immediate and delayed implant placements were performed (Keller et al. 1999a), but it was not reported in which of the two groups of implants these losses occurred. Implant losses occurred both before and after the start of prosthetic loading, but again data are incomplete and it was not possible to specify the exact time distribution of losses.

The survival rate of implants placed in conjunction with the reconstructive procedure was 85.8% (range: 79–95%). For implants placed in a staged approach, the survival rate was 89% (range: 67–95%). Conversely, no well-defined implant success criteria were found in the majority of articles. Only three publications (Watzinger et al. 1996; Stoelinga et al. 2000; Chiapasco et al. 2006b) reported 88.1%, 91%, and 82.9% success rates, respectively, according to well-defined criteria (Table 7).

Discussion

The analysis of the available publications demonstrated on average a poor methodological quality with regard to: (a) type of study (11 retrospective clinical series and only one prospective study); (b) completeness of follow-up; and (c) success criteria of implants. Despite these limits, the following observations can be drawn:

1. Le Fort I osteotomy, in association with interpositional bone grafts and immediate or delayed implant placement, is a reliable, albeit demanding, procedure that should be limited to severe maxillary atrophy associated with an unfavorable intermaxillary relationship. In these situations, techniques such as onlay bone grafting, even if they can recreate adequate bone volumes for implant placement, may not be able to correct inadequate intermaxillary relationship: this might lead to inadequate final prosthetic outcome from a functional and/or esthetic viewpoint.
2. The procedure is associated with relevant, albeit temporary, postoperative morbidity. Pain and hip-related discomfort were observed in almost all patients but were transient in the majority of cases.
3. Partial or total failure of the grafting procedure is very limited (4.5%). Some authors (Krekmanov 1995; Yerit et al. 2004) consider the preservation of the sinus mucosa a critical factor for reducing this complication, although others reported a 100% success rate of the grafting procedure despite total removal of the sinus mucosa (Isaksson et al. 1993; Nyström et al. 1997; Keller et al. 1999a).
4. Survival rates of implants placed in the reconstructed maxillae are, on average, lower (range: 67–95% – mean 87.5%) than those reported for implants placed in native bone.
5. The choice of implant placement timing is still controversial, because some authors prefer simultaneous placement (Isaksson et al. 1993; Krekmanov 1995; Lekholm et al. 1999b; Yerit et al. 2004), while others prefer implant placement after graft consolidation (Cawood et al. 1994; Nyström et al. 1997; Kahnberg et al. 1999; Keller et al. 1999a; Stoelinga et al. 2000; Chiapasco et al. 2006b).
6. None of the authors proposed immediate loading of implants placed in the reconstructed maxillae.
7. No indications have been found concerning the choice of length and diameter of implants placed in the reconstructed areas, although a tendency toward longer implants, which can engage the entire volume of the grafted bone, has been observed. In fact, a higher failure rate was found with shorter implants (Krekmanov 1995; Keller et al. 1999a). On average, six to eight implants per patient have been suggested, but no specific indications concerning the number of implants to be placed have been found.

Bone splitting/ridge expansion techniques

Patients and methods

The search provided 374 publications, of which 27 were screened as full-text articles. A total of three studies were selected (Engelke et al. 1997; Bruschi et al. 1998; Chiapasco et al. 2006c).

Overall, 392 patients were treated with bone splitting/expansion of narrow edentu-

lous ridges and immediate placement of implants. A total of 733 implants were placed in the expanded edentulous sites at the time of the expansion procedure. The gap created by splitting was either left empty or filled with different materials such as collagen sponge, BBM, AB chips, and HA. In one article, the interposed grafting material was covered with e-PTFE membranes (Engelke et al. 1997). Dental rehabilitation with removable or fixed implant-supported prostheses was started 3–6 months afterwards. Patients were followed from 6 to 68 months after the start of prosthetic loading (Table 8).

Results

Success rates of the surgical procedures ranged from 98% to 100%. The fracture of the buccal plate was the most common complication. The survival rate of implants ranged from 91% to 97.3%, while success rates ranged from 86.2% to 97.5% (Table 8).

Discussion

Bone splitting/expansion seems to be a reliable and relatively non-invasive technique to correct narrow edentulous ridges. Survival and success rates of implants placed in the expanded ridges are consistent with those related to implants placed in native, non-reconstructed bone. The gap created by sagittal osteotomy/expansion undergoes spontaneous ossification, following a mechanism that is similar to that occurring in fractures. New bone formation permits a consolidation between the oral and buccal bone plates of the alveolus, and implants placed in expanded ridges seem to withstand the biomechanical demands of loading. However, some considerations have to be made.

Bone splitting/expansion can be applied only when the buccal and palatal/lingual plates are separated by spongy bone. Therefore, the indications are more limited as compared with onlay grafts and GBR, which can also be applied in cases presenting with severe horizontal atrophy. One other limit is represented by unfavorable inclination of implants placed in expanded areas. This procedure may lead to excessive buccal inclination of implants, which may create problems from a functional and esthetic viewpoint. In case of unfavorable bone angularity, GBR or bone grafting techniques seem to represent more adequate surgical procedures.

The significantly higher number maxillary expansion procedures is justified by the fact that maxillary ridges, due to the lower bone density and thinner cortical buccal plate, are easier to treat, as compared with mandibular ridges. Mandibular sagittal osteotomy, although possible as demonstrated by some authors (Chiapasco et al. 2006c), is more difficult, due to the denser bone of the buccal plate. The drawbacks of this anatomical condition are represented by higher difficulty in expanding, risk of a more invasive and more traumatic surgical procedure, and risk of a buccal plate fracture.

Although implant survival rates are comparable to those obtained in case of implants placed in native non-augmented bone, there is a paucity of data with regard to the stability over time of the initial bone volume obtained after expansion. Only one out of three articles (Chiapasco et al. 2006c) evaluated horizontal bone changes with the aid of surgical calipers, resulting in a median value of 0.5 mm (range: 0.5–1.5 mm) 3 years after the start of prosthetic loading. It is therefore recommendable that future reports should address this aspect.

Sagittal osteotomy with interpositional bone grafts and delayed implant placement

Patients and methods

From the initial number of articles retrieved (374), six were screened as full text, but none of the articles fulfilled criteria for inclusion. Therefore, although this procedure has been described in the literature, there are no available data due to insufficient sample size and/or follow-up.

Distraction osteogenesis (DO)

Patients and methods

From the initial 106 articles retrieved, 32 were screened as full text and seven were considered suitable for inclusion. However, data were retrieved only from five articles, because two publications (Chiapasco et al. 2001, 2004a) reported data of the same group of patients presented in a more recent publication (Chiapasco et al. 2004b). A total of 123 patients, presenting with vertical resorption of partially or totally edentulous alveolar ridges, were treated with distraction devices. Both intraoral intraosseous devices and intraoral extraosseous devices were used (see Table 9 for details). The rate of distraction per day ranged from 0.5 to 1 mm. A total of 327 implants were placed, 62 of which served both as intraoral intraosseous distraction devices and as definitive implants for prosthetic restorations. Two hundred and sixty-five implants were placed 2–3 months after the comple-

Table 9. **Vertical distraction osteogenesis – characteristics of included studies**

Author and year	Study type	No. pts	Defect site	Type device	Distr succ %	Bone gain (mm)	No. impl (timing)	Follow-up (months)	Imp surv %	Imp succ %
Gaggl et al. (2000)	PCS	34	Max/mand	Intraoral/intraosseous	ND	3–6	62 (imm)	9	96	ND
Rachmiel et al. (2001)	RCS	14	Max/mand	Intraoral/intraosseous	97	8–13	23 (del)	6–20	100	ND
Raghoebar et al. (2002)	PCS	10	Mand	Intraoral/intraosseous	100	6–8	20 (del)	6–20	95	ND
Jensen et al. (2002)	PCS	28	Max/mand	Intraoral/intraosseous intraoral/extraosseous	96.7	4–15	84 (del)	12–60	90.4	ND
Chiapasco et al. (2004b)	PMCS	37	Max/mand	Intraoral/extraosseous	97.2	4–15	138 (del)	15–55	100	94
Total		123					327			

RCS, retrospective case series; PCS, prospective clinical series; PMCS, prospective multicenter clinical series; no. pts, number of patients treated; max, maxilla; mand, mandible; distr succ, success rate of the distraction procedure; imm, immediate placement; del, delayed placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

tion of distraction, once sufficient maturation of the bone in the distraction gap occurred.

Prosthetic rehabilitation was started 3–6 months after implant placement. Both fixed and removable implant-supported prostheses were used, but only two articles reported adequate information on prosthetic rehabilitation. Follow-up after the start of prosthetic loading ranged from 6 to 60 months (Table 9).

Results

Postoperative recovery after distraction was uneventful in 71% of the patients. In 13% of the patients, minor complications occurred, such as change of distraction vector (successfully corrected during distraction with prosthetic/orthodontic appliances) and transient paresthesia in the innervation area of the mandibular nerve. In 1.6% of the patients, the programmed bone gain was not reached, but it was, however, possible to complete treatment with shorter implants. In 11% of the patients, a partial relapse of the initial bone gain was observed, which, however, permitted implant placement after further minor augmentation procedures (it is worth noting that this complication occurred only in patients treated with intraoral–intraosseous devices). In two patients, a total failure of the procedure was reported (1.6%). Therefore, the overall success rate of the procedure was 98.4%. The vertical bone gain ranged from 3 to 15 mm. Out of 327 implants placed, 11 were removed, with an overall survival rate of 97%. All failures occurred in the group where intraoral intraosseous devices were used.

Success rate according to well-defined criteria (Albrektsson et al. 1986) was reported only in one article (Chiapasco et al. 2004b), in which no implants (out of 138) were lost, but eight, although osseointegrated, presented peri-implant bone resorption rates higher than those proposed for successful implants, resulting in a success rate of 94.2% (Table 9).

Discussion

Despite the limited number of patients and implants placed in the retrieved articles, the following conclusions can be drawn:

(1) DO provides an opportunity to obtain a natural formation of bone between the distracted segment and basal bone in a relatively short time span, thus avoiding the necessity of AB harvesting. This leads to a reduction of morbidity and a shortening of operating times. Soft tissues can follow the elongation of the underlying bone (neo-histogenesis) and there is a lower risk of infection of the surgical site (0% in this case series). Both limited and extended (fully edentulous patients) defects can be treated.

(2) Histologic results seem to demonstrate that DO allows the formation of an adequate quality and quantity of bone tissue, which can allow primary stability of implants and favorably withstand the biomechanical demands of loaded implants. Biopsies taken at the time of implant placement, after consolidation of the distracted area (McAllister 2001; Raghoebar et al. 2002; Zaffe et al. 2002; Chiapasco et al. 2006d), demonstrated that distraction is able to induce new bone formation that matures in a manner similar to natural bone.

(3) Survival and success rates of implants placed in distracted areas are consistent with those reported in the literature as regards implants placed in native, non-regenerated/reconstructed bone (Albrektsson et al. 1986; Adell et al. 1990a; Lekholm et al. 1994, 1999a; Lindquist et al. 1996; Buser et al. 1997; Arvidson et al. 1998; Weber et al. 2000; Leonhardt et al. 2002). Yet, some disadvantages of this technique must be underlined:

(a) Frequent lingual/palatal inclination of the distracted segment has been reported by some authors, with an incidence varying from 11% to 39% (Jensen et al. 2002; Chiapasco et al. 2004b), probably due to local muscle pull, inappropriate device positioning, and/or poor device trajectory. To solve this complication, different solutions including fixed or removable prosthodontic and orthodontic devices to guide the distracted segment to its proper final position have been suggested. Ideally, a multidirectional alveolar distraction device would allow to modify and guide the vector in several planes of space. Some authors (Watzek et al. 2000; Robiony et al. 2004) reported their experience with such a device, resulting in a reduced incidence of distracted segment malposition, but short follow-ups and lack of sufficient information concerning the success rates of implants placed in the distracted areas do not allow to draw significant conclusions.

(b) The majority of authors reported some relapse of initial bone gain, before implant placement, due to marginal bone loss of the most coronal part of the distracted segment. Therefore, a 20% overcorrection was suggested by some authors (Saulacic et al. 2005). Conversely, crestal bone changes around implants after the start of prosthetic loading seem to be similar to those occurring in case of implants placed in native, non-reconstructed bone, as demonstrated by experimental (Block et al. 1998b) and clinical studies (Rachmiel et al. 2001; Jensen et al. 2002; Chiapasco et al. 2004b).

(c) As compared with other augmentation procedures, such as GBR or bone grafting, vertical distraction does not allow simultaneous correction of narrow ridges, which is only possible with overdistraction of the segment and secondary height reduction until adequate bone width is obtained. However, overcorrection may expose to surrounding soft tissues tears and/or ischemia. The second possibility is secondary bone grafting at the time of distraction device removal (Block & Baughman 2005), but this procedure reduces one of the main advantages of alveolar distraction, that is, no need for bone harvesting.

(d) As compared with GBR and grafting procedures, which can be applied both for mandibular and maxillary defects, vertical distraction seems to be more indicated in case of correction of mandibular defects. This may be related to difficulties in maintaining an adequate vector in the maxilla, due to inextensibility of palatal fibromucosa. Secondly, maxillary sinus pneumatization can preclude the possibility of DO, due to insufficient bone height to perform the osteotomy.

Table 10. **Free flaps – characteristics of included studies**

Author and year	Study type	No. pts	Defect site	Donor site	Graft succ %	No. impl (timing)	Follow-up (months)	Imp surv %	Imp succ %
Jaquiéry et al. (2004)	RCS	5	Max/mand	Fibula	87.5	19 (imm)	12	88.2	ND

RCS, retrospective clinical series; no. pts, number of patients treated; max, maxilla; mand, mandible; graft succ, success rate of the grafting procedure; no. impl, number of implants placed; imm, immediate placement; del, delayed placement; imp surv, implant survival rate; imp succ, implant success rate; ND, no data.

Revascularized free flaps

Patients and methods

The search allowed to retrieve 31 articles: among these, 10 were screened as full text but only one was selected (Jaquiéry et al. 2004). A total of five patients, affected by extreme atrophy of the mandible, were treated with revascularized fibula free flaps. A total of 19 implants were placed in the fibula before tissue transfer in the oral cavity. Prosthetic rehabilitation was started 2–3 months after implant placement. Both fixed and removable implant-supported prostheses were used. The mean follow-up after the start of prosthetic loading was 12 months (Table 10).

Results

Postoperative recovery was uneventful in four out of five patients. In one patient, early failure of the bone transplant and implants occurred. Out of 19 implants placed, seven were removed in two patients treated. The survival rate of implants was 72% (Table 10).

Discussion

The extremely limited sample of patients treated with revascularized flaps used for the rehabilitation of severely atrophic jaws does not allow to draw meaningful conclusions. However, also on the basis of the relevant experience obtained by revascularized flaps used for the reconstruction of postoncologic defects (Schmelzeisen et al. 1996; Roumanas et al. 1997; Chiapasco et al. 2000, 2006e), some preliminary considerations can be anticipated:

(1) Free revascularized flaps, as compared with non-vascularized bone grafts, present some advantages that can be summarized as follows: (a) very limited bone resorption of the graft before and after implant placement; and (b) no need for adequate soft tissue recipient bed. This means that the bone transplant can survive also in case of hypotrophic, hypovascularized, scarry tissues.

(2) Free revascularized flaps, as compared with non-revascularized bone grafts, presents the following disadvantages: (a) the harvesting technique is more complicated; (b) the operating time is longer; (c) the morbidity is higher; (d) the hospitalization is longer; (e) the costs are increased; and (f) a specific expertise in microsurgical techniques is mandatory.

Therefore, free flaps should be limited to patients presenting with extreme atrophy of the jaws associated with poor local conditions of the recipient bed, due to hypovascular, hypotrophic, scarry hard, and soft tissues.

Conclusion

This literature review has demonstrated that a wide range of different surgical procedures can be used to correct deficient edentulous ridges. It has also been demonstrated that, on the basis of available data, it is difficult or impossible to demonstrate that a particular surgical procedure offers a better outcome as compared with another, as far as the predictability of the augmentation and survival/success rates of implants placed in the augmented sites are concerned. Every surgical procedure presents advantages and disadvantages, which must be carefully evaluated before surgery. Moreover, it is not yet known whether some surgical procedures that are widely used in the clinical practice, such as GBR procedures in case of fenestrations/dehiscences, sinus grafting procedures in case of limited/moderate sinus pneumatization, or reconstruction of atrophic edentulous mandibles with onlay AB grafts, are really useful for the improvement of long-term survival of implants.

The main limit encountered in this literature review has been the overall poor methodological quality of the published articles. This may reduce the possibility of drawing significant conclusions. As suggested by Esposito et al. (2006), in order to understand when bone augmentation procedures are needed and which are the most effective techniques for the specific clinical indications, larger well-designed long-term trials are needed. Such trials should be reported according to Consolidated Standards of Reporting Trials (CONSORT) guidelines (Moher et al. 2001). It was also stated that it is difficult to provide clear indications with respect to which procedures are actually needed. Priority should be given to those procedures that appear simpler, less invasive, involve less risk of complications, and reach their goals within the shortest time frame. Esposito et al. (2006), by selecting only randomized clinical trials dealing with augmentation procedures, found only nine articles fulfilling their criteria and reported the following conclusions:

(1) some bone substitutes may be equally effective as AB grafts for augmenting atrophic maxillary sinuses;

(2) osteodistraction and various GBR techniques are able to regenerate bone in a vertical direction. However, there is insufficient evidence to indicate which technique could be preferable. Osteodistraction is of little use in the presence of thin ridges, but may allow more vertical regeneration. Complications with GBR techniques were common, and in some cases determined the failure of the intervention;

(3) there is no reliable evidence supporting superior success of any of the alternative techniques for augmenting bone at fenestrated implants; and

(4) major bone grafting procedures of extremely resorbed mandibles may not be justified.

However, they stressed the fact that these findings were based on a few trials including a few patients, generally having a short follow-up, and being often judged to be at high risk of bias.

Our review, which included a higher number of studies, because of less strict selection criteria, confirmed, on average, conclusions by Esposito et al. (2006).

Despite the above-mentioned limits, the following considerations can be made:

(1) bone augmentation with AB grafts and GBR techniques, sagittal osteotomies, and Le Fort I osteotomy are sufficiently documented; vertical DO is sufficiently documented but the patient and implant sample is limited;
(2) horizontal DO lacks sufficient documentation to draw meaningful conclusion;
(3) bone augmentation with revascularized free flaps lacks sufficient documentation to draw meaningful conclusion;
(4) sinus floor augmentation with autogenous and non-autogenous grafting materials is well documented, although more data are needed to correlate survival rates of implants either to initial bone volumes or the type of grafting material; and
(5) nasal floor augmentation lacks sufficient documentation to draw a meaningful conclusion.

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