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Autogenous bone harvesting and grafting in advanced jaw resorption: Morbidity, resorption and implant survival

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Aim: To analyse the morbidity arising from autogenous bone graft harvesting, graft resorption and implant survival in grafted sites.
Materials and methods: Only comparative clinical trials on the harvest of autogenous bone grafts were selected. Studies were excluded if they compared autogenous bone grafts to bone substitutes or vascularised free bone grafts.
Results: A total of 24 studies were included in the review. Six intraoral or distant donor sites were identified. The highest level of evidence was reached by a randomised controlled trial. The mandibular ramus was the source of bone that was preferred by the patients. From this intraoral donor site bone was harvested under local anaesthesia on an outpatient basis. Patients' acceptance of chin bone harvesting was low. It led to a considerable morbidity that included pain, superficial skin sensitivity disorders and wound healing problems at the donor site. Patients even preferred iliac crest bone harvesting over bone harvesting from the chin, although this distant donor site required general anaesthesia and a hospital stay. The harvest of posterior iliac crest block led to less morbidity than the harvest of anterior iliac crest block grafts. When only cancellous bone was needed, percutaneous bone harvesting from the iliac crest led to less morbidity than an open approach to the iliac crest.
Conclusions: Dependent on the required graft structure and amount of bone needed, ramus grafts, block bone grafts from the posterior iliac crest and cancellous bone grafts harvested with a trephine from the anterior iliac crest should be chosen.

Conflict-of-interest statement: *The authors declare that they have no conflict of interest.*

■ Introduction

Edentulism profound marginal periodontitis, trauma, malformation, neoplasia and insufficient dentures can lead to atrophy of the alveolar crest[1]. Advanced jaw resorption can cause problems when the placement of dental implants is intended. Limited residual alveolar bone volume potentially results in aesthetic and functional compromise. Therefore, an adequate quantity and quality of bone can be considered a prerequisite for a successful oral rehabilitation with dental implants[2].

Augmentation procedures allow the re-establishing of bone volume that is adequate for implant placement. Autogenous bone, allografts, xenografts, alloplastic materials, and mixtures of the various materials have been used for this purpose[3]. Among the different available materials, only autogenous bone combines osteoconductive, osteoinductive, and osteogenic properties[4]. Autogenous

bone is believed to be the most effective grafting material[5]. Consequently, it is not surprising that the use of autogenous grafts is still considered to be the method of choice when augmentation procedures have to be performed on patients with advanced jaw resorption[6]. The high predictability of these procedures has been stressed. Success rates exceeding 95% have been achieved, even when major augmentation procedures with autogenous bone had to be carried out for severely resorbed jaws[7].

A number of different donor sites are available for the harvest of bone grafts. The grafts differ considerably as far as embryology, histology, mechanical properties and the volume that can be harvested are concerned. Membranous as well as endochondral bone grafts from regional or distant sites are available. The choice of a specific donor site often is based on a number of different aspects like resorption rate of the graft or the donor site morbidity[2].

The present review aimed at comparing different donor sites for autogenous bone based on comparative studies. The focused question was: Does a donor site exist that is superior to alternative sites, in terms of the extent of donor site morbidity, the quantity of available bone, the extent of bone graft resorption and the survival or success rate of dental implants placed in the augmented sites?

Materials and methods

Search strategy

A systematic search strategy was used. In the initial phase of the review, a computerised literature search for human studies was performed (Medline and Embase databases, 1 January 1966 to 31 December 2013). There was no language restriction.

In addition, a hand search was carried out in: *Annals of Periodontology; British Journal of Oral and Maxillofacial Surgery; Clinical Implant Dentistry & Related Research; Clinical Oral Implants Research; Dental Clinics of North America; European Journal of Oral Implantology; European Spine Journal; Implant Dentistry; The International Journal of Oral and Maxillofacial Surgery; International Journal of Periodontics and Restorative Dentistry; International Journal of Prosthodontics; Journal of Clinical Periodontology; Journal of Cranio-Maxillofacial Surgery; Journal of Oral Implantology; Journal of Oral and Maxillofacial Surgery; Journal of Periodontology; Journal of Prosthetic Dentistry; Journal of the American Dental Association; Medicina Oral Patologia Oral y Cirugia Bucal; Mund-, Kiefer- und Gesichtschirurgie; Oral and Maxillofacial Surgery; Oral and Maxillofacial Surgery Clinics of North America; Oral Surgery Oral Medicine Oral Pathology; Periodontology 2000; Scandinavian Journal of Plastic and Reconstructive Surgery; The International Journal of Oral and Maxillofacial Implants; The Journal of Bone and Joint Surgery*; and *The Knee.*

Moreover, the Cochrane Controlled Trials Register and The Cochrane Health Group Specialized Register were checked for publications on harvesting of autogenous bone grafts.

The full texts of publications with potential relevance were obtained. Additional articles were identified from the reference lists of the retrieved papers.

Search terms

Keywords were 'bone graft' OR 'autogenous bone graft' OR 'autologous bone graft' OR 'autogenous bone harvesting' OR 'autologous bone harvesting'. The search was limited to 'human trial' (what the Medical Subject Headings (or MeSH) term clinical studies). Additionally, the MeSH terms 'clinical trial', 'comparative study', 'controlled clinical trial', 'randomised controlled trial', 'meta-analysis', and 'review' were also used.

Inclusion criteria

The inclusion criteria for study selection were: (i) comparative clinical studies; (ii) exclusive use of autogenous bone grafts for the augmentation procedure; and (iii) a number of at least 10 patients.

Exclusion criteria

Publications dealing with *in vitro* studies, preclinical (animal) studies, cadaver studies, case reports and reviews were excluded. Human studies not meeting all the inclusion criteria were also excluded from the review. In addition, studies were excluded if: (i) additional augmentation procedures were performed with materials other than autogenous bone (e.g.

xenografts, allografts, barrier membranes, growth factors, stem cells, etc.); (ii) vascularised free bone grafts were used; (iii) distraction osteogenesis was used; (iv) augmentation procedures were compared to short implants; (v) data presentation that did not allow distinguishing results for the different types of grafts used; (vi) bone grafts were harvested from patients suffering from malformations; (vii) augmentation procedures were carried out following the removal of benign or malignant tumours; (viii) the included patients had received radiation therapy or chemotherapy; and (ix) the studies reported on a patient cohort that had been the basis for a previous publication by the same authors.

Selection of studies

Titles derived from the broad search were screened based on the inclusion criteria. Subsequently, abstracts of all titles considered relevant were obtained and again screened for meeting the inclusion criteria. If an abstract was not available in the database, the abstract of the printed article was used. Again, a selection was made based on the inclusion criteria, and relevant full texts were obtained. The final selection of the publications to be included in the review was based on an analysis of the 'Materials and methods' and 'Results' sections of the full-text articles concerning the fulfilment of the inclusion and exclusion criteria.

Data extraction

From the selected papers, data were extracted on the following: author(s); year of publication; study design; follow-up period; number of patients; donor site; kind of anaesthesia; graft volume; grafting procedure; complications and donor site morbidity; graft resorption; implant survival; and implant success.

Results

Initial electronic search

By the electronic search, a total of 798 titles were identified. Out of these, 316 abstracts were obtained. Screening of the abstracts led to the selection of 136 full texts. Based on a hand search, an additional 43 relevant abstracts were included and the respective full texts were obtained. Further selection of studies was based on a total of 232 full texts. A total of 24 original articles fulfilled the inclusion criteria and did not meet any exclusion criteria. The study with the highest level of evidence was a randomised controlled one[8].

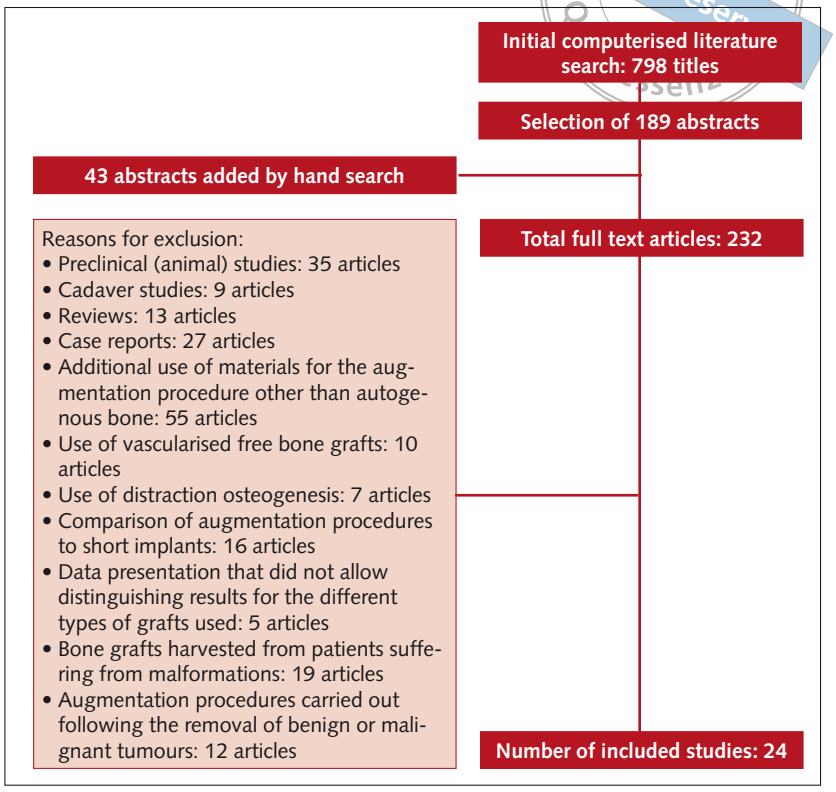

Fig 1 Search strategy for identification of relevant articles.

Exclusion of studies

Reasons for excluding studies after the full text was obtained were: preclinical (animal) studies (35 articles); cadaver studies (9 articles); reviews (13 articles); case reports (27 articles); additional use of materials for the augmentation procedure other than autogenous bone (55 articles); use of vascularised free bone grafts (10 articles); use of distraction osteogenesis (7 articles); comparison of augmentation procedures to short implants (16 articles); data presentation that did not allow distinguishing results for the different types of grafts used (5 articles); bone grafts harvested from patients suffering from malformations (19 articles); or augmentation procedures carried out following the removal of benign or malignant tumours (12 articles, Fig 1).

Included studies

A total of 24 articles were selected for inclusion in a narrative style review. They are presented in Table 1. In the selected comparative studies, six donor sites for bone harvesting were identified. They comprised the calvarium, the mandibular ramus, the chin, the anterior iliac crest, the posterior iliac crest and the proximal tibia.

Patients' acceptance of bone harvesting

A questionnaire-based interview survey shows that harvesting bone grafts for preprosthetic procedures is widely accepted by potential patients[18]. Some 61% of the interviewees were willing to undergo bone grafting if this procedure would facilitate implant placement. However, 23% of the patients were willing to accept bone harvesting from the iliac crest, but 15% of the patients indicated that they would prefer bone harvesting from the chin. The majority of the patients (85%) answered that they would prefer bone harvesting from the retromolar region[18].

When the harvesting of chin bone grafts was proposed to patients who would benefit from an augmentation procedure, again the limited acceptance of this donor site became obvious[21]. Patients had cosmetic concerns and feared changes of the chin contour. Conversely, cosmetic concerns did not arise when bone harvesting from the ramus was proposed[21].

In one study, patients were asked to compare the postoperative strain put on them by the bone harvesting procedure with their preoperative expectations[16]. The two patient cohorts that were compared received bone harvesting from the anterior iliac crest either with an anteromedial or a superolateral approach. Both procedures were well accepted. For the anteromedial and the superolateral approach, the postoperative course was considered better than expected by 26 out of 30 patients and 34 out of 40 patients, respectively[16].

The acceptability of bone harvesting from intraoral sites did not statistically significantly differ between chin and ramus grafts[25]. However, the acceptability of ramus bone harvesting increased significantly when it was combined with the removal of the third molar.

Following chin bone harvesting, patients sometimes complain about an altered chin contour. In one study, 10 out of 29 patients noted changes of their chin contour when bone was harvested from this site[14]. Comparable complaints were not described for a cohort of 24 patients who underwent ramus bone harvesting[14]. On clinical examination, contour changes following chin bone harvesting could not be verified.

Characteristics of bone graft harvesting procedures

Bone harvesting from the mandibular ramus and the chin was performed, preferably under local anaesthesia and was sometimes combined with intravenous sedation (Table 1). Instead, for all other donor sites bone harvesting under general anaesthesia was preferred (Table 1). The surgical access to the ramus has been described as being more difficult than the access to the chin[21]. As far as the duration of surgery was concerned, bone harvesting from the proximal tibia with a trephine took a mean time of 15 mins, while trephine bone harvesting from the iliac crest took 21 mins[19]. As far as the duration of surgery for other donor sites and harvesting techniques is concerned, there are no data available from comparative studies. The same is true for the assessment of the duration of the inpatient period following bone graft harvesting. The comparison of bone harvest from the iliac crest with a trephine compared to an open approach showed that the length of the hospital stay was significantly shorter for the trephine procedure (4.1± 0.9 days and 2.2 ± 0.4 days, respectively, $P < 0.05$)[26].

Bone graft volume and density

Bone from the ramus was preferred for vertical and horizontal onlay augmentation procedures compared to chin bone. A greater volume of chin bone could be harvested, compared to retromolar bone[15]. A mean volume of 1.74 cm^3 has been found for chin bone grafts, while the mean volume for ramus bone grafts was 0.9 cm^3 [21]. Therefore, bone from the chin was preferred when a bilateral sinus floor augmentation had to be performed[15].

The percutaneous harvesting of iliac crest bone with a trephine was limited to 10 cm^3, while

larger volumes could be harvested using an open approach[20].

When the available bone volume at the anterior iliac crest was compared to the proximal tibia, it was significantly less (17.63 cm^3 and 38.60 cm^3, respectively, $P < 0.001$)[22].

When the bone density of grafts from the anterior iliac crest, the posterior iliac crest and the chin were compared at the time of the grafting procedure, the density of the anterior iliac crest bone (35.1 ± 7.6% at the time of grafting, 36.1 ± 7.6% 6 months after grafting) and the density of the posterior iliac crest bone grafts (30.7 ± 9.5% at the time of grafting, 34.5 ± 6.5% 6 months after grafting) did not change significantly[27]. The density of chin bone grafts reduced significantly during that time interval (74.6 ± 8.6% at the time of grafting; 54.0 ± 8.6% 6 months after grafting, $P = 0.003$)[27]. When bone density was measured in Hounsfield Units (HU), the density of particulated grafts (chin and iliac crest) increased significantly over a time interval of 5 years (704 ± 213 HU at time of grafting, 868 ± 169 HU after 5 years, $P = 0.0313$)[30]. During the same time interval, block bone grafts (chin and iliac crest) did not change statistically significantly, as far as HU were concerned ($P = 0.3750$)[30].

Donor site morbidity

It has been shown that the patient perception of the morbidity of harvesting of bone grafts from the chin or the mandibular ramus did not lead to statistically significant differences when the morbidity was rated on a visual analogue scale. For both procedures, the morbidity was low[15]. However, an altered sensation in the mandibular incisors has been identified as a source of morbidity on a frequent basis following chin bone harvesting. This problem was described by 29% of the patients who underwent this procedure[21]. Root canal treatment became necessary in 2 out of 282 teeth following chin bone harvesting[15]. It has been stressed that altered sensations did not occur in patients who underwent ramus bone harvesting[21].

The occurrence of superficial skin sensitivity disorders has been identified as an issue with intraoral bone harvesting. Superficial skin sensory disturbances were found significantly more often after chin bone harvesting, compared to bone harvesting from retromolar sites[13-15]. A percentage of 9.6% for superficial skin sensitivity impairment has been described following chin bone harvesting, while sensitivity disorders were not found following ramus bone harvesting[21]. However, postoperative pain during chewing and bleeding were only reported after retromolar bone harvesting[15]. The problem did not occur following ramus bone harvesting. Conversely, incision-line dehiscence was exclusively found following chin bone harvesting in 10.7% of the cases[21]. A comparable problem did not occur following ramus bone harvesting.

It has been described in the current literature that besides harvesting bone from the ramus, bone harvesting from the calvarium as well as the iliac crest can be performed without significant patient morbidity as far as pain and discomfort are concerned[12,13]. However, it has to be stressed that comparative studies that evaluate the morbidity of calvarial bone harvesting are scarce.

On the other hand, a number of comparative studies have been dedicated to the assessment of donor site morbidity arising from bone harvesting from the iliac crest.

After bone harvesting from the anterior iliac crest by an open approach, patients complained about significantly more pain in the initial postoperative phase compared to the harvesting from the posterior iliac crest ($P = 0.004$)[23]. Pain sensations even seemed to last for a longer period of time when the anterior iliac crest is used as a donor site ($P = 0.0017$)[9]. Bone harvesting from the posterior iliac crest led to significantly less minor complications (e.g. haematomas) compared to bone harvesting from the anterior iliac crest ($P = 0.006$).[9] As far as superficial skin sensitivity disorders were concerned, they were also significantly more pronounced following open bone harvesting from the anterior iliac crest, compared to the posterior iliac crest ($P = 0.023$)[23].

When an anterolateral approach to the anterior iliac crest was compared to a superolateral approach to the anterior iliac crest, there was no statistically significant difference in persistent postoperative pain (17% and 34%, respectively), gait disturbance (17% and 25%, respectively), and the need for the use of crutches (37% and 50%, respectively)[16]. Neither of the two different approaches was able to reduce the

Table 1 Compilation of the studies included in the review (/ = no data available).

Authors	Design of study	Follow-up period	No. of patients	Patient age (years)	Donor site	Kind of anaesthesia
Ahlmann et al, 2002[29]	Retrospective	≥ 2 years	66 42	Range 12–77	Anterior iliac crest Posterior iliac crest	General General
Carinci et al, 2005[10]	Prospective	16.5 ± 7.7 months	21 47	48.2 ± 8.4 (both cohorts)	Iliac crest Calvarium	/
Chiapasco et al, 2012[11]	Prospective	19 months on average	7 11	49.1 (both cohorts)	Calvarium Ramus	General Local (combined with sedation)
Chiapasco et al, 2013[12]	Prospective	23.9 months on average	15 19 6 4	50.2 ± 16.1 53.5 ± 10.5 44.3 ± 18.3 40.5 ± 15.3	Calvarium Calvarium (with pericranium) Ramus Ramus (with pericranium)	Local or general (all cohorts)
Chiapasco et al, 2014[13]	Prospective	33 months on average	9 10 6 7 11 7	53.8 ± 13.0 40.9 ± 17.0 59.3 ± 4.4 55.9 ± 13.2 44.8 ± 12.1 49.2 ± 14.9	Calvarium (tissue level implant) Ramus (tissue level implant) Iliac crest (tissue level implant) Calvarium (bone level implant) Ramus (bone level implant) Iliac crest (bone level implant)	Local or general (all cohorts)
Clavero et al, 2003[14]	Prospective	18 months	29 24	Mean of 48 years (both cohorts)	Chin Ramus	Local (combined with sedation, both cohorts)
Cordaro et al, 2011[15]	Cross sectional	29 months on average	41 37	Range 18–68 (both cohorts)	Ramus Chin	Local (combined with sedation, both cohorts)
Cricchio and Lundgren, 2003[16]	Retrospective	2 years	30 40	56 on average (both cohorts)	Anteromedial iliac crest Superolateral iliac crest	General General
Eufinger and Leppänen, 2000[17]	Retrospective	Range 1–6 years	26 26	12.2 on average	Anterior iliac crest (trephine) Anterior iliac crest (open approach)	General General
Felice et al, 2009[8]	Randomised controlled	18 months on average	10 10	55.2 ± 13.6 52.7 ± 7.6	Anterior iliac crest (both groups)	General General
Hof et al, 2014[18]	Cross sectional (Questionnaire-based assessment of patients' perspectives)	/	150	Range 18–84	Chin Ramus Iliac crest	Local Local General
Ilankovan et al, 1998[19]	Prospective	7 days	15 15	Range 14–66 (both cohorts)	Proximal tibia (trephine) Anterior iliac crest (trephine)	/

Graft volume	Grafting procedure	Complications	Graft resorption	Implant survival	Implant success
54.53 cm³ on average 55.12 cm³ on average	/	Haematoma, sensory disturbance, pain Sensory disturbance	/	/	/
/	Onlay/inlay (both cohorts)	None None	39% 17%	/	/
/	Onlay/sinus floor augmentation (both cohorts)	Dehiscence at recipient site None	0.41 ± 0.67 mm 0.52 ± 0.45 mm	100% 100%	90.3% 93.1%
/	Onlay (all cohorts)	Dehiscence at recipient site Dehiscence at recipient site Dehiscence at recipient site None	0.64 ± 2.35 mm 0.23 ± 0.50 mm 1.86 ± 3.76 mm 0	100% 98.97% 100% 100%	91.03% 94.18% 100% 100%
/	Onlay (all cohorts)	None None None Dehiscence None Dehiscence	0.21± 0.37 mm 0.23 ± 0.30 mm 0.36 ± 0.39 mm 0.35 ± 0.52 mm 0.48 ± 0.42 mm 1.34 ± 1.33 mm	100% 100% 100% 100% 100% 100%	100% 100% 100% 90.3% 93.5% 76.4%
/	Onlay/inlay (both cohorts)	Pain, bleeding, swelling, bruising, neurosensory disturbance, functional limitations in eating, chewing, limited drinking, and speaking, reduced mouth opening (both cohorts)	/	/	/
/	Onlay/sinus floor augmentation (both cohorts)	Swelling, bleeding, pain, sensory disturbance, prolonged healing Swelling, pain, sensory disturbance (lip, teeth), prolonged healing	/	/	No difference between the two cohorts
/	/	Persistent pain, gait disturbance Persistent pain, gait disturbance	/	/	/
/	Onlay (both cohorts)	Pain, wound infection Pain	/	/	/
/	Interpositional graft Onlay	Dehiscence at recipient site Dehiscence and infection at recipient site	13.6 ± 14.4% 44.5 ± 15.7%	100% 100%	90% 86.9%
/	/	/	/	/	/
17 cm³ on average, range 5 to 26 cm³ (both cohorts)	Inlay/onlay Inlay/onlay	Pain, gait disturbance Pain, gait disturbance	/	/	/

Table 1 *(cont.)* Compilation of the studies included in the review (/ = no data available).

Authors	Design of study	Follow-up period	No. of patients	Patient age (years)	Donor site	Kind of anaesthesia
Kreibich et al, 1994[20]	Cross sectional	/	58 (both groups)	/	Anterior iliac crest (percutaneous) Anterior iliac crest (open approach)	/
Misch, 1997[21]	Prospective	6 months	19 31	/	Ramus Chin	Local (combined with sedation, both cohorts)
Nikolopoulos et al, 2008[22]	Cross sectionall	/	15 15	Range 24–96 (both cohorts)	Anterior iliac crest Proximal tibia	/
Nkenke et al, 2004[23]	Prospective	1 month	25 25	52.0 ± 9.6 52.9 ± 9.1	Anterior iliac crest Posterior iliac crest	General (both cohorts)
Pollock et al, 2008[24]	Prospective	19.8 months on average	52 24	46.1 on average 45.6 on average	Anterior iliac crest (trephine) Anterior iliac crest (open approach)	General (both cohorts)
Raghoebar et al, 2007[25]	Prospective	12 months	15 15 15	29 ± 7	Chin Ramus Ramus (simultaneous third molar removal)	Local (all cohorts)
Sandor et al, 2003[26]	Prospective	3 days	54 22	22.6 ± 9.6 24.2 ± 9.6	Anterior iliac crest (trephine) Anterior iliac crest (open approach)	/
Schlegel et al, 2006[27]	Prospective	6 months	18 15 28		Chin Anterior iliac crest Posterior iliac crest	Local General General
Sbordone et al, 2009[28]	Retrospective	3 years	40 (both cohorts)	46.8 ± 12.1 (both cohorts)	Chin Anterior iliac crest	General (both cohorts)
Sbordone et al, 2012[29]	Retrospective	6 years	16 (both cohorts)	55.4 ± 8.2 (both cohorts)	Anterior iliac crest (both cohorts)	General (both cohorts)
Sbordone et al, 2013[30]	Retrospective	6 years	10 7	Range 24–96 (both cohorts)	Chin/anterior iliac crest block Chin/anterior iliac crest particulate	not specified (both cohorts)
Wiltfang et al, 2005[31]	Retrospective	5 years	100 (both cohorts)	56.3 (both cohorts)	Anterior iliac crest Posterior iliac crest	General General

Graft volume	Grafting procedure	Complications	Graft resorption	Implant survival	Implant success
≤ 10 cm³ Not specified	/	Postoperative pain, abnormal neurology, wound tenderness Postoperative pain, pain on walking, abnormal neurology, wound tenderness	/	/	/
0.9 cm³ on average 1.74 cm³ on average	Onlay (both cohorts)	Pain Pain, dehiscence, neurosensory disturbance of teeth and soft tissue	Up to 25% Up to 25%	/	/
17.63 cm³ 38.60 cm³	/	/	/	/	/
10 cm³ 14 cm³	Onlay/sinus floor augmentation (both cohorts)	Pain, gait disturbance, neurosensory impairment Pain, gait disturbance, neurosensory impairment	/	/	/
/	/	Haematoma, meralgia paraesthetica, superficial infection Haematoma, meralgia paraesthetica, chronic pain	/	/	/
Range 1 to 3 cm³ Not specified Not specified	Onlay (all cohorts)	Prolonged postoperative pain, altered sensations in lower incisors, transient hypoesthesia of labial gingiva, paraesthesia, meteorotropism Prolonged postoperative pain Prolonged postoperative pain, delayed socket healing	/	100% 1 implant loss 100%	/
≤ 30 cm³ (both cohorts)	/	Pain, gait disturbance (both cohorts)	/	/	/
/	Sinus floor augmentation (all cohorts)	/	/	/	/
/	Onlay (both cohorts)	/	Maxilla 4.6 ± 0.9 mm Mandible / Maxilla 2.6 ± 1.4 mm Mandible 4.0 ± 1.6 mm	Maxilla 100% Mandible / Maxilla 100% Mandible 98.1%	/
1.25 cm³ 1.25 cm³	Onlay (both cohorts)	/	Maxilla 105.5% Mandible 87%	Maxilla 100% Mandible 100%	/
>0.5 cm³ >0.5 cm³	Sinus floor augmentation (both cohorts)	/	21.5% 39.2%	100% 86.6%	
/	Onlay/sinus floor augmentation (both cohorts)	/	Anterior less than posterior	92.4% 93.9%	/

donor site morbidity of iliac crest bone harvesting by an open approach, significantly[16].

The donor site morbidity of anterior iliac crest bone harvesting is significantly reduced when a percutaneous approach is used instead of an open approach[20]. Lower postoperative pain (P <0.02), pain on walking (P <0.05), superficial skin sensitivity impairment (P <0.01) and wound tenderness (P <0.05) were documented[20]. Significantly reduced postoperative pain with trephine hip bone harvesting has been confirmed by other authors (P <0.05)[26]. Unassisted ambulation also could be reached earlier when a trephine was used, compared to an open approach (2.8 days and 4.1 days, respectively)[26]. Harvesting of bone from the iliac crest with a trephine reduced the analgesic consumption significantly compared to an open approach (P <0.008)[17]. Although there is one study in the current literature that found comparable results as far as donor site morbidity was concerned when a trephine and an open method were used for bone harvesting from the iliac crest, it has never been described that the trephine technique increases donor site morbidity[24]. Moreover, the length of the scar that resulted from the surgical approach was significantly shorter when the incision was made for trephine harvesting compared to an open approach (24.2 mm and 60.3 mm, respectively, P <0.0001)[17].

When bone harvesting with a trephine from the proximal tibia and the anterior iliac crest were compared, pain and difficulty in walking were lower for the tibia group[19].

Complications at recipient site

After onlay augmentation with ramus, iliac crest or calvarial bone grafts, the rate of dehiscences were comparable for the different types of bone grafts[11-13]. There was a tendency towards a lower rate of dehiscences with ramus bone grafts. However, statistically significant results were not found.

When the rate of complications (e.g. mucosal dehiscence or infection) was compared between sites augmented by inlay grafts or onlay grafts, the rate was comparable for both techniques (30% for each technique)[8].

The small amount of data on complications following bone grafting at the recipient site seems to show that the kind of bone graft chosen only has a minor influence on the complication rate.

Graft resorption

Resorption of bone grafts is a major issue following augmentation procedures. It has been stated that the volume of block bone grafts (chin and iliac crest) did not change significantly over a 6-year period (P = 0.2754)[30]. The same result was found for particulated grafts (P = 0.0781)[30]. During a 5-year follow-up period, resorption of bone grafts from the anterior iliac crest did not differ statistically significantly from the resorption of bone grafts from the posterior iliac crest[31]. Block bone grafts from the iliac crest as well as the chin used for sinus floor augmentation tended to show less resorption during a 6-year follow-up interval compared with particulated bone grafts from the same donor sites (21.5% and 39.2% resorption, respectively)[30].

When the resorption of iliac crest bone grafts used for vertical or horizontal onlay augmentation was compared between maxilla and mandible, the resorption in the maxilla was significantly more pronounced after 2 years[29]. After 6 years, 87% of resorption was found in the mandible, while the grafts were completely resorbed in the maxilla[29].

It has been shown that the resorption of onlay grafts was significantly more pronounced for chin grafts, compared to iliac crest bone grafts[28]. Block bone grafts from the chin and the ramus did not differ as far as resorption was concerned when they were used for onlay augmentation procedures[21].

The results for graft resorption are conflicting when calvarial bone is involved in comparative studies. It has been described that graft resorption was more pronounced for calvarial grafts compared to ramus bone grafts after a mean interval of 23.9 months[12]. On the other hand, the same working group described that calvarial bone showed less resorption than mandibular ramus bone, while graft resorption was the most pronounced for iliac crest bone grafts[13]. At the time of implant placement, ramus bone grafts showed a resorption of 0.42 ± 0.39 mm, while calvarial bone grafts showed a resorption of 0.18 ± 0.33 mm[11]. After a mean of 19 months of prosthetic loading, graft resorption was 0.52 ± 0.45 mm with mandibular ramus bone and 0.41± 0.67 mm with calvarial bone[11].

Results with the same tendency were also found by other authors. Graft resorption was significantly less for calvarial bone after 10 months of follow-up compared to iliac crest bone grafts ($P = 0.004$)[10]. However, after 30 months, the difference in resorption was no longer statistically significant[10]. Age and gender of the patients, the site to be augmented, and the type of augmentation surgery did not influence graft resorption significantly[10].

When onlay bone grafting was compared to inlay bone grafting, the initial height gain of the alveolar crest was significantly larger for the onlay procedure[8]. However, the loss in vertical dimension was significantly lower for inlay bone grafting compared to onlay bone grafting (0.5 mm and 2.75 mm, respectively, $P < .001$)[8].

Implant survival and success

Implant survival and success rate are important parameters that are at least in part dependent on the preceding augmentation procedures. When implant sites grafted with chin bone or bone from the ramus no differences in implant success could be found[15]. After a mean follow-up period of 23.3 months, an implant success rate of 95.5% was found[15]. During an average follow-up interval of 23.9 months, the survival and success rate for implants placed in ramus bone grafts was 100%. For implants placed in calvarial grafts, a survival rate of 99% and a success rate of 91% were reached[12].

After a mean prosthetic loading period of 19 months, the implant survival rate was 100% for implant sites grafted with mandibular ramus bone, as well as for implant sites grafted with calvarial bone[11]. The success rate was 90.3% for implants placed in calvarial bone and 93.1% for implants placed in mandibular ramus bone[11]. All failures were attributed to peri-implant disease.

After a mean follow-up period of 33 months, the implant success rate was 93.5% for implant sites grafted with mandibular ramus bone, 90.3% for sites grafted with calvarial bone, and 76.4% for sites grafted with iliac crest bone. Irrespective of the graft origin, an influence of the implant design on the success rate was found[13].

A 3-year cumulative implant survival rate of 100% following onlay grafting regardless of source (either chin or iliac crest bone) could be identified for the maxilla[28]. With the mandible grafted with iliac crest onlay grafts, the 3-year cumulative implant survival rate was 98.1%.

After a follow-up period of 5 years, the implant survival rate was 92.4%, when the implant sites had been grafted with bone from the anterior iliac crest, and 93.9% when the grafting procedure had been carried out with bone from the posterior iliac crest[31]. The difference did not show a statistical significance.

When implant survival is compared for sites augmented by inlay grafts or onlay grafts, the survival rate is 100% for both techniques[8]. With 90.0% and 86.9%, respectively, implant success is also comparable for both techniques[8].

Discussion

Although a number of alternatives exist, autogenous bone is still considered one of the most popular materials for preprosthetic augmentation procedures[32]. A wide variety of donor sites are available for the harvest of autogenous bone. Grafts that are harvested by an intraoral approach (e.g. coronoid process, tuber, zygomatic buttress) as well as grafts that are harvested from distant sites (e.g. rib, radius, femur) have been described[33-36]. Quality, quantity and high predictability of uneventful healing at the recipient sites are major reasons to opt for autogenous bone. However, harvesting of bone potentially causes donor site morbidity. Morbidity is a major issue for the patients. They appreciate procedures that reduce morbidity associated with implant-based oral rehabilitation[37]. Bone substitutes avoid donor site morbidity. However, although excellent clinical and histological outcomes have been reported for smaller defects, the predictability of the repair of larger defects is still limited[38]. Therefore, in cases where large amounts of bone are required, autogenous bone is considered the first choice[38]. Nevertheless, preprosthetic augmentation procedures have to be considered elective surgery.

Therefore, besides a successful reconstruction of the alveolar crest, patient acceptance of the procedure should be high, while the morbidity of the procedure should be minimal[1]. The present review aimed at comparing different donor sites for auto-

genous bone based on comparative studies. The focused question was: Does a donor site exist that is superior to alternative sites in terms of the extent of donor site morbidity, the quantity of available bone, the extent of bone graft resorption, and the survival or success rate of dental implants placed in the augmented sites?

Patients' acceptance of bone harvesting

The analysed literature reveals that bone harvesting is accepted by patients if this procedure is necessary to allow placing implants[18]. The least popular donor site was the chin, while a majority of the participants of the study would prefer bone harvesting from the mandibular ramus. Even more participants opted for iliac crest bone harvesting than for chin bone harvesting. It seems that these patient decisions are based on major aesthetic concerns that arise when chin bone harvesting is planned[21]. Surprisingly, approximately one third of the patients who undergo chin bone harvesting complain about an altered chin contour that cannot be verified on clinical examination[14]. Again, this finding hints at the limited acceptance of chin bone harvesting by the patients.

During the postoperative course, the patients tend to consider the reconstructive procedures performed with anterior iliac crest bone better than expected[16]. This finding reflects the good acceptance of this bone harvesting procedure that usually even has to be carried out under general anaesthesia (Table 1).

As far as patients' acceptance of calvarial or tibial bone harvesting is concerned, no relevant data could be identified in the present review.

Characteristics of bone graft harvesting

Bone harvesting from intraoral sites is preferably performed under local anaesthesia (Table 1). Consequently, this kind of bone harvesting can be performed with fewer risks than bone harvesting from distant sites, where general anaesthesia is preferred. The access to the chin bone has been described as being easier than that to the mandibular ramus (Misch, 1997)[21]. Both techniques are performed on an outpatient basis, while harvesting of bone from distant sites is associated with a hospital stay and again increases costs[26]. Only limited data are available on the duration of bone harvesting surgery. It has been documented that bone harvesting from the proximal tibia with a trephine can be performed faster than bone harvesting from the iliac crest with the same technique[19]. This fact seems to be a reason to prefer tibial bone grafts over iliac crest bone grafts. In this context, it has to be noted that the use of trephines instead of open harvesting techniques reduces the inpatient period significantly[26].

Based on the harvesting characteristics, it seems that bone harvesting from the mandibular ramus should be preferred by experienced surgeons. Bone harvesting from a distant site seems to increase costs and should be performed with a trephine in order to reduce the inpatient period. However, one has to keep in mind that bone harvesting is limited to non-structural, cancellous grafts, when trephines are used.

Bone graft volume and density

Chin grafts have the highest bone density. Their density is even considerably higher after the completion of the healing time compared to iliac crest bone grafts[27]. However, the available bone volume is small compared to distant sites where volumes over 50 cm^3 can be collected[9]. Therefore, it can be assumed that distant donor sites will be preferred when major augmentation procedures have to be performed on extremely resorbed jaws.

Donor site morbidity

Morbidity is one of the most important criteria for the selection of a specific donor site in elective preprosthetic surgery. The chin seems to fall behind the ramus bone graft, because of the relatively high percentage of superficial skin sensitivity disorders and altered sensations in the mandibular incisors, compared to ramus bone grafts[14,15,21].

When distant donor sites have to be adopted, it can be assumed that the morbidity arising from tibial bone harvesting is low[19]. Unfortunately, this site has not been an intensive focus of clinical trials in the past. The same is true for calvarial bone grafts. But the availability of bone relevant data on morbidity is missing. In contrast, the morbidity of iliac crest

bone harvesting has attracted a lot of interest in the past. It has been shown that bone grafts from the posterior iliac crest lead to lower postoperative pain, less superficial skin sensitivity disorders and less gait disturbances compared to the anterior iliac crest[9,23]. A further reduction in morbidity can be achieved by the use of trephines, which allow accessing the iliac crest through small incisions[17].

Graft resorption

Graft resorption is a major issue following augmentation procedures. It has been stated that membranous bone is superior to enchondral bone in maintaining volume in the initial phase following the augmentation procedure. There seemed to be a higher tendency to resorption of the iliac crest onlay grafts compared with calvarial onlay grafts[10]. However, this tendency seems to decrease with an increasing follow-up interval[10]. Some authors have even reported resorption rates of calvarial bone grafts that exceeded that of other bone grafts[12].

It seems that interpositional bone grafts lead to more predictable results compared to onlay bone grafts. However, the interpositional bone graft technique requires an experienced surgeon, while performing an onlay bone graft requires a shorter learning curve. Because of the more pronounced resorption, it has been recommended to oversize onlay bone grafts. Once implants have been placed in the augmented sites, the outcomes are similar for interpositional and onlay grafts[8]. Due to a reduced tendency towards resorption, it has been recommended to prefer block bone grafts over particulated autogenous bone grafts for sinus floor augmentation[30].

Especially as far as bone resorption around dental implants is concerned, it seems that there is a clear dependence on the types of implants used[13]. It seems that graft resorption is present with every grafted site to a variable extent. Based on the knowledge derived from the review, interpositional grafting should be used wherever possible. An alternative is overcorrection during onlay grafting. Moreover, types of implants should be chosen that only lead to minimal resorption of peri-implant bone.

Implant survival and success

Implant survival was high in the selected studies independent from the source of bone chosen for the augmentation procedure (Table 1). The lowest survival rate was found with particulated grafts for the chin, as well as anterior iliac crest bone after 6 years (86.6%)[30]. Even when extensive graft resorption was described, it was possible to reach an implant survival rate of 100% after 6 years[29]. Also for implant success, high values were found throughout the different selected studies (Table 1). Only two studies reported on success rates below 90%[8,13]. A specific kind of implant combined with iliac crest only grafts led to an implant success rate of 76.4% after 33 months[13]. When a different implant type was used, the success rate increased up to 100% after the same time interval. These data again demonstrate the influence of the selected implant types on the implant success rate.

The data on implant survival and success do not allow the identification of a bone graft that is associated with a significant improvement of these parameters. Even with complete resorption of the grafted bone, an implant survival rate of 100% can be reached[11]. It seems that the type of bone graft has only a limited influence on implant survival and success. Instead, confounders like the type of implant installed seem to have a major influence on implant survival and success.

When the aim of the treatment concept is to reduce patient morbidity to a minimum, bone should be harvested from the mandibular ramus. However, even bone harvesting from this donor site can lead to relevant impairments of the patient[15,25]. Therefore, it has to be kept in mind that alternatives to autogenous bone exist for some indications of bone grafting. For example, as far as sinus floor augmentation is concerned, it seems that the use of bone substitutes finally leads to implant survival rates that are comparable to those that can be achieved with implants placed in sites grafted with autogenous bone[32]. For these grafting indications, autogenous bone should no longer be considered the 'golden standard'. In the future, there is a perspective to reduce the morbidity of autogenous bone harvesting by the adoption of tissue engineering approaches[39,40].

Conclusions

The mandibular ramus is the source of bone that is preferred by the patients. From this intraoral donor site, bone is harvested under local anaesthesia on an outpatient basis. In contrast, patients' acceptance of chin bone harvesting is low. Harvesting of chin grafts leads to a considerable morbidity that includes pain, superficial skin sensitivity disorders and wound healing problems at the donor site. Patients even prefer iliac crest bone harvesting over bone harvesting from the chin, although this distant donor site requires general anaesthesia and a hospital stay. The analysis of the comparative studies reveals that the posterior iliac crest should be preferred over the anterior iliac crest when large amounts of block bone grafts are needed. Conversely, when only non-structural cancellous grafts are needed, percutaneous bone harvesting from the iliac crest with a trephine should be preferred.

The data provided by the included studies did not allow evaluation of the relevance of tibial and calvarial bone harvesting. It seems that the type of bone graft does not have a major influence on implant survival and success.

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