Maxilla augmentation with calvarial bone

Thomas F. Putters

The research presented in this thesis was performed and financed at the Department of Oral and Maxillofacial Surgery, University Medical Center Groningen, The Netherlands.

Lay-out: Saar de Vries
Printing: Gildeprint

ISBN (printed version) 978-94-640-2020-5
ISBN (electronic version) 978-94-640-2024-3

Maxilla augmentation with calvarial bone

rijksuniversiteit groningen

Maxilla augmentation with calvarial bone

Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. dr. C. Wijmenga
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op

woensdag 11 maart 2020 om 14.30 uur

door

Thomas Franciscus Putters
geboren op 2 februari 1976
te Tilburg

Promotores
Prof. dr. G.M. Raghoebar
Prof. dr. A. Vissink

Copromotor
Dr. J. Schortinghuis

Beoordelingscommissie
Prof. dr. H.J.A. Meijer
Prof. dr. A.J.W.P. Rosenberg
Prof. dr. E.A.J.M. Schulten

Paranimfen
B.J. Melenhorst
R.P. Wiewel

Contents

Chapter 1

Introduction

Introduction

A complete upper denture is the conventional treatment for patients with an edentulous maxilla in order to restore oral functioning and aesthetics.[1] Patients' satisfaction with this conventional treatment varies and usually decreases with time. This is, amongst others, related to the progressive resorption of the edentoulous maxilla and patient bond factors such as treatment-expectations and the wish to wear a denture with natural dentition functionalities.[2] Other common problems are pain during mastication and an increasing lack of retention due to progressive bone resorption.

Fabrication of an implant-supported overdenture was shown to be a good option. It improves oral functioning and patient satisfaction, including for those with denture retention problems due to the resorption of the maxilla, inability to wear dental prosthesis because of anatomical variations of the maxilla like the absence of an archy palate, a shallow buccal-alveolar sulcus and a prominent gag reflex.[3,4] Dental implants improve the retention and stability of the overdentures and eliminate pain during mastication.[5,6]

While implant-supported dentures are an effective treatment for upper denture problems, the amount of bone needed for reliable implant placement can be limited or insufficient in the presence of alveolar ridge resorption and maxillary sinus pneumatization (Fig. 1). Such cases require bone augmentation surgery. Autogenous bone, bone substitutes, and a mixture of autologous bone and bone substitutes are the most commonly used grafting materials for such a procedure. Autogenous bone grafts have advantages over other graft types due to their ostegenic, osteoinductive and osteoconductive characteristics. Therefore, autologous bone is considered the gold standard for large bone defects.[7]

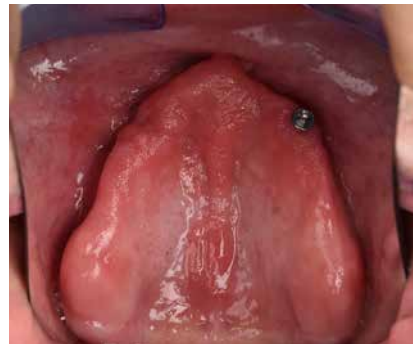


Fig 1A. Severely resorbed maxilla in a patient with unsuccessful implant placement.

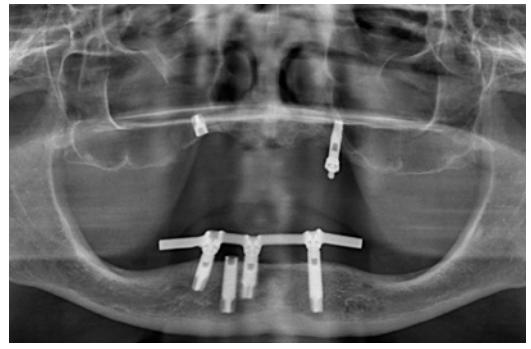


Fig 1B. Orthopanthomogram: extensive sinus pneumatisation.

Augmentation with intra-orally harvested bone (i.e., retromolar, tuberosity, ramus, chin) can suffice when a small amount of bone is needed for adequate implant placement, with good primary stability. Here, augmentation can often be performed simultaneously with implant placement. Harvesting of intra-oral bone is accompanied by minor donor site morbidity.[8]

Severe resorption of the maxilla necessitates extensive pre-implant placement augmentation surgery is needed often composing of bilateral sinus floor augmentation surgery. This surgery is in need of much larger amounts of bone. Again autogenous, heterogenous, synthetic materials or a combination of these materials can be used to graft the maxillary sinus floor.[7] These larger bone graft usually have to be harvested extra-orally, e.g., from the anterior or posterior iliac crest, calvarium, tibia or rib.[9] (Fig. 2) The anterior iliac crest is most commonly used as donor site for such reconstructive surgery.[10]

The morbidity of harvesting anterior iliac crest bone is said to be low, but gait disturbance as an early complications does occur rather often.[11] Other authors report higher complication rates.[12] The anterior iliac crest provides copious amounts of bone to harvest and is easy accessible. Moreover, harvesting anterior iliac crest bone can be combined with preparatory surgery at the intra-oral site when two surgical teams are working simultaneously thereby reducing surgery time. Despite these benefits, the procedure has its inherent donor site morbidity. The most common complications are pain at the donor site and gait disturbance. Less frequent complications include nerve injury, hematoma, infection and fracture at the donor site.[12]

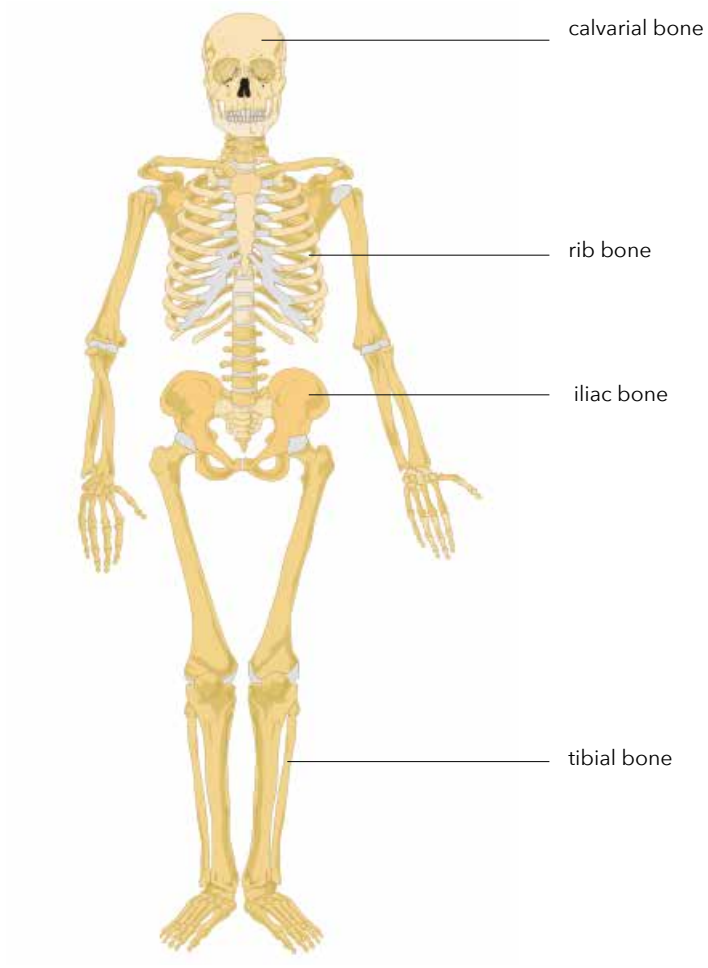


Fig 2. Extra-oral locations for bone harvesting.

As harvesting anterior iliac crest has its inherent, occasionally disturbing, morbidity, donor sites with a presumed lower morbidity have to be investigated. Harvesting calvarial bone might serve as an alternative because this bone is rather accessible and has been reported to be accompanied with minor complaints.[13] Harvesting cavarial bone is not accompanied by gait disturbance and it is presumed that there is less postoperative pain and bone resorption.[14,15] Haematoma and altered nerve sensation are also reported to be low for this donor site. [16,17] However, there is a danger of major, although very rare, complications such as laceration of the superior sagittal sinus, brain injury, depression of the scull and meningitis.[18,19,20] Hence, the calvarian bone harvesting method needs to be modified in order to reduce these major complications even further. Moreover, it is not clear how the comorbidity of grafting calvarial bone relates to that of grafting iliac bone.

There is a difference between the bone structure and embryologic origins of iliac and calvarial grafts. Calvarial bone has a much higher cortical/cancellous ratio than iliac bone. The calcarium is membranous and iliac bone is endochondral bone. The clinical implications of these features are not clear and require further clarification.

Aim of the thesis

The general aim of the research described in this thesis was to assess whether calvarial bone serves as a reliable alternative for anterior iliac crest bone when applied to augment the severely resorbed maxilla in pre-implant placement augmentation surgery.

The specific aims are:

- to develop a safe surgical technique for harvesting calvarial bone (chapter 2);
- to compare donor site morbidity and intra-oral complications on harvesting calvarial and anterior iliac crest bone (chapters 3, 4, 5);
- to assess whether dental implants can be placed simultaneously during the surgical procedure to reconstruct the maxilla with calvarial bone (chapter 6).

References

1. Patel J, Granger C, Morrow L. The Effect of Complete Denture Occlusion on Function and Patient Quality of Life: Systematic Review. Eur J Prosthodont Restor Dent. 2018: 26: 24-30.
2. Thalji G, McGraw K, Cooper LF. Maxillary Complete Denture Outcomes: A Systematic Review of Patient-Based Outcomes. Int J Oral Maxillofac Implants. 2016: 31: 169-181.
3. Turkyilmaz I, Company AM, McGlumphy EAS. Should edentulous patients be constrained to removable complete dentures? The use of dental implants to improve the quality of life for edentulous patients. Gerodontology. 2010 : 27: 3-10.
4. Cardoso RG, Melo LA, Barbosa GA, Calderon PD, Germano AR, Mestriner W Junior, Carreiro AD. Impact of mandibular conventional denture and overdenture on quality of life and masticatory efficiency. Braz Oral Res. 2016: 3: 1-7.
5. Slot W, Raghoebar GM, Vissink A, Meijer HJA. Maxillary overdentures supported by four or six implants in the anterior region: 1-year results from a randomized controlled trial. J Clin Periodontal. 2013: 40: 303-310.
6. Boven GC, Raghoebar GM, Vissink A, Meijer HJA. Improving masticatory performance, bite force, nutritional state and patient satisfaction with implant overdentures: A systematic review of the literature. J Oral Rehabil. 2015: 42: 220-233.
7. Sakkas A, Wilde F, Heufelder M, Winter K, Schramm A. Autogenous bone grafts in oral implantology-is it still a "gold standard"? A consecutive review of 279 patients with 456 clinical procedures. Int J Implant Dent. 2017: 3: 23-40.
8. Sittitavornwong S, Gutta.R. Bone graft harvesting from regional sites. Oral Maxillofac Surg Clin North Am. 2010: 22: 317-330.
9. Zouhary KJ. Bone graft harvesting from distant sites: concepts and techniques. Oral Maxillofac Surg Clin North Am. 2010: 22: 301-316.
10. Kuik K, Putters TF, Schortinghuis J, Minnen van B, Vissink A, Raghoebar GM. Donor site morbidity of anterior iliac crest and calvarium bone grafts: A comparative case-control study. J Cranio Maxillo Facial Surg. 2016: 44: 364-368.
11. Kalk WW, Raghoebar GM, Jansma J, Boering G. Morbidity from iliac crest bone harvesting. Clin Implant Dent Relat Res. 2003: 5: 161-169.
12. Dimitriou R, Mataliotakis GI, Angoules AG, Kanakaris NK, Giannoudis PV. Complications following autologous bone graft harvesting from the iliac crest and using the RIA: a systematic review. Injury. 2011: 42: 3-15.
13. Kellman RM. Safe and dependable harvesting of large outer-table calvarial bone grafts. Arch Otolaryngol Head Neck Surg. 1994: 120: 856.
14. Mertens C, Steveling HG, Seeberger R, Hoffmann J, Freier K. Reconstruction of severely atrophied alveolar ridges with calvarial onlay bone grafts and dental implants. Clin Implant Dent Relat Res. 2013: 15: 673-683.
15. Lizuka T, Smolka W, Hallerman W, Mericske-stern R. Extensive augmentation of the alveolar ridge using autogenous calvarial split bone grafts for dental rehabilitation. Clin Oral Implants Res. 2004: 15: 607-615.
16. Gutta R, Waite P. Outcomes of calvarial bone grafting for alveolar ridge reconstruction. Int J Oral Maxillofac Implants. 2009: 24: 131-136.
17. Smolka W. Calvarial grafts for alveolar ridge reconstruction prior to dental implant placement: an update. Oral Maxillafac Surg. 2014: 18: 381-386.
18. Touzet S, Ferri J, Wojcik T, Raoul G. Complications of calvarial bone harvesting for maxillofacial reconstructions. J Craniofac Surg. 2011: 22: 178-181.
19. Tessier P, Kawamoto H, Posnick J, Raulo Y, Tulasme JF. Taking calvarial grafts, either split in situ or splitting of the parietal bone flap ex vivo. Tools and techniques: A 9650-case experience in craniofacial and maxillofacial surgery. Plast Reconstr Surg. 2005 Oct: 116: 74-88.
20. Frodel JL, Marentette LJ, Quatella VC. Calvarial bone graft harvest. Techniques, considerations, and morbidity. Arch Otolaryngol Head Neck Surg. 1993: 119: 17-23.

Chapter 2

Safe harvesting of outer table parietal bone grafts using an oscillating saw and a bone scraper: A refinement of technique for harvesting cortical and "cancellous"-like calvarial bone

This chapter is an edited version of the manuscript:
Jurjen Schortinghuis, Thomas F. Putters, Gerry M. Raghoebar
Safe harvesting of outer table parietal bone grafts using an oscillating saw and a bone scraper: A refinement of technique for harvesting cortical and "cancellous"-like calvarial bone
J. Oral Maxillofac Surg. 2012; 70: 963-965

Summary

Calvarial bone is a readily available source of bone for preimplantation augmentation procedures of the alveolar process. However, the calvaria consist mostly of cortical bone, and cancellous bone of the diploic space is scarce. A bone scraper (Safescraper Twist; META, Reggio Emilia, Italy) was used to create a beveled trough around the calvarial outer table graft to facilitate its removal with an oscillating saw. Using the scraper, copious amounts (10 mL) of "cancellous"-like bone could be collected. This new application of the Safescraper Twist obviated milling down additional cortical pieces.

Introduction

Calvarial cortical bone grafting is becoming increasingly popular because of easy access and relatively minor complaints after harvesting.[1] In maxillofacial surgery, calvarial bone grafts can be used for reconstructions of the nose[2] or in preimplantation procedures to build up the alveolar process for the placement of implants.[3,4]

In augmenting techniques of the maxilla or mandible, there is often a need for cancellous bone. When augmenting the atrophied maxilla, for example, cancellous bone is used to fill part of the maxillary sinuses and to fill gaps between bone blocks fixed to the residual alveolar ridge. Often, a combination of autologous bone and bone substitutes is used when an inadequate volume of cancellous bone is harvested.

The iliac crest serves as a donor site where cortical and cancellous bone can be harvested and is used frequently in the Netherlands for preimplantation augmentation. A major drawback for using this site is that a patient can develop considerable pain and gait problems after harvesting the bone.[5,6] Harvesting from the calvaria eliminates gait problems, but other complications have been described, such as meningitis, accidental dural exposure and tear, entry into the sagittal sinus, and coup/contrecoup brain damage because of the use of osteotomes.[7]

In 1994, Kellman[1] described a technique to safely and dependably harvest large, outer table, calvarial bone grafts using an oscillating saw inserted between the outer and inner tables into the diploic space. To facilitate entry of the flexible saw blade, a wide (1 to 2 cm) trough with its depth at the diploe was created with a burr around the graft to be harvested. Kellman[1] reported no major complications and the technique proved to be safe.

When calvarial bone is harvested, the graft consists of cortical bone. The only minimal source of "cancellous"-like bone is the thin diploe. To obtain this cancellous-like bone, a bone mill is used to mill down part of the hard cortical graft or an additional piece has to be harvested for this purpose.

To avoid this drawback and to provide a solution, a bone scraper[8] was used to create the trough and collect copious (10 mL) amounts of cancellous-like bone before the graft was removed. The Safescraper Twist (META, Reggio Emilia, Italy) is a ready-to-use bone scraper that can contain a 2.5-mL volume of scraped bone in its collection chamber. This instrument provides an easy, quick, and safe way to harvest bone. Furthermore, using the scraper, the outline of the donor site was easily contoured after the outer table graft was removed. Thus, extra cancellous-like bone was obtained and the outline was less conspicuous.

The surgical technique is presented in figures 1 through 3 (according to Kellman[1]).

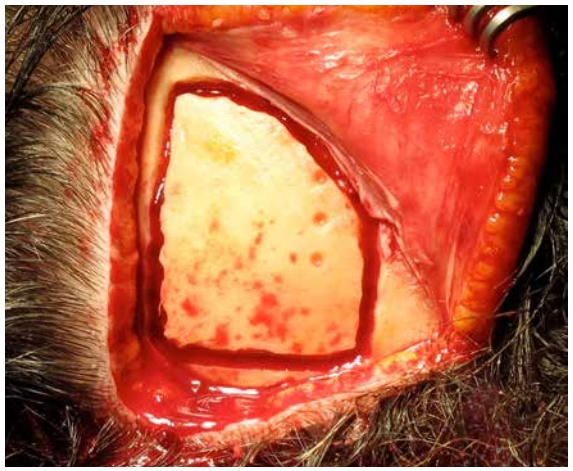


Fig 1. After raising a full-thickness flap, the outline of the graft is marked with a drill. The diploe is identified by an increase in bleeding after drilling.

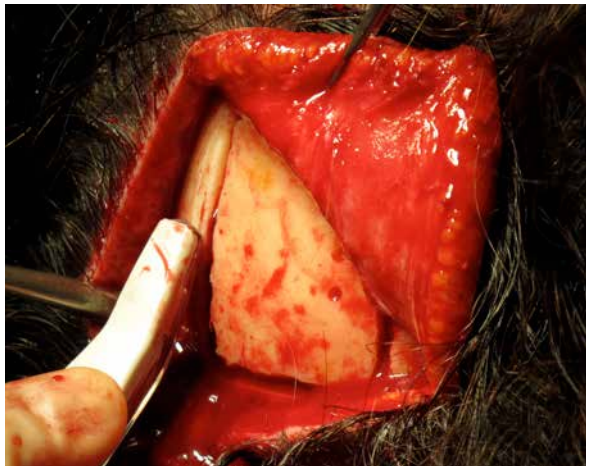


Fig 2A. A 1-cm-wide trough is created using the bone scraper. Large amounts of cancellous-like bone are harvested (>10 mL).

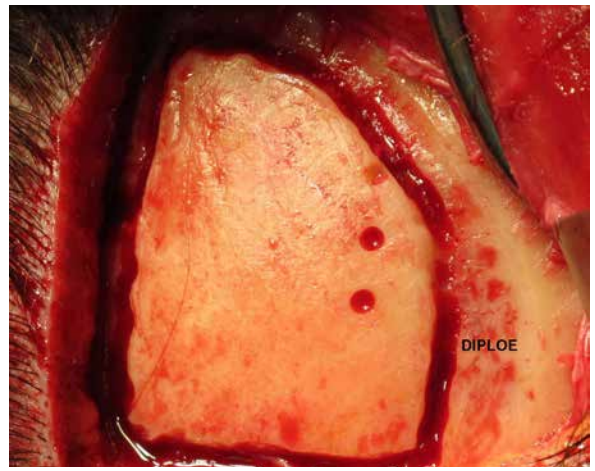


Fig 2B. The diploe is identified by an increase in bleeding.

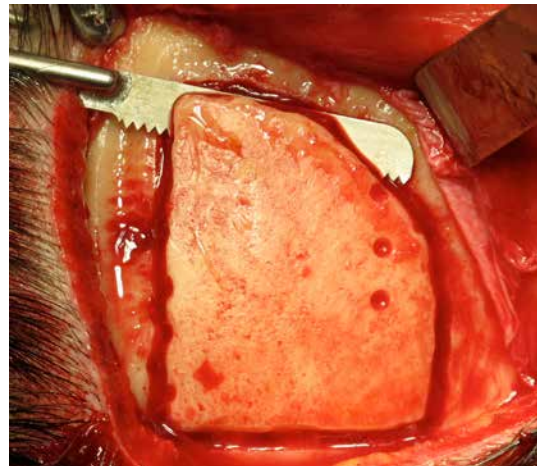


Fig 3. Using the trough, the oscillating saw is easily entered into the diploic space and the outer table cortical graft is removed. Care is taken to maintain visability of the tip of the saw during sawing to prevent accidental displacement of it. After removal of the graft, the bone scraper is used to flatten-out the defect.

Discussion

The Safescraper Twist was a useful instrument for grafting large amounts (10 mL) of cancellous-like calvarial bone. It avoids bone loss when a drill is used to make the bevel of the trough. Furthermore, using part of the graft or harvesting a second graft to mill down cortical bone is avoided. This refinement of the technique also has the potential to limit the use of expensive bone substitutes. Bone substitutes, however, are also used to prevent volume loss in the grafted area because these are, in general, slowly resorbed. The resorption pattern of scraper-harvested calvarial bone is not known and may be a subject of further investigation.

In summary, use of a bone scraper when harvesting calvarial bone is easy and practical for harvesting and contouring, avoiding unnecessary bone loss and the need to mill down hard cortical bone, and its use may limit the use of bone substitutes.

References

1. Kellman RM; Safe and dependable harvesting of large outer-table calvarial bone grafts. Arch Otolaryngol Head Neck Surg. 1994:120:856-860.
2. Cheney ML, Gliklich RE; The use of calvarial bone in nasal reconstruction. Arch Otolaryngol Head Neck Surg. 1995:121:643-648.
3. Smolka W, Bosshardt DD, Mericske-Stern R, Iizuka T; Reconstruction of the severely atrophic mandible using calvarial split bone grafts for implant-supported oral rehabilitation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006:101:35-42.
4. Gutta R, Waite PD; Outcomes of calvarial bone grafting for alveolar ridge reconstruction. Int J Oral Maxillofac Implants. 2009:24:131-136.
5. Kim DH, Rhim R, Li L, Martha J, Swaim BH, Banco RJ, Jenis LG, Tromanhauser SG; Prospective study of iliac crest bone graft harvest site pain and morbidity. Spine J. 2009:9,886-892.
6. Schaaf H, Lendeckel S, Howaldt HP, Streckbein P; Donor site morbidity after bone harvesting from the anterior iliac crest. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010 :1009:52-58.
7. Frodel JL Jr, Marentette LJ, Quatela VC, Weinstein GS; Calvarial bone graft harvest. Techniques, considerations, and morbidity. Arch Otolaryngol Head Neck Surg. 1993:119:17-23.
8. Zaffe D, D'Avenia F; A novel bone scraper for intraoral harvesting: a device for filling small bone defects. Clin Oral Implants Res. 2007:18:525-533.

Chapter 3

A prospective study on the morbidity resulting from calvarial bone harvesting for intraoral reconstruction

This chapter is an edited version of the manuscript:
T. F. Putters, J. Schortinghuis, A. Vissink, G. M. Raghoebar
A prospective study on the morbidity resulting from calvarial bone harvesting for intraoral reconstruction
Int. J. Oral Maxillofac. Surg. 2015; 44: 513–517

Summary

Calvarial bone grafts are used for reconstruction of the maxilla or mandible to enable implant placement. The aim of this study was to assess the morbidity resulting from the use of calvarial bone grafts to reconstruct the maxilla and mandible. Thirty-six consecutive patients were included in this prospective study (14 men and 22 women; mean age 59 ± 8.2 years). Perioperative and postoperative complications related to harvesting of the calvarial bone were scored, as well as the occurrence of intraoral complications (average follow-up 25 ± 12 months). Perioperative exposure of the dura occurred in four patients and the graft broke during harvesting in five patients. With a change in the technique, these complications no longer occurred. Postoperative pain levels at the calvarial donor site were low (visual analogue scale (VAS) 1.9 ± 2.0 on day 1) and of short duration (5.2 ± 4.7 days to becoming pain-free). In all cases sufficient bone could be harvested to enable the placement of implants. The exposure of the dura and the intraoral complications were of no clinical consequence. Therefore, calvarial bone grafts appear to be promising for use in pre-implant intraoral reconstructions.

Introduction

In edentulous patients, resorption of the maxilla and mandible can result in pro-blems wearing a denture due to a lack of supporting bone. The placement of dental implants is advocated to increase the retention of dentures.[1] However, in the case of severe resorption, there is insufficient bone volume to place the dental implants. In The Netherlands, the anterior iliac crest is the most commonly used donor site for reconstruction of the maxilla or mandible to obtain more bone volume.[2] A drawback of the use of anterior iliac crest bone grafts is donor site morbidity.[2] This morbidity includes gait disturbances, pain, and hypo-sensitivity of the lateral aspect of the thigh due to neuropraxis of the lateral femoral nerve.[3,4]

An alternative to the anterior iliac crest donor site is the calvarium.[5] Calvarial bone grafts have been used for the reconstruction of the orbital walls, nasal bones, cranial defects, and defects of the maxilla and mandible.[6] They have also been used for maxillary reconstructions to enable the placement of dental implants.[7,8] It is assumed that calvarial bone grafting is accompanied by less donor site morbidity than iliac crest grafting,[9,10] but investigations have primarily been retrospective in nature.[5,6] Therefore, the purpose of this study was to prospectively assess the donor site morbidity of calvarial bone harvesting in a group of 36 consecutive patients in whom a calvarial bone graft was used to reconstruct the maxilla or mandible as a pre-implant placement procedure.

Materials and methods

This prospective observational study was performed with the approval of the ethics committees of the study hospitals (Scheper Hospital and Refaja Hospital).

Patients

From April 2010 to December 2013, 36 consecutive patients were included in the study. This convenience sample was chosen to serve as a baseline for power calculations for future studies.

Inclusion criteria were the following: (1) patient referral to the department of oral and maxillofacial surgery by a dentist or prosthetic specialist because of problems wearing a denture (pain, mobility, loss of retention, chewing problems) due to severe resorption of the edentulous maxilla or mandible. (2) A computed tomography (CT) scan demonstrating an insufficient amount of remaining bone in the maxilla and/or mandible for the placement dental implants (less than 4 mm bone height in the maxillary sinus area; less than 4 mm bone width in the anterior maxillary area; less than 10 mm bone height in the mandible), and in addition a CT scan of the calvarium with frontal reconstructions demonstrating sufficient thickness of the temporal bone (>5 mm) in the area between the tuberculum articulare and the end of the mastoid bone. (3) Written informed consent.

Patients taking bisphosphonates, chemotherapeutic, and/or immunosuppressive drugs were excluded.

Calvarial bone harvesting technique

The operative procedure for harvesting of the calvarial bone is described in detail in a previous publication by Schortinghuis et al.[11] In brief, the outline of the tabula externa graft was marked with a burr until the diploë was encountered. Next, using a bone scraper,[12] a trough was made outside the graft. For the first 10 patients in this study, the calvarial graft was removed in one piece by undermining the corners with an oscillating saw.[13] Using a curved chisel, the graft was then loosened in one piece from the tabula interna. In the subsequent patients, parallel saw-cuts were made in situ so that the graft could be removed piece by piece thus preventing graft breakage. Autopolymerizing bone cement was used to reconstruct the defect (Palacos; Heraeus Medical GmbH, Haarlem, The Netherlands).

Augmentation of the maxilla

After exposure of the maxillary bone, a sinus lift procedure was performed on both sides and the 'scraped' calvarial bone was placed under the maxillary sinus membrane. The cortical calvarial bone graft was sawn into different pieces that were fixed onto the remaining alveolar process using 1.5-mm osteosynthesis screws. A lag-screw technique was used: by drilling a wider hole in the graft, the screw head exerts a compression force onto the graft when tightening it to the alveolar process. After fixation, special care was taken to round off sharp bone edges, since calvarial bone is hard and can have sharp edges that may penetrate the overlying mucosa. The remaining cancellous bone was used to fill the gaps. Collagen membranes were used to cover the augmented sites. Primary wound closure was accomplished using resorbable sutures (Vicryl Rapide 3–0; Johnson & Johnson, Amersfoort, The Netherlands).

Augmentation of the mandible

After exposure of the mandibular bone, calvarial bone blocks were fixed on the alveolar process to augment the anterior part of the mandible. Cancellous bone was used to fill the gaps. After placement of a collagen membrane, the wound was closed in layers.

Postoperative care

Patients were given a broad-spectrum antibiotic (amoxicillin/clavulanic acid) and non-steroidal anti-inflammatory drugs (ibuprofen) for 1 week. Patients were instructed to maintain a soft diet and were not allowed to wear their maxillary denture for 2 weeks. After 4 months, six dental implants were placed in the augmented maxilla. Two dental implants were placed in the augmented mandible. All patients were enrolled in a dental hygiene protocol consisting of patient instructions, regular professional cleaning of the peri-implant area when needed, and regular follow-up with a dental hygienist for the prevention of peri-implantitis.

Morbidity assessments

During the grafting procedure of the calvarial bone, the following items were recorded: exposure of the dura (yes/no), dural tear (yes/no), accidental fall of bone (yes/no), fracture of the graft during removal (yes/no), and the duration of the harvesting procedure (min). The number of days of hospitalization was also recorded.

Postoperative pain was scored on a 10-cm visual analogue scale (VAS), ranging from 'no pain' (0) to 'the worst pain imaginable' (10). Pain at the donor site and at the receptor site was scored once a day for 30 days. The scores were kept in a logbook.

The following data were recorded by the surgeon at postoperative weeks 1, 2, 6, 12, 16, and 32, and at 12, 18, 24, and 30 months after surgery: donor site (calvarial) aspect of the scar (dehiscence yes/no, erythema yes/no, swelling yes/no, pain yes/no), hair loss (yes/no), localized pain (yes/no), and contour deficit (yes/no). When a contour deficit was present, it was determined whether or not this was bothersome to the patient (yes/no). With regard to the receptor site (maxilla/mandible), the presence of dehiscence (yes/no), fistula (yes/no), erythema (yes/no), loss of implants (yes/no), gingivitis (yes/no) were also recorded at the same timepoints by the maxillofacial surgeon. Peri-implant bone loss was assessed using postoperative orthopantomographic radiographs obtained at 6 weeks, 12 weeks, 12 months, and 24 months. The amount of peri-implant bone loss was calculated considering the peri-implant bone level on the postoperative radiograph taken the day after surgery as the baseline. A bone attachment loss of >2 mm was considered as bone loss. Sensory disturbances of the mandible were also recorded.

During the placement of implants, or placement of healing abutments in the case of immediate implantation, the loss of bone or presence of signs of bone resorption (yes/no) was recorded.

Results

A total of 36 consecutive patients gave informed consent to participate in the study and underwent surgery. Fourteen were male and 22 female, and their mean age was 59 ± 8.2 years. The mean follow-up was 25 ± 12 months. For 31 patients, only an augmentation procedure was performed (maxilla *n* = 26, mandible *n* = 4, maxilla and mandible *n* = 1); implants were inserted 4 months later (Straumann standard dental implants; Institut Straumann AG, Basel, Switzerland). The remaining five patients underwent augmentation of the maxilla with the simultaneous placement of dental implants (Biomet T3 implants; Biomet 3i, Palm Beach Gardens, FL, USA). In the anterior region of the maxilla, the implants were inserted in the buccal plated alveolar process at tooth locations 12, 14, 22, and 24. In the sinus region, the implants were placed in the simultaneously augmented sinus floor at locations 16 and 26. At 4 months postoperative, the implants were recovered, the osteosynthesis screws removed, and healing abutments placed.

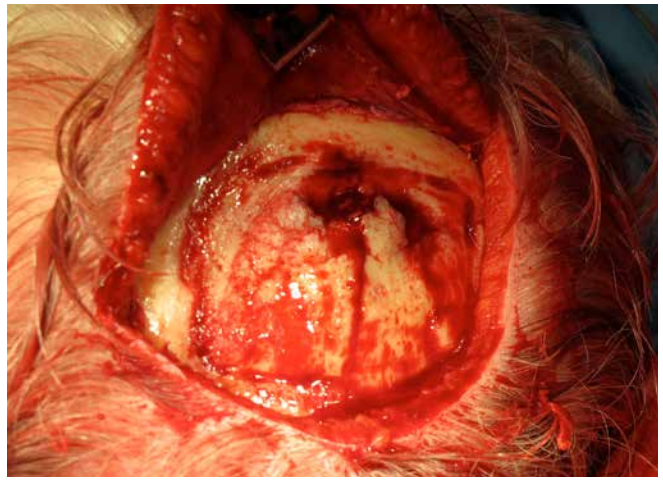


Fig 1. A dural exposure as complication of calvarial bone harvesting.

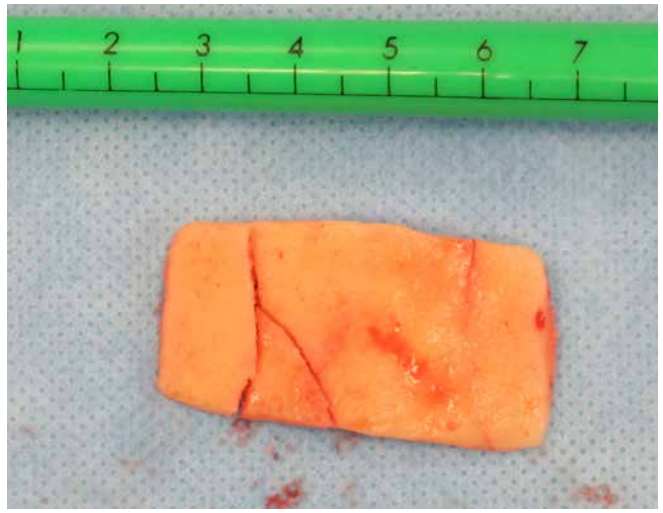


Fig 2. Outer table graft breakage.

Table 1. Postoperative pain (VAS) on days 0, 1, 7, and 30 for the donor site (calvarium and anterior iliac crest) and receptor site (intraoral); results are given as the mean SD (range).

VAS at day	0	1 *	7	30	Number of postoperative days until VAS reaches 0
Calvarium	2.7 ± 2.3 [0 - 7]	1.9 ± 2.0 [0 – 7]	0.4 ± 0.8 [0 – 3]	0	5.2 ± 4.7 [0 – 18]
Intraoral	2.2 ± 2.4 [0 – 8]	1.8 ± 1.8 [0 – 6]	0.9 ± 1.6 [0 – 5]	0	5.3 ± 5.1 [0 – 17]
Anterior Iliac crest (Nkenke 2004)[3]		7.0 ± 1.5 [3 – 9]	3.7 ± 1.4 [1 – 5]	1.4 ± 0.7 [1 – 3]	---

*Nenke et al (2004) reported the VAS at the second day after surgery.[4]

During the harvesting procedure, the dura was exposed without dural tear in three cases (Fig. 1); in one case there was a small dural tear leading to leakage of cerebrospinal fluid. All exposures were <1 cm^2. The exposures did not require additional treatment, and the scalp was closed over the exposures. In five cases, the graft broke or showed signs of impending breakage while using the chisel during removal, visible by the appearance of a white line across the graft (Fig. 2). The duration of the harvesting procedure was a mean 56 ± 10 min. The grafts could be fixed onto the maxillary alveolar process with ease.

Of the 36 patients, 26 completed the VAS scoring (Table 1). These were patients who underwent maxilla augmentation with/without the placement of dental implants. Ten patients did not complete the scores, did not return them, or failed to even start recording the VAS scores. The patients who reported no pain (n = 5, VAS = 0) did report that the scalp and the augmented maxilla felt a bit sensitive, but not painful. All patients were discharged from hospital the day after surgery.

No erythema, swelling, or hair-loss was observed during an average follow-up of 25 ± 12 months. There was also no complication requiring urgent treatment, such as meningitis or epidural haematoma. For the first seven patients, no bone cement was used to fill the defect. Postoperatively, the defect was covered by hair, but it was palpable. None of the patients found this bothersome. After placing bone cement into the defect in the subsequent patients, the contour was restored satisfactorily. One patient had a persistent sensitive 'spot' on the scalp, next to the bone cement. There were no signs of inflammation. Ten weeks after surgery, the pain disappeared spontaneously.

Intraorally, a dehiscence of the maxillary bone with signs of inflammation was observed in two patients. One patient suffered an actinomycosis maxillary sinusitis with sequestration of a bone piece. This was treated successfully with surgery and antibiotics. After 4 months, five implants instead of six were placed in the maxilla. In the other patient, a dehiscence appeared of a sharp buccal plate in the second right upper molar region 5 months after implant placement. The exposed bone plate was rounded off and primary wound closure was achieved. Wound healing progressed undisturbed in the other patients. One patient experienced transient sensory disturbances in the mandible.

A total of 185 dental implants were placed in the maxilla at 4 months after the augmentation. A total of 28 implants were placed at the same time as the augmentation. In one patient with delayed implant placement, a small cortical plate came loose at a location where two calvarial pieces were fixed on top of each other. In another case, a buccal plate came partially loose while drilling the implant bed. This had no consequence on the final result. All implants were placed with primary stability. After reflection of the mucoperiosteum at 4 months, it was observed that virtually no bone resorption was present: the screw heads had not become more visible, as we have sometimes observed with iliac crest grafts. During the implant procedure, the grafted bone appeared to be well incorporated. In the patients who underwent immediate implant placement, no bone resorption was observed around the implants during retrieval of the implants at 4 months.

One implant was lost due to peri-implantitis at 1 year after placement. In another patient, progressive peri-implant bone loss was observed next to all six implants due to poor dental hygiene and a failure to visit the dental hygienist. No other peri-implant problems were encountered.

Discussion

This prospective study indicates that morbidity related to the calvarial donor site and the augmented maxilla or mandible is low, and that calvarial bone is suitable for augmentation of the alveolar process to allow for reliable placement of dental implants. Although potentially severe complications can occur when grafting calvarial bone, such as accidentally entering the superior sagittal sinus, dural tears, intracranial lesions, and coup/contrecoup lesions,[6] it seems that these complications are rare[6] and can be avoided by using the correct technique, as used in this study.[11]

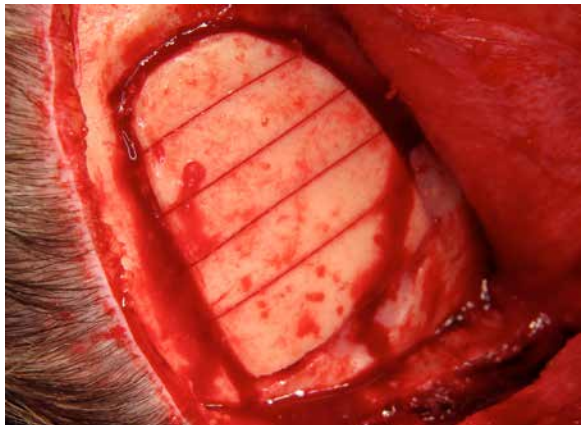


Fig 3. Before removing the graft, parallel saw-cuts are made in the outer table. Piece-by-piece removal prevents dural exposure and graft fracture.

The dura was exposed in four cases during removal of the complete graft. The diploic space was difficult to identify in these cases. During deepening of the trough, the diploë is identified by an increase in bleeding (spot-bleeding). It seems that in certain patients the diploic space is less vascularized and therefore an accurate depth is more difficult to determine. Also a smaller diploic space makes the outer and inner cortical layer more adherent, so removing the last attachments using a chisel may break off a small piece of the internal cortex. The use of a chisel was sometimes necessary because it was difficult to saw underneath the entire graft. The saw was used at the corners of the graft and as far as possible underneath it, as long as we could maintain visibility of the saw-tip.

The use of a chisel caused breakage or near-breakage of the graft, making it more difficult to obtain bone pieces of the correct size. By making parallel saw-cuts into the graft in situ, the tabula externa could be removed piece by piece more easily (Fig. 3). If needed, the chisel was used, with less force. Once this technique was implemented, there were no further cases of breakage of the graft or dural exposure. Nevertheless, the dural exposures that occurred before we changed the technique were all without clinical consequences.

Our results are in accordance with those of Scheerlinck et al.,[14] who harvested calvarial bone 26 times; the inner table of the skull was trephined in only one case, without a dural leakage.

In the patients in the present study, almost no morbidity occurred at the calvarial donor site. All patients tolerated the procedure well and experienced little or no pain afterwards. This is in accordance with the results reported by others.[5,14] A limitation of our study is the absence of a control group. However, comparing the results of our study with those of studies in which anterior iliac crest bone was harvested, patients in the latter studies seemed to experience more pain and were hospitalized for longer.[3] In a well designed prospective study, Nkenke et al.[4] reported VAS scores of 7.0 ± 1.5 for the anterior iliac crest donor site on the second postoperative day. This is significantly different from the VAS of 1.9 ± 2.0 on the first postoperative day at the calvarial donor site recorded in the present study. In our study, patients were pain-free at an average of 5.2 ± 4.7 days (range 0–18 days) after surgery, whereas the patients who underwent anterior iliac crest grafting reported pain after 30 days.[4] In other prospective studies, pain scores for the anterior iliac crest at 1 week rated 4.9 and after 6 months still 1.4[15] and 1.6,[3] supporting the observation that donor site pain may be of longer duration for the anterior iliac crest. However, other studies have reported low donor site morbidity for the anterior iliac crest;[16] this may be related to the type of study performed (pro-spective vs. retrospective) or the surgical technique used.[17,18] These findings suggest the need for a prospective randomized clinical trial to compare the donor site morbidity of calvarial and anterior iliac crest bone harvesting.

Other possible complications that are reported in the literature related to outer table calvarial bone grafts are postoperative infection, dizziness, alopecia, and scar problems.[14,19] We did not encounter any of these problems. The scalp healed well, without scar problems, or alopecia.

During the implant procedure, a well incorporated graft could be observed by bleeding of the bone when drilling the implant bed. Also, there appeared to be minimal bone resorption, which could be observed by the screw heads not becoming more prominent. A recent study comparing iliac crest and calvarial only grafts in the resorbed mandible reported a vertical bone resorption after 6 months of 8.4% in the calvarial group and 24% in the iliac crest group,[20] supporting our clinical observation that calvarial bone seems to have a low resorption rate. Again, a prospective randomized clinical trial is suggested to compare the bone volume changes between calvarial and anterior iliac crest grafts used for maxillary reconstruction.

In conclusion, calvarial bone appears to be a promising bone source for augmentation of the maxillary or mandibular process as a pre-implant procedure. When using an appropriate technique, morbidity at the donor site is virtually absent.

References

1. Slot W, Raghoebar GM, Vissink A, Meijer HJ. Maxillary overdentures supportes by four or six implants in the anterior region; 1-year results from a randomized controlled trial. J Clin Periodontol 2013:40:303-310.
2. Kalk WW, Raghoebar GM, Jansma J, Boering G. Morbidity from iliac crest bone harvesting. J Oral Maxillofac Surg 1996:54:1424-1430.
3. Kim DH, Rhim R, Li L, Martha J, Swaim BH, Banco RJ, Jenis LG, Tromanhauser SG. Prospective study of iliac crest bone graft harvest site pain and morbidity. Spine J 2009:9:886-892.
4. Nkenke E, Weisbach V, Winckler E, Kessler P, Schultze-Mosgau S, Wiltfang J, Neukam FW. Morbidity of harvesting of bone grafts from the iliac crest for preprosthetic augmentation procedures: A prospective study. Int J Oral Maxillofac Surg 2004:33:157-163.
5. Touzet S, Ferri J, Wojcik T, Raoul G. Complications of calvarial bone harvesting for maxillofacial reconstructions. J Craniofac Surg 2011:22:178-181.
6. Tessier P, Kawamoto H, Posnick J, Raulo Y, Tulasne JF, Wolfe SA. Taking calvarial grafts, either split in situ or splitting of the parietal bone flap ex vivo. Tools and techniques: V. A 9650-case experience in craniofacial and maxillofacial surgery. Plast Reconstr Surg 2005:116S:54-71.
7. Donovan MG, Dickerson NC, Hanson LJ, Gustafson RB. Maxillary and mandibular reconstruction using calvarial bone grafts and Branemark implants: a preliminary report. J Oral Maxillofacial Surg 1994:52:588-594.
8. Lenssen O, Barbier L, De Clercq C. Immediate functional loading of provisional implants in the reconstructed atrophic maxilla: preliminary results of a prospective study after 6 months of loading with a provisional bridge. Int J Oral Maxillofac Surg 2011:40:907-915.
9. Hunter D, Baker S, Sobol SM. Split calvarial grafts in maxillofacial reconstruction. Otolaryngol Head neck Surg 1990:102:345-350.
10. Schaaf H, Lendeckel S, Howaldt HP, Streckbein P. Donor site morbidity after bone harvesting from the anterior iliac crest. Oral Surg Oral Med Oral Pathol Oral Endod 2010:109:52-58.
11. Schortinghuis J, Putters TF, Raghoebar GM. Safe harvesting of outer table parietal bone grafts using an oscillating saw and a bone scraper: a refinement of technique for harvesting cortical and “cancellous”-like calvarial bone. J Oral Maxillofac Surg. 2012 :70:963-965.
12. Zaffe D, D’Avenia F. A novel bone scraper for intraoral harvesting: a device for filling small bone defects. Clin Oral Implants Res 2007:18:525-533.
13. Kellman RM. Safe and dependable harvesting of large outer-table calvarial bone grafts. Arch Otolaryngol Head Neck Surg 1994:120:856-860.
14. Scheerlinck LME, Muradin MSM, van der Bilt A, Meijer GJ, Koole R, van Cann EM. Donor site complications in bone grafting: comparison of iliac crest, calvarial, and mandibular ramus bone. Int J Oral Maxillofac Implants 2013:28:222-227.
15. Becker ST, Warnke PH, Behrens E, Wiltfang J. Morbidity after iliac crest bone graft harvesting over an anterior versus posterior approach. J Oral Maxillofac Surg 2011:69:48-53.
16. Barone A, Ricci M, Mangano F, Covani U. Morbidity associated with iliac crest harvesting in the treatment of maxillary and mandibular atrophies: a 10-year analysis. J Oral Maxillofac Surg 2011:69:2298-2304.
17. Marianetti TM, Staffoli S, Di Nardo F, Foresta E, Gasparini G, Pelo S. Intracortical versus anteromedial approach for iliac crest bone harvesting in preprosthetic surgery: a randomized prospective clinical trial. J Craniofac Surg 2013:24:369-372.
18. Cricchio G, Lundgren S. Donor site morbidity in two different approaches to anterior iliac crest bone harvesting. Clin Implant Dent Relat Res 2003:5:161-169.
19. Libert I, De Clercq C, Neyt N, Abeloos J, Lamoral P, De Ceulaer J, Swennen G, Lippens F. Complications of calvarial bone harvesting for maxillofacial reconstructions. Int J Oral Maxillofac Surg 2013:42:1344.
20. Mertens C, Decker C, Seeberger R, Hoffmann J, Sander A, Freier K. Early bone resorption after vertical bone augmentation. A comparison of calvarial and iliac grafts. Clin Oral Implants Res 2013:24:820-825.

Chapter 4

Donor site morbidity of anterior iliac crest and calvarium bone grafts: A comparative case-control study

This chapter is an edited version of the manuscript:
Thomas F. Putters, Karel Kuik, Jurjen Schortinghuis, Baucke van Minnen,
Arjan Vissink, Gerry M. Raghoebar
Donor site morbidity of anterior iliac crest and calvarium bone grafts: A comparative case-control study
J Maxillofac surg. 2016; 44: 364-368

Summary

Purpose: Notwithstanding its donor site morbidity, autogenous bone graft harvesting is still considered the gold standard for cases of extreme resorption of the alveolar ridge. The aim of this study was to assess donor site morbidity of calvarium and anterior iliac crest harvesting.

Material and methods: A total of 27 edentulous patients who had undergone calvarial bone harvesting were matched with 27 edentulous patients in which anterior iliac crest bone was harvested. All patients had been treated between March 2011 and December 2013. Patients were matched according to age, sex, and duration of follow-up. Donor site morbidity was assessed by medical records, patient questionnaires, and physical examination. Patients were recalled to assess persisting morbidity of the harvesting procedure.

Results: Exposure of the dura occurred in three patients in the calvarial group. Postoperative pain (based on a visual analog scale) after harvesting was significantly higher in the anterior iliac crest group. Scars were significantly longer and contours deficits were significantly more prominent after calvarial harvesting, although not bothersome to the patients. Long-term pain was negligible in both groups, and satisfaction with the procedure did not differ.

Conclusion: Both harvesting techniques were accompanied by low long-term donor site morbidity and high patient satisfaction.

Introduction

Implant-supported dentures have widely been recognized as a treatment option in edentulous patients with compromised retention of their conventional dentures.[1,2] In cases of extreme resorption of the maxillary alveolar ridge, pre-prosthetic augmentation surgery is often needed to provide a basis for implant placement. A common bone grafting procedure to allow for implant placement in such cases is maxillary sinus floor elevation surgery.[16] Commonly, particularly when a large graft is needed, autogenous bone is still considered the gold standard in bone grafting.[21]

The anterior iliac crest is most used as a donor site for bone augmentation in cases of severe resorption. Access to the anterior iliac crest is relatively easy; iliac crest harvesting can be set up in a two-team surgical approach to reduce surgery time; and this donor site can provide large amounts of cortical and cancellous bone.[10] The major drawback of this procedure is its donor site morbidity, with chronic donor site pain and sensory disturbances being common.[6]

Calvarial bone grafts provide an alternative to iliac bone grafts.[18] The outer cortex of the posterior parietal calvarial bone provides an abundant amount of cortical bone, and copious amounts (>10 cm^3) of cancellous bone can be harvested from the diploic space.[15] When compared to iliac crest bone harvesting, the morbidity of calvarial harvesting is thought to be lower, but neurologic sequelae may interfere with the safety of the procedure.[9,18] With the introduction of a safer harvesting technique, as described by Kellman[8] (1994) and modified by Schortinghuis et al.[15] (2012) , the risk of intracranial complications is minimized.

Despite the reported data on donor site morbidity accompanying various bone grafting sites [18,21,19,6,14,13] the debate as to which donor site is preferable is still open. Therefore, the aim of this comparative study was to assess donor site morbidity and patient satisfaction with anterior iliac crest and calvarial bone grafts used for pre-implant augmentation procedures.

Material and methods

Patients

This retrospective case control study included consecutive edentulous patients with extreme maxillary atrophy with an indication for pre-prosthetic maxillary augmentation surgery to provide a basis for implant placement. All included patients underwent augmentation surgery between March 2011 and December 2013 with either autogenous calvarial or anterior iliac crest grafts. The patients were treated at the departments of Oral and Maxillofacial Surgery of the Scheper Hospital Emmen (SZE), the Refaja Hospital Stadskanaal (REF), or the University Medical Center Groningen (UMCG).

In SZE and REF, calvarial harvesting was the routine pre-prosthetic augmentation procedure. At UMCG, the anterior iliac crest was the routine donor site. The calvarial bone was harvested with the technique of Schortinghuis et al.[15] (2012). The anterior iliac crest bone was harvested according to the technique of Kalk et al.[7] (1996).

All patients were asked to complete a questionnaire and were recalled for a clinical follow-up. In REF and SZE, a total of 28 consecutive patients meeting the inclusion criteria had been treated with calvarial harvesting. At UMCG, a total of 58 consecutive patients meeting the inclusion criteria had been treated with anterior iliac crest harvesting. To create equal-size homogenous groups, patients from the calvarial group were matched to consecutive patients from the anterior iliac crest group according to duration of follow-up, age, and sex. Patients were chosen on the basis of the order of the referred criteria.

The study was approved by the Medical Ethical Committee (METc) of the University Medical Center Groningen, reference SH2014-2.

Evaluation

Medical records

Patients' demographics, perioperative, and postoperative complications concerning the donor site were retained from standardized medical records.

Questionnaire

All patients were asked to complete a mail-in, cross-sectional, custom-made questionnaire before the follow-up session. In this questionnaire, a variety of topics were assessed (Appendix A). Postoperative donor site pain and patient satisfaction were measured by the use of a 10-cm visual analog scale (VAS), ranging from no pain (0) to the worst pain imaginable (10) and from very unsatisfied (0) to very satisfied (10).

Physical examination

Physical examination during follow-up was limited to the donor site area, and was assessed by an independent investigator (K.K.) in the same hospitals as those in which the patients had undergone their operations. The following variables were assessed in all patients: contour deficits, tenderness, sensibility, and length of the scar. In the calvarial group, alopecia around the donor site, defined as evident hair loss next to the scar, was assessed in addition.

The contour of the donor site was examined in a standardized manner. In the iliac group, the anterior superior iliac spine was localized, and the iliac crest was palpated dorsally. In the calvarial group, the calvarium was palpated on the operated parietal side of the head. Contour deficits were noted as subtle or evident deficits. Patients were asked whether the examination of the donor site was accompanied by tenderness or pain.

Tactile sensibility of the donor site was tested by lightly touching the skin with the use of a piece of cotton wool, during which test the patients were blinded and had to identify the number of contacts. Furthermore, superficial pain was tested by the use of a sharp and dull instrument. The patients were blinded and had to discriminate between a sharp needle and a dull cotton bud.

Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS, version 22, IBM, Chicago, IL, USA). For composing two homogenous groups, the Student t test was used in the case of a parametric variable, the Mann–Whitney U test was used in the case of a nonparametric variable. The Pearson χ^2 test was used to compare the categorical variable sex between groups. Concerning the outcome data, the Pearson χ^2-test (or, if necessary, Fisher exact test) was used to compare dichotomous variables. For comparison of categorical variables with an outcome scale greater than 2, the Fischer–Freeman–Halton exact test was used. Comparison of the means of continuous variables, pain experience, scar length, and satisfaction rate was tested with the Mann–Whitney U test. With regard to pain experience, the Pearson r test was used to assess correlations with age, body mass index (BMI), and follow-up duration. Significance was set at the α level of 0.05.

Results

Of the 28 eligible patients who underwent operation at either SZE (n = 13) or REF (n = 15), 27 were willing to join our study. These 27 calvarial bone patients were matched to 27 anterior iliac crest patients who underwent operation at UMCG. None of the patients had undergone a previous operation at the donor site. The clinical characteristics of both groups are listed in Table 1. Perioperative morbidity, early postoperative complications, and late post-operative complications specified by donor site are presented in Table 2. Table 3 shows the postoperative VAS scores, scar length, and patient satisfaction of both groups.

Early morbidity

Calvarial bone

During harvesting of the calvarial bone graft, dural exposures occurred in three patients and resulted in a perforation in one patient. The perforation was resolved and healing was uneventful. In one of the two patients with just a perioperative dura exposure, postoperatively a persistent intermittent clear wound exudate occurred that did not resolve spontaneously or with antibiotics. On the assumption that a dural fistula was present, this patient undersent reoperation. A dural tear was not found, however. After closure of the scalp, the wound healed uneventful. Another patient had complaints of prolonged localized tenderness of the scalp. A CT scan revealed the presence of an irregular rim as a result of the bone cement that was applied in the defect. After surgical correction, the tenderness resolved.

Anterior iliac crest bone

A minor bicortical perforation occurred perioperatively in one patient during harvesting of the iliac crest bone graft, with no clinical consequences. There was no necessity for reoperation at the donor site.

Late morbidity

Calvarial bone

Two patients (7%) had preoperative difficulties with walking due to known comorbidities. In all other patients with difficulties during daily activities (Table 2), these difficulties were related to known comorbidities that developed after the harvesting procedure, none of which was donor site related. None of the patients experienced problems with wearing hats or caps.

Table 1. Clinical characteristics of the calvaria and iliac crest groups.

	Calvarium n=27		Anterior iliac crest n=27	
Sex				
Male	14		12	
Female	13		15	
	Median	IQR*	Median	IQR
Age (years)	60	56-66	61.6	55-67
BMI (kg/m²)	25.6	22.9-31	26.3	23.4-28.2
Follow-up (years)	2.4	1.1-2.9	2.5	1.4-2.9

*Interquartile range.

Five patients in whom clinical examination revealed sensory disturbances at the donor site (hyperalgesia or hypalgesia along the scar) were observed; all were unaware of it. In all patients, contour deficits were detected. Twenty-three of those patients were aware of it, as shown in Table 2.

Anterior iliac crest bone

In the anterior iliac crest group, four patients (15%) had pre-operative difficulties with walking related to known comorbidities, none of which was donor site related. One patient with unexplained difficulties during daily activities since the harvesting procedure, with pain during physical examination of the iliac crest and difficulties with wearing a belt and trousers, was referred to an ortho-pedic surgeon. No surgical intervention was needed, and with time the patient could wear his belt and trousers without problems. In all other patients with difficulties during daily activities (Table 2), these difficulties were related to known comorbidities that developed after the harvesting procedure, none of which donor site related.

The three patients in whom sensory disturbances (hypalgesia in combination with hypesthesia, solitary hypalgesia, and hyper-algesia along the scar) were observed during examination; all patients were unaware of it. Of the total anterior iliac crest group, 18 patients had a subtle contour deficit. Five patients in this group were aware of it, as shown in Table 2.

Table 2. Comparison of the calvarial and anterior iliac crest group.

	Calvarium n = 27	Anterior iliac crest n = 27	*p*-value
Per-operative complications	3	1	0.61
Dura mater exposure without dura tear	2	0	
Dura mater tear with leakage of cerobrospinal fluid	1	0	
Accidental bicortical perforation of the iliac crest	0	1	
Early post-operative complications			
Donor site hematoma	0	2	0.491
Need for extra surgical interventions	2	0	0.491
Need for extra non-surgical interventions:	2	4	0.669
Referral physiotherapy because of persistent pain during movement	0	4	
CT-scan because of prolonged tenderness of the scalp	1	0	
Antibiotics because of edema and prolonged tenderness of the scalp	1	0	
Late postoperative complications			
Difficulties in daily functioning in past week*:			
Walking	5	9	0.214
Walking stairs	5	9	0.214
Cycling	2	1	1.000
Headache in past week	9	9	1.000
Tenderness during palpation	3	3	1.000
Sensory disturbances:	5	3	0.704
Hypalgesia in combination with hypesthesia**	0	1	
Solitary hypalgesia along the scar	1	1	
Hyperalgesia along the scar	4	1	
Localized alopecia	2	0	
Contour examination:			
Evident deficit	13	0	
Subtle deficit	14	18	
normal contour	0	9	<0.001
Contour alteration (subjective)	23	5	<0.001

* None were donor site related, with the exception of one patient with unexplained difficulties after anterior iliac crest harvesting.

** Innervated by lateral cutaneous branch of subcostal nerve.

Table 3. Scar length, postoperative pain, and patient satisfaction in the calvarial and anterior iliac crest groups.

	Calvarium		Anterior iliac crest		*p*-value
	Median	IQR*	Median	IQR	
Visible scar length (cm)	12.0	10-12.5	6.5	6-7	<0.001
Post-operative pain score (VAS)					
Directly after harvesting (on recall)	0.5	0-3.0	4.7	2.4-8.0	<0.001
At long-term follow-up (median 2.5yr)	0.0	0.1-0	0.0	0-0	0.818
Patients' satisfaction	10.0	9.4-10	10.0	8.3-10	0.484

* interquartile range.

Subjective morbidity

Calvarial bone

No significant correlation was found between the VAS scores and age, follow-up duration, and BMI ($p > 0.05$; Pearson r, Table 4). Patients' satisfaction was high (Table 2). The far majority of the patients (96%) stated that they would recommend the procedure to other patients, and all of them were willing to repeat the same operation.

Anterior iliac crest bone

No significant correlation was found comparing the VAS-scores and age, follow-up duration and BMI ($p > 0.05$; Pearson r, Table 4). Patients' satisfaction was high (Table 2). Again, the great majority of the patients (96%) stated that they would recommend the procedure to other patients and would be willing (89%) to repeat the same operation.

Calvarial versus anterior iliac crest bone

As shown in Table 2, there were no significant differences in incidence of perioperative and early post-operative complications. More subtle contour alterations were palpable in the calvarial group ($p < 0.001$), and more calvarial patients considered that the contour along the donor site felt altered ($p < 0.001$, Table 2). Furthermore, a larger scar was present in calvarial patients ($p < 0.001$, Table 3). Notwithstanding these unfavorable results for the calvarial group, none of the patients in this group considered the contour alteration as bothersome or were

Table 4. Correlation (Pearson *r*) between VAS scores of both groups and age, BMI and follow-up.

	Age	BMI	Follow-up
Post-operative pain score (VAS) (calvarium)			
Directly after harvesting (on recall)	0.037	0.206	-0.117
At follow-up (median 2.4yr)	0.141	-0.296	0.075
Post-operative pain score (VAS) (Anterior ili/ac crest)			
Directly after harvesting (on recall)	-0.353	-0.180	0.010
At follow-up (median 2.5 yr)	-0.236	0.025	-0.013

dissatisfied with the aesthetic result of the scar. Finally, early postoperative pain was greater in the anterior iliac crest patients (Table 3,p< 0.001).

Discussion

This retrospective case-control study assessed differences in donor site morbidity at short- and long-term follow-up after iliac crest and calvarial bone harvesting. The main finding of the study was that the perioperative en postoperative complication rate was rather low and well perceived by the patients for both procedures, as reflected in the comparable and fairly high patient satisfaction. Early postoperative pain was higher in iliac crest patients than in calvarial patients.

The occurrence of dura exposures (11%) in this study is similar to the data reported by Scheerlinck et al.[14] (2013). Touzet et al.[19] (2011) reported an occurrence of dura exposures of only 2%. The most likely explanation for this relatively high occurrence, despite the small study sample in our group, was our previously used technique whereby the calvarial graft was removed in one piece. By piece-by-piece removal, after making parallel saw-cuts in the graft in situ, dural exposures can be prevented.[15,12] We applied this technique in the last 14 patients of this study, and in none of these patients did a dura exposure occur.

Major complications as a result of harvesting of cranial grafts, such as intracranial hematomas or neurologic sequelae[9], were not observed in our study. It is noteworthy that the necessity for reoperation tended to occur more often in the calvarial group. There were no perioperative complications of clinical relevance in the iliac crest group. Other complications as a result of iliac harvesting, such as fractures, infections, seromas, or vascular injuries [6,14,3] were not observed in our study.

The pain level experienced directly after harvesting was higher in the anterior iliac crest group in comparison with the calvarial group. Although a retrospective assessment of pain introduces recollection bias, our results are in accordance with other retro-spective studies in which early postoperative pain was seen more frequently after anterior iliac crest harvesting in comparison to calvarial harvesting.[14, 13] Also, prospective studies that included postoperative VAS scores directly after either calvarial or anterior iliac crest harvesting have shown comparable results. [11,5,4,12]

Long-term pain at the donor site in this study was rated as low in both harvesting groups. This is in accordance with the long-term pain at the donor-site observed in other studies. [3,5]

Tessier et al.[17,18] (2005) described the common occurrence of calvarial irregularities after splitting the calvaria in situ. Touzet et al. [19](2011) observed, in 82% of the patients in whom calvarial bone was harvested, a depression of the donor site, which accounted for 100% of the nonreconstructed cases. In the 18% of patients without a depression, harvesting was followed by a reconstruction using biomaterials. In our patients, the defect resulting from calvarial harvesting was reconstructed with bone cement. Despite this, an evident depression was palpable in approximately half of our calvarial patients, but in none of the patients was this clinically bothersome. This raises the question as to whether a contour defect after calvarial harvesting should be considered a clinically relevant complication. The rather high number of contour defects for calvarial bone in comparison to contour defects following iliac crest harvesting may be due to the fact that a deficit in the bony contour can easily and accurately be palpated on the scalp, whereas the inner table of the anterior iliac crest is more difficult to reach during physical examination.

Concerning late morbidity, we found no significant differences in answers to questions concerning daily functioning between both harvesting groups, or with donor site related problems reported with regard to daily functioning in the long term. Barkhuysen et al.[3] (2010) investigated difficulties concerning daily functioning after iliac crest harvesting. In contrast to their findings, we encountered more daily problems with walking and climbing stairs (Table 2). Barkhuysen et al.[3] (2010) excluded patients with comorbidities such as coxarthrosis, rheumatic disorders, lower back pain, and hip or knee prosthesis, whereas we did not exclude these patients.

The occurrence of sensory loss in the iliac harvesting group was similar to the findings of Kalk et al. [7] (1996). Solitary hypalgesia in both groups can be explained by transsection of local nerve endings during the harvesting procedure. In our calvarial harvesting group, we found, in four patients, hyperalgesia during examination; one of them was aware of a more sensitive scalp. Touzet et al.[19] (2011) reported, in 1.5% of the cases, a residual dysesthesia; however, in this study, hyperalgesia is not reported. Both Tessier et al.[17,18] (2005) and Touzet et al.[19] (2011) attributed the occurrence of sensory alterations to a coronal incision, because of the parasagittal course of the nerves supplying the scalp. The calvarial patients in our study all underwent a parasagittal incision of the scalp, thereby decreasing the chance of cutting through sensory nerves with a parasagittal course. The cause of the relative high occurrence of hyperalgesia is as yet unknown, but Wesley et al. [20] (2011) reported a tendency for more patients to develop postoperative hyperalgesia when extensive electrocautery was used. In addition, Touzet et al. [19] (2011) reported electrocautery to be a major factor for developing alopecia after calvarial harvesting. Thus, limiting the use of electrocautery when harvesting calvarial bone is recommended.

Conclusion

In the early postoperative period, in this study donor site pain was higher after iliac crest harvesting than after calvarial bone harvesting. In the calvarial patient group, scar length was longer and nonclinical relevant contour deficits were detected more often. Long-term morbidity was low and patient satisfaction high for both techniques. Randomized prospective studies are needed to determine which harvesting technique is preferred.

References

1. Abraham CM: A brief historical perspective on dental implants, their surface coatings and treatments. Open Dent J 2014:16;8:50-55.
2. Adell R, Lekholm U, Rockler B, Brånemark PI: A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981:10:387-416.
3. Barkhuysen R, Meijer GJ, Soehardi A, Merkx MA, Borstlap WA, Bergé SJ, Bronkhorst EM, Hoppenreijs TJ: The effect of a single dose of bupivacaine on donor site pain after anterior iliac crest bone harvesting. Int J Oral Maxillofac Surg 2010:39:260-265.
4. Barone A, Ricci M, Mangano F, Covani U: Morbidity associated with iliac crest harvesting in the treatment of maxillary and mandibular atrophies: a 10-year analysis. J Oral Maxillofac Surg 2011:69:2298-2304.
5. Becker ST, Warnke PH, Behrens E, Wiltfang J: Morbidity after iliac crest bone graft harvesting over an anterior versus posterior approach. J Oral Maxillofac Surg 2011:69:48-53.
6. Dimitriou R, Mataliotakis GI, Angoules AG, Kanakaris NK, Giannoudis PV: Complications following autologous bone graft harvesting from the iliac crest and using the RIA: a systematic review. Injury 2011:42:S3-S15.
7. Kalk WW, Raghoebar GM, Jansma J, Boering G: Morbidity from iliac crest bone harvesting. J Oral Maxillofac Surg 1996:54:1424-1430.
8. Kellman RM: Safe and dependable harvesting of large outer-table calvarial bone grafts. Arch Otolaryngol Head Neck Surg 1994:120:856-860.
9. Kline jr. RM, Wolfe SA: Complications associated with the harvesting of cranial bone grafts. Plast Reconstr Surg 1995:95:5-20.
10. Mertens C, Decker C, Seeberger R, Hoffmann J, Sander A, Freier K: Early bone resorption after vertical bone augmentation--a comparison of calvarial and iliac grafts. Clin Oral Implants Res 2013:24:820-825.
11. Nkenke E, Weisbach V, Winckler E, Kessler P, Schultze-Mosgau S, Wiltfang J, Neukam FW: Morbidity of harvesting of bone grafts from the iliac crest for preprosthetic augmentation procedures: a prospective study. Int J Oral Maxillofac Surg 2004:33:157-163.
12. Putters TF, Schortinghuis J, Vissink A, Raghoebar GM: A prospective study on morbidity from calvarial bone harvesting for intraoral reconstruction. Int J Oral Maxillofac Surg 2015 :44:513-517.
13. Riachi F, Naaman N, Tabarani C, Berberi A, Salameh Z: Comparison of morbidity and complications of harvesting bone from the iliac crest and calvarium; a retrospective study. J Int Oral Health 2014:6:32-35.

14. Scheerlinck LM, Muradin MS, Van der Bilt A, Meijer GJ, Koole R, Van Cann EM: Donor site complications in bone grafting: comparison of iliac crest, calvarial and mandibular ramus bone. Int J Oral Maxillofac Implants 2013:28:222-227.

15. Schortinghuis J, Putters TF, Raghoebar GM: Safe harvesting of outer table parietal bone grafts using an oscillating saw and a bone scraper: a refinement of technique for harvesting cortical and "cancellous"-like calvarial bone. J Oral Maxillofac Surg 2012:70:963-965.

16. Raghoebar GM, Timmenga NM, Reintsema H, Stegenga B, Vissink A: Maxillary bone grafting for the insertion of endosseous implants: results after 12-124 months. Clin Oral Impl Res 2001:12:279-286.

17. Tessier P: Autogenous bone grafts taken from the calvarium for facial and cranial applications. Clin Plast Surg 1982:9:531-538.

18. Tessier P, Kawamoto H, Posnick J, Raulo Y, Tulasne JF, Wolfe SA: Taking calvarial grafts, either split in situ or splitting of the partieal bone flap ex vivo--tools and techniques: V.A 9650-case experience in craniofacial and maxillofacial surgery. Plast Reconstr Surg 2005 :116(5 Suppl):54S-71S.

19. Touzet S, Ferri J, Wojcik T, Raoul G: Complications of calvarial bone harvesting for maxillofacial reconstructions. J Craniofac Surg 2011:22:178-181.

20. Wesley CK, Unger RH, Rosenberg M, Unger MA: Factors influencing post-operative hyperesthesia in hair restoration surgery. J Cosmet Dermatol 2011:10:301-306.

21. Zouhary KJ: Bone graft harvesting from distant sites: concepts and techniques. Oral Maxillofac Surg Clin North Am 2010:22:301-316.

Appendix A. Questionnaire

Pre-existing complaints

Did you experience pain at the donor site before the harvesting procedure?
Yes/No

Did you experience any numbness at the donor site before the harvesting procedure?
Yes/No

Did you experience difficulties with walking before the harvesting procedure?
Yes/No

Did you have any operation at the donor site before the harvesting procedure?
Yes/No

Questions concerning daily functioning

Did you experience difficulties with walking in the past week?
Yes/No

Did you experience difficulties with walking stairs in the past week?
Yes/No

Did you experience difficulties with cycling in the past week?
Yes/No

Did you experience any headache in the past week?
Yes/No

Do you nowadays have difficulties with wearing a hat/cap?
Yes/No

Do you nowadays have difficulties with wearing a belt?
Yes/No

Do you nowadays have difficulties with wearing trousers?
Yes/No

Subjective morbidity

Does the contour of the operated donor site feels altered?
Yes/No

Has the sensibility changed at the donor site after the harvesting procedure?
Yes/No

Did you experience pain at the donor site directly after the harvesting procedure?
VAS-score

0 (no pain) _____10 (worst pain imaginable)

Do you experience pain nowadays at the donor site?
VAS-score

0 (no pain) _____10 (worst pain imaginable)

Patients' satisfaction

Are you satisfied concerning the end result?
VAS-score

0 (very unsatisfied) _____10 (very satisfied)

Would you recommend the procedure to other patients with the same problem?
Yes/No

Would you be willing to undergo the same operation when needed?
Yes/No

Are you satisfied with the scar aesthetics at the donor site?
Yes/No

Do you consider the altered contour of the donor site bothersome?
Yes/No

Chapter 5

Morbidity of anterior iliac crest and calvarial bone donor graft sites: a 1-year randomized controlled trial

This chapter is an edited version of the manuscript:
T. F. Putters, D. E. Wortmann, J. Schortinghuis, B. van Minnen, C. Boven,
A. Vissink, G. M. Raghoebar
Morbidity of anterior iliac crest and calvarial bone donor graft sites: a 1-year randomized controlled trial
Int J Oral Maxillofac Surg 2018 Nov; 47: 1474-1480

Summary

Autogenous bone graft harvesting is still commonly considered the gold standard for the reconstruction of a severely resorbed maxillary alveolar ridge; however, the preferred donor site remains a subject of debate. This study compared the morbidity of calvarial and iliac crest donor sites after harvesting. Twenty edentulous patients with an insufficient volume of maxillary bone for reliable implant placement were assigned randomly to either calvarial (n = 10) or anterior iliac crest (n = 10) bone harvesting groups. All patients underwent a maxillary sinus floor elevation procedure combined with widening of the alveolar process using buccal bone blocks. Donor site morbidity was assessed before, during, and at 1 year after the surgery through patient questionnaires, physical examination, and medical records. No perioperative complications occurred. The anterior iliac crest group reported minor postoperative pain after harvesting. The scars after calvaria harvesting were significantly longer (P = 0.003), but this was not bothersome for the group of patients. Long-term pain was negligible and satisfaction was high in both groups. Both the calvaria and anterior iliac crest are associated with low long-term donor site morbidity and high patient satisfaction. Thus, patient-centred decision-making is appropriate when selecting the preferred harvesting method for that patient.

Key words: bone augmentation, iliac crest, calvarial bone, morbidity, patient satisfaction

Introduction

Implant overdentures are widely recognized as the treatment of choice for edentulous patients experiencing problems wearing conventional dentures. Pre-implant augmentation surgery is needed in severe cases of resorption whereby insufficient bone volume is present for adequate implant placement and stability.

Several augmentation techniques have been described,[1] either with human bone, animal bone, synthetic materials, or a combination of these. Grafting with autogenous bone is still considered the gold standard.[2] Bone can be grafted from numerous places in the human body, of which the anterior iliac crest is mostly used when a large volume is needed.[2] The anterior iliac crest is easily accessible and can provide considerable amounts of cortical and cancellous bone. Furthermore, when using a two-team surgical approach, the bone harvesting can be done simultaneously with the augmentation surgery, thereby reducing surgery time. However, the common limitation of this procedure is the inherent donor site morbidity including pain, sensory disturbances, and gait problems.[3]

The calvaria offers an alternative to the iliac crest as a donor site when large bone grafts are needed. Grafts taken from the outer cortex of the posterior parietal skull bone provide a large volume of cortical bone, while the diploic space contains copious amounts of cancellous bone.[4] The associated donor site morbidity is suggested to be low compared to iliac crest bone grafting. However, the possibility of neurological sequelae represents the major argument against calvarial bone grafting.[5] The recently developed safe harvesting technique, introduced by Kellman[6] and modified by Schortinghuis et al.[4], decreases the risk of intracranial complications to a minimum.

Despite the existing extensive knowledge on donor site morbidity associated with various bone grafting sites,[1,3,7–11] the best donor site remains undefined. Accordingly, a prospective comparative trial was designed to assess donor site morbidity and patient satisfaction following anterior iliac crest and calvarial bone harvesting when applied as a pre-implant augmentation procedure to reconstruct a severely resorbed maxilla.

Materials and methods

Patients

Between November 2014 and March 2016, 20 patients fulfilled the inclusion criteria for this study. All patients had been referred to the Department of Oral and Maxillofacial Surgery of the Universal Medical Centre Groningen (UMCG) because of problems while wearing an upper denture (pain, mobility, loss of retention, chewing) due to severe resorption of the edentulous maxilla. The patients were eligible to be included in this study when the available bone volume was insufficient for reliable implant placement, i.e., <3 mm bone height in the maxillary sinus area and <2 mm bone width in the anterior maxillary area, as assessed on a cone beam computed tomography (CBCT) scan. Furthermore, the thickness of the temporal bone (>5 mm) in the area between the articular tubercle and the end of the mastoid bone had to be suitable, as assessed on a CBCT scan of the calvaria with frontal reconstructions. Exclusion criteria were the following: presence of contraindications to surgery due to severe health problems, former or current use of intravenous bisphosphonates, currently pregnant or lactating, and a previous operation at the donor site. Informed consent was obtained from all patients. The study was approved by the Medical Ethics Committee of UMCG. The eligible participants were divided randomly into two equal groups. One group was treated using calvarial bone for the augmentation procedure (n = 10) and the other group with bone from the anterior iliac crest (n = 10).

Surgery

Calvarial bone was harvested after raising a full-thickness flap. Next, the outline of the outer table graft was marked with a burr until the diploë was encountered. A bone scraper (SafeScraper Twist; META, Reggio Emilia, Italy) was used to create a bevelled trough around the calvarial outer table graft to facilitate its removal with a reciprocating saw. Using the scraper, copious amounts (>10 ml) of 'cancellous'-like bone could be collected. Parallel saw-cuts were made in situ so that the graft could be removed piece by piece thus preventing graft breakage[4,12]. The defect in the skull was reconstructed with bone cement (Palacos; Zimmer Biomet, Warsaw, Indiana, USA).

Anterior iliac crest bone was harvested according to the technique of Kalk et al.[13]. The incision was started 1 cm behind the anterior superior iliac spine and continued posteriorly, following the iliac crest. It was carried down sharply to the midcrest, dividing the musculotendinous aponeurosis of the tensor muscle of the fascia lata and the oblique abdominal muscles, without transecting muscle fibres. The bony ilium was exposed directly by reflecting the iliac muscle sub-periosteally and the donor site was exposed with a retractor. The corticocancellous bone blocks were harvested by making two horizontal and five vertical cuts. The superior horizontal cut was made midcrestal with a reciprocating saw. The inferior horizontal cut was made 4 cm inferior in the inner table with a curved osteotome. The horizontal cuts were connected by verticals cuts using a reciprocating saw. After removal of the corticocancellous bone block piece by piece from the inner table, additional cancellous bone was harvested with gouges and curettes. Care was taken not to perforate the lateral cortex.

All of the operations were performed at UMCG by an experienced oral and maxillofacial surgeon. After harvesting the calvarial or iliac crest bone, sinus elevation surgery was performed according to the procedure described by Raghoebar et al.[14]

Broad-spectrum antibiotics (amoxicillin–clavulanic acid) and non-steroidal anti-inflammatory drugs (NSAIDS) (ibuprofen) were prescribed for 1 week post-surgery. Patient instructions included a soft diet and not wearing the maxillary denture for 2 weeks.

After 4 months, the dental implants were placed in the augmented maxilla. All of the patients were enrolled for a dental hygiene protocol.

Outcome measures

The primary outcome measure was donor site morbidity (perioperative, early, and late postoperative). The secondary outcome measures were patient satisfaction, self-reported postoperative pain, and implant survival.

For the assessment of perioperative donor site morbidity, the presence (reported as yes/no) of each of the following items was recorded during the grafting procedure: dura exposure, dural tear, accidental falling of the graft, graft fracture during removal and/or bicortical perforation of the iliac crest, and size of the graft. The duration of the harvesting procedure was measured (min). The hospitalization period was also recorded in days. During implant placement, bone loss or signs of bone resorption (yes/no) were recorded.

With regard to early postoperative donor site morbidity, the morbidity data of both groups were recorded by the surgeon at 1, 2, 6, 16, 20, and 28 weeks postoperative. The following items were each assessed with regard to the donor site (reported as yes/no): scar aspects (dehiscence, erythema, swelling, and pain), hair loss, localized pain, and contour deficit. If contour deficits were present, the patient was asked whether or not this was bothersome (yes/no). With regard to

the receptor site, the presence of dehiscence, fistula, erythema, loss of implant, and gingivitis were also recorded (reported as yes/no).

Late postoperative donor site morbidity was assessed at 1 year after prosthetic loading. All patients were invited for a physical examination by an independent investigator at UMCG. The following variables were investigated: contour deficits, sensitivity, tenderness, and length of the scar. In addition, alopecia around the donor site, defined as evident hair loss next to the scar, was assessed for the calvaria group.

The assessments of the donor site contour changes were standardized for both groups. The operated parietal surface of the head was palpated, or the contour of the operated anterior superior iliac crest was dorsally palpated after localizing the iliac spine. Subtle or evident deficits were reported. The patients were asked to report tenderness or pain accompanying the examination.

Tactile sensitivity of the donor site was determined by touching the skin lightly with a piece of cotton wool. Patients were asked to identify the number of contacts. Sensitivity was established by touching with a dull cotton bud and a sharp needle, and the participants had to discriminate between them. The patients were blinded for both tests.

For the assessment of postoperative pain, the participants graded the donor site pain experienced (skull or iliac crest region) following augmentation and implantation surgery for 30 days at 12:00 a.m. each day. Twelve months after prosthetic construction, the participants were asked to score their current pain. This was measured using a 10-cm visual analogue scale (VAS), ranging from 'no pain' (0) to 'the worst pain imaginable' (10).

Patient satisfaction was assessed at 12 months post-augmentation. This was measured with a VAS, with 0 representing 'a bad outcome' and 10 'a good outcome'.

Implant survival was investigated by assessing loose and lost implants, which were recorded at any time after placement.

Statistical analysis

The data management and analysis were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA). The Student *t*-test, Mann–Whitney *U*-test, and Pearson χ^2 test were used to compare the outcomes of the parametric variables, non-parametric variables, and categorical sex variable, respectively, between the groups. Concerning the outcome data, the Pearson χ^2 test (or, if necessary, Fisher's exact test) was used to compare any dichotomous variables.

Categorical variables with an outcome scale greater than 2 were compared with the Fisher–Freeman–Halton exact test. The means of continuous variables, pain experience, scar length, and satisfaction rate were compared with the Mann–Whitney *U*-test. With regard to pain experience, a Pearson's *r* test was used to assess the correlations with age, body mass index (BMI), and duration of follow-up. Significance was set at an α level of 0.05.

Results

Clinical characteristics

Table 1 describes the baseline characteristics of the study patients. One patient in each group had minor intraoral wound dehiscence. Both were closed with a pedicle mucosal flap and they healed without further complaints.

Table 1. Characteristics of the calvaria and anterior iliac crest groups[a].

	Calvaria group *n* = 10	Anterior iliac crest group *n* = 10
Sex		
Male	5	4
Female	5	6
Age at implant placement (years)	65.9 ± 8.7	63.5 ± 7.0
BMI (kg/m^2)	30.6 ± 7.9	28.5 ± 6.13
Time between augmentation and implant placement (years)	0.5 ± 0.2	0.4 ± 0.1

BMI, body mass index.

[a]Results are presented as the number, or the mean ± standard deviation.

Implant survival

In all cases, the augmentation procedure resulted in sufficient bone volume for implant placement at the prosthodontically preferred sites. A total 44 implants were placed in each group. One patient in each group lost an implant because of mobility during the osseointegration phase, resulting in a 1-year implant survival rate of 97.7%.

Perioperative morbidity (Tables 2 and 3)

Table 2. Complications in the calvaria and anterior iliac crest groups.

	Calvaria group $n = 10$	Anterior iliac crest group $n = 10$	*P*-value[a]
Perioperative complications			
Dura mater exposure without dura tear	0	-	
Dura mater tear with leakage of CSF	0	-	
Accidental bicortical perforation of the iliac crest	-	0	
Breakage of graft	1	0	0.317
Early postoperative complications			
Donor site haematoma	0	0	
Need for extra surgical interventions	0	0	
Need for extra non-surgical interventions	0	0	
Referral to physiotherapy because of persistent pain during movement	0	0	
CT scan because of prolonged tenderness of the scalp	0	0	
Antibiotics because of oedema and prolonged tenderness of the scalp	0	0	
Late postoperative complications[b]			
Difficulties in daily functioning at 12 months postoperative			
Walking	0	1	0.317
Climbing stairs	0	1	0.317
Cycling	0	0	
Persistent headache episodes	0	0	
Difficulties with wearing			
Headgear	0	0	
Pair of trousers	0	1	0.317
Belt	0	1	0.317
Tenderness during palpation	1	0	0.317
Sensory disturbances	1	1	
Hyperalgesia in combination with hypoalgesia	0	1	0.317
Solitary hypoalgesia along the scar	1	0	0.317
Solitary hyperalgesia along the scar	0	0	
Localized alopecia	0	0	
Contour examination			
Evident deficit	2	0	0.146
Subtle deficit	5	3	0.170
Normal contour	3	7	0.089
Contour alteration (subjective)	1	1	
Implants			
Participants with 4 implants	8	8	
Participants with 6 implants	2	2	

CSF, cerebrospinal fluid; CT, computed tomography.
[a]Mann–Whitney *U*-test.
[b]Assessed at the 12-month follow-up meeting.

Table 3. Grafting aspects, scar length, postoperative pain, and patient satisfaction in the calvaria and anterior iliac crest groups.

	Calvaria group Mean ± SD	Anterior iliac crest group Mean ± SD	*P*-value[a]
Grafting			
Graft surface (cm^2)	13.5 ± 1.8	18.3 ± 3.6	0.001*
Graft operation time (min)	53 ± 13	42 ± 8	0.033*
Visible scar length (cm)	9.6 ± 2.5	5.7 ± 2.2	0.003*
Postoperative pain score (0–10) at long-term follow-up	0.1 ± 0.1	0.4 ± 0.9	0.270
Patient satisfaction (0–10)	8.0 ± 2.9	9.4 ± 0.5	0.142

SD, standard deviation.
[a]Independent samples t-test; *significant difference.

The harvesting of calvarial bone took an average of 53 ± 13 min. One monocortical bone strip fractured during harvesting, but without hampering the augmentation procedure. The mean graft surface was 13.5 ± 1.8 cm^2.

The harvesting of anterior iliac crest bone took an average 42 ± 8 min. The mean graft surface was 18.3 ± 3.6 cm^2.

Early morbidity (Table 2)

In the calvaria group, no dura mater exposure or dura tear occurred during the bone harvesting procedures. There was no case of donor site haematoma. No extra (non)surgical interventions were needed at the donor site.

In the anterior iliac crest group, no bicortical perforation of the iliac crest occurred. No donor site haematoma was observed. There was no requirement for extra (non)surgical interventions or for referral to a physiotherapist because of persistent pain during movement.

Late morbidity (Tables 2 and 3)

None of the patients in the calvaria group reported difficulties in daily functioning (walking, climbing the stairs, or cycling) at 12 months postoperative. Persistent episodes of headache did not occur. One patient reported a subjective contour alteration. Physical examination revealed five subtle and two explicit contour deficits (including the patient who reported the contour alteration). The mean scar length was 9.6 ± 2.5 cm. Solitary hypoalgesia along the scar was observed in one patient.

With regard to the anterior iliac crest group, difficulties in daily functioning were reported by two patients at 12 months postoperative. Difficulties with wearing a pair of trousers or a belt were each reported once. Persistent headache episodes did not occur. One patient reported a subjective contour alteration, whereupon a physical examination revealed that a subtle contour deficit was indeed present. No contour defects were observed in the other patients. The mean scar length was 5.7 ± 2.2 cm. Sensory disturbances at the donor site were noted by one patient (hyperalgesia in combination with hypoalgesia).

Postoperative pain

In the assessment of the calvaria group patients, direct postoperative pain scores in relation to sex, age, and BMI were not significantly correlated, as determined by a Pearson product-moment correlation test ($P > 0.05$, Pearson's r). At the 1-year follow-up, the mean VAS score for current pain of the skull was 0.1 ± 0.1. The participants were highly satisfied with the result of the procedure after 12 months (mean score of 8.0 ± 2.9 on a 0–10 VAS, Table 3).

For the anterior iliac crest group, the Pearson product-moment correlation test revealed a relationship between BMI and the direct postoperative pain scores. After excluding one outlier, the BMI and post-augmentation pain scores for the hip region were significantly correlated ($r = 0.830$, $n = 9$, $P = 0.006$). Direct postoperative pain scores were not correlated with sex or age ($P > 0.05$, Pearson's r). At the 1-year follow-up, the mean VAS score for current pain of the skull was 0.4 ± 0.9. The participants in this group were very satisfied with the results after 12 months (mean VAS score 9.4 ± 0.5, Table 3).

Calvarial versus anterior iliac crest bone

The operating time was significantly shorter for the anterior iliac crest group than for the calvaria group ($P = 0.03$, independent samples t-test). Grafts taken from the skull were significantly smaller in surface area than the grafts from the iliac crest ($P = 0.001$, independent samples t-test), but the harvested bone volume from both procedures was sufficient for all the augmentation procedures applied. There were no significant differences in early and late complications between the two groups.

The physical examination at the 1-year follow-up revealed more contour alterations in the calvaria group ($P = 0.089$, Mann–Whitney U-test), and the scars after calvarial bone grafting were significantly longer than the scars after anterior iliac crest grafting ($P = 0.003$, independent sample t-test). Although these results seem unfavourable for the calvaria group, the subjective outcomes of the contour alterations and scar formation were similar in the two groups.

On comparing the pain diaries of the two groups, it was evident that there was a difference in postoperative pain development. Fig. 1 shows that post-augmentation pain was similar until day 5, following which the anterior iliac crest group experienced more pain at the donor site and intraorally than the calvaria group. The pain reported for both procedures was minor, which may explain the observation of no significant differences between the groups over the 30-day postoperative period in this patient cohort (Independent sample t-test, p-values ranging from $p = 0.047$ to $p = 1.00$). Also, the pain curves of the two groups were similar after implantation (Fig. 2).

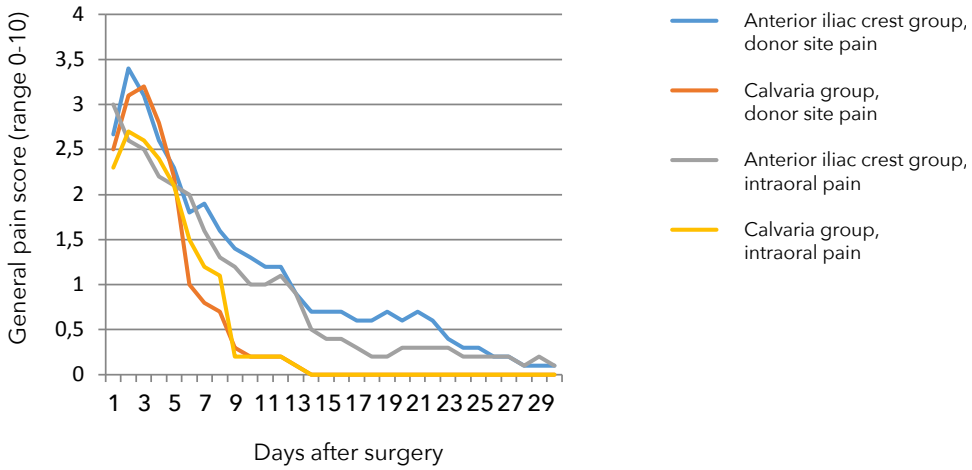


Fig 1. Pain scores following augmentation surgery.

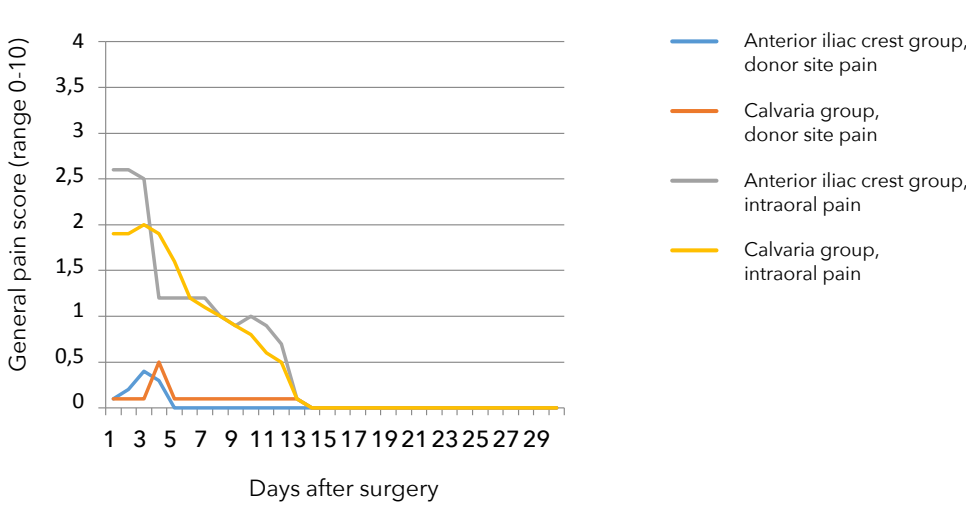


Fig 2. Pain scores following implantation surgery.

Discussion

No apparent difference in short- or long-term donor site morbidity between calvaria and anterior iliac crest harvesting was evident. This study revealed that few complications occurred and that the pain experienced was very minor, hence patient satisfaction was high.

As mentioned, the complication rate was negligible for both calvaria and iliac crest harvesting. This result is somewhat different from the morbidity reported in the literature, as iliac crest harvesting is commonly associated with a higher rate of minor complications than calvaria harvesting[7,8]. Furthermore, any complications occurring following calvaria harvesting are generally more severe, especially dura exposure[2,5,8,9,11]. The fact that no complications were observed after calvaria harvesting may be due to the technique applied, which prevents dura exposure[4].

Regarding late morbidity, the postoperative mobility assessment showed that two patients in the iliac crest bone harvesting group had minor gait problems, but this did not interfere with their daily activities. This observation is in line with the reported postoperative impaired mobility following iliac crest and calvaria harvesting[9,15–19].

Furthermore, any pain experienced by patients is commonly reported to be higher following iliac crest bone harvesting[8,9]. A similar pattern was observed in the present study, as shown in Fig.1, but the postoperative pain experienced was rather low, hence the lack of a significant difference between the two groups with regard to postoperative pain up to 30 days after treatment. However, postoperative pain levels in the iliac crest region and BMI were strongly correlated. This may be due to accessibility of the donor site and forces on the operated area during rehabilitation.

The occurrence of sensory disturbances did not differ significantly between the groups. Such sensory alterations, probably due to the transection of local nerve endings, are well known consequences of both procedures: Kalk et al.[13] described sensory loss after iliac crest harvesting, and Kuik et al. [7], Scheerlinck et al.[9], and Touzet et al.[11] have described several presentations of altered sensitivity after calvaria harvesting. The changes after calvaria harvesting are thought to be more prominent when a coronal incision is used, as nerves supplying the scalp follow a parasagittal course. Hence, a parasagittal incision of the scalp was used to minimize the chance of cutting through the sensory nerves[10,11]. Some sensitivity could have been due to the described correlation between the extensive use of electrocautery and postoperative hyperalgesia20 and/or the strong correlation between electrocautery and alopecia[11].

Several studies have described contour alterations after calvarial bone harvesting. To prevent an aesthetically undesirable outcome, reconstruction using biomaterials directly after obtaining the graft is generally advised. In the current study, the bone alterations in the calvaria group patients were reconstructed with bone cement. Despite this, contour deficits were seen on physical examination in more than half of the participants at the 12-month follow-up. However, this was reported as bothersome by only one patient. Kuik et al. described similar results[7]. Hence, this raises the question of whether objectively reported contour changes are relevant in the context of calvarial bone harvesting. Furthermore, the anatomical differences between the two donor sites might explain the different results on examination: irregularities in the parietal skull are easier to identify than alternations to the inner table of the anterior iliac crest.

Furthermore, the restoration of the skull defect caused by the harvesting of calvarial bone was performed with the bone cement Palacos. Although the reconstruction is aesthetically favourable, the cement itself may cause complications such as allergic reactions and infection. However, no such complications were observed. Furthermore, as pointed out by Zanotti et al.[21] , all currently available materials for cranial reconstruction have their inherent advantages and disadvantages, and none of these materials lacks an infection risk or potential biological toxicity.

The aim of this study was to make a fair comparison between bone grafting techniques. Some limitations can be pointed out. Although postoperative pain and mobility were primary parameters, the presurgical level of daily physical functioning and usage of pain medication were not assessed at inclusion. It is possible that the frequent use of NSAIDs was a confounding factor. Furthermore, the participants were only followed-up for 1 year postoperatively. Long-term effects could have been analysed better by extending this follow-up period. Moreover, the differences in functionality of the grafts in the long term were not assessed. Specific assessments of bone metabolism at a microscopic level could provide further information about the sustainability and stability of the grafts. The patient-reported outcomes in the present study consisted of pain levels and general satisfaction with the procedure. Following the current trend towards patient-centred decision-making in medical science, the assessment of patient experiences deserves a more prominent role when considering treatment options for pre-implantation surgery. Future studies should pay special attention to this point.

To conclude, both the calvaria and anterior iliac crest are appropriate options for pre-implantation maxillary augmentation with regards to donor site morbidity. The complication rate is low for both procedures and the level of patient satisfaction is high. Therefore, when deciding between these two options, it is recommended that patient-specific factors be taken into account. Pain following calvaria harvesting is apparently lower than that after anterior iliac crest harvesting, especially in those with a higher BMI. Furthermore, the findings of this and previous studies advocate taking the patient's daily mobility into account when choosing a procedure: calvaria harvesting might be more favourable for highly active patients. However, in the case where large bone volumes are required or limited surgical time is available, the iliac crest (two-team approach) might be the donor site of choice. Furthermore, due to the frequently described contour changes after harvesting, the use of the calvaria as a donor site requires a direct reconstruction with biomaterial. Finally, to reduce the risk of alterations in sensitivity and alopecia, it is recommended that the use of electrocautery is minimized.

Acknowledgements

The assistance of Mrs A. Bezema in the collection of all questionnaires and data is greatly appreciated.

References

1. Zouhary KJ. Bone graft harvesting from distant sites: concepts and techniques. Oral Maxillofac Surg Clin North Am 2010: 22: 301–316.
2. Sakkas A, Wilde F, Heufelder M, Winter K, Schramm A. Autogenous bone grafts in oral implantology—is it still a "gold standard"? A consecutive review of 279 patients with 456 clinical procedures. Int J Implant Dent 2017: 3: 23-40.
3. Dimitriou R, Matalliotakis GI, Angoules AG, Kanakaris NK, Giannoudis PV. Complications following autologous bone graft harvesting from the iliac crest and using the RIA: a systematic review. Injury 2011: 42(Suppl 2): S3–S15.
4. Schortinghuis J, Putters TF, Raghoebar GM. Safe harvesting of outer table parietal bone grafts using an oscillating saw and a bone scraper: a refinement of technique for harvesting cortical and "cancellous"-like calvarial bone. J Oral Maxillofac Surg 2012: 70: 963–965.
5. Kline RM Jr, Wolfe SA. Complications associated with the harvesting of cranial bone grafts. Plast Reconstr Surg 1995: 95: 5–13.
6. Kellman RM. Safe and dependable harvesting of large outer-table calvarial bone grafts. Arch Otolaryngol Head Neck Surg 1994: 120: 856–860.
7. Kuik K, Putters TF, Schortinghuis J, Van Minnen B, Vissink A, Raghoebar GM. Donor site morbidity of anterior iliac crest and calvarium bone grafts: a comparative case–control study. J Craniomaxillofac Surg 2016: 44: 364–368.
8. Riachi F, Naaman N, Tabarani C, Berberi A, Salameh Z. Comparison of morbidity and complications of harvesting bone from the iliac crest and calvarium: a retrospective study. J Int Oral Health 2014: 6: 32–35.
9. Scheerlinck LM, Muradin MS, Van der Bilt A, Meijer GJ, Koole R, Van Cann EM. Donor site complications in bone grafting: comparison of iliac crest, calvarial, and mandibular ramus bone. Int J Oral Maxillofac Implants 2013: 28: 222–227.
10. Tessier P, Kawamoto H, Posnick J, Raulo Y, Tulasne JF, Wolfe SA. Taking calvarial grafts, either split in situ or splitting of the parietal bone flap ex vivo—tools and techniques: V. A 9650-case experience in craniofacial and maxillofacial surgery. Plast Reconstr Surg 2005: 116(5 Suppl): 54S–71S.
11. Touzet S, Ferri J, Wocjik T, Raoul G. Complications of calvarial bone harvesting for maxillofacial reconstructions. J Craniofac Surg 2011: 22: 178–181.
12. Putters TF, Schortinghuis J, Vissink A, Raghoebar GM. A prospective study on the morbidity resulting from calvarial bone harvesting for intraoral reconstruction. Int.J.Oral Maxillofac. Surg 2015: 44:513-517.
13. Kalk WW, Raghoebar GM, Jansma J, Boering G. Morbidity from iliac crest bone harvesting. J Oral Maxillofac Surg 1996: 54: 1424–1429.
14. Raghoebar GM, Timmenga NM, Reintsema H, Stegenga B, Vissink A. Maxillary bone grafting for insertion of endosseous implants: results after 12–124 months. Clin Oral Implants Res 2001: 12: 279–286. J Oral Maxillofac Surg 2015: 44: 513–517.
15. Barkhuysen R, Meijer GJ, Soehardi A, Merkx MA, Borstlap WA, Bergé SJ, Bronkhorst EM, Hoppenreijs TJ. The effect of a single dose of bupivacaine on donor site pain after anterior iliac crest bone harvesting. Int J Oral Maxillofac Surg 2010: 39: 260–265.
16. Becker ST, Wanke PH, Behrens E, Wiltfang J. Morbidity after iliac crest bone graft harvesting over an anterior versus posterior approach. J Oral Maxillofac Surg 201: 69: 48–53.
17. Barone A, Ricci M, Mangano F, Covani U. Morbidity associated with iliac crest harvesting in the treatment of maxillary and mandibular atrophies: a 10-year analysis. J Oral Maxillofac Surg 2011: 69: 2298–2304.
18. Almaiman Manar M. Complication of anterior iliac bone graft harvesting in 372 adult patients from May 2006 to May 2011 and a literature review. Craniomaxillofac Trauma Reconstr 2013: 6: 257–266.
19. Nkenke E, Weisbach V, Winckler E, Kessier P, Schultze-Mosgau S, Wiltfang J, Neukam FW. Morbidity of harvesting of bone grafts from the iliac crest for preprosthetic augmentation procedures: a prospective study. Int J Oral Maxillofac Surg 2004: 33: 157–163.
20. Wesley CK, Unger RH, Rosenberg M, Unger MA. Factors influencing postoperative hyperesthesia in hair restoration surgery. J Cosmet Dermatol 2011: 10: 301–306.
21. Zanotti B, Zingaretti N, Verlicchi A, Robiony M, Alfieri A, Parodi PC. Cranioplasty: review of materials. J Craniofac Surg 2016: 27: 2061–2072.

Chapter 6

Immediate dental implant placement in calvarial bone grafts to rehabilitate the severely resorbed edentulous maxilla: a prospective pilot study

This chapter is an edited version of the manuscript:
Thomas F. Putters, Gerry M. Raghoebar, Jenneke Klein-Nulend,
Arjan Vissink, Jurjen Schortinghuis
Immediate dental implant placement in calvarial bone grafts to rehabilitate the severely resorbed edentulous-maxilla: a prospective pilot study
J Craniomaxillofac Surg. 2019 Jan; 47: 23-28

Summary

Introduction: The aim of this study was to describe the surgical technique of immediate dental implant placement in calvarial grafs for augmentation of the severely resorbed maxilla and to assess the treatment results.

Methods: In 13 patients the maxilla was augmented with calvarial bone followed by simultaneous dental implant placement (total: 68 implants). In the frontal "knife edge" region, implants were inserted in the buccal plated area. In the maxillary sinus area, implants were inserted into alveolar bone that was plated buccally or palatally through the sinus window. After 4 months, the implants were retrieved and subsequently loaded. Per-operative and post-perative variables were scored. One bone biopsy was taken for histological analysis.

Results: The surgical procedure and wound healing was uneventful. During abutment connection after 4 months, all implants were fully osseointegrated with no signs of graft resorption. Radiographically, the average peri-implant bone loss after 1 year of functional loading was 0.23±0.44 (mean±SD) mm. No implants were lost. Histological examination revealed vital calvarial and maxillary bone with active remodeling.

Conclusion: Immediate dental implant placement in calvarial bone grafts to rehabilite severely resorbed maxilla is technically feasible and seems to have a high success rate.

Key words: Maxilla augmentation; calvarial bone graft; dental implant; immediate implant placement; resorbed maxilla; osseointegration.

Introduction

Placement of dental implants in the severely atrophied maxilla can be a challenge due to the limited amount of bone available. To ensure enough bone to place the dental implants with reliable stability, autogenous bone needs be transplanted to the maxilla. To create sufficient bone volume in the extremely resorbed maxilla, the floor of the maxillary sinus is usually augmented with anterior iliac crest grafts, combined with buccal plating.[9] After a healing period of 3-6 months, dental implants can be placed in the grafted maxilla. The implants then need to osseointegrate for another 3 months, after which the denture can be made. This rather long treatment period of approximately 8 months can be bothersome to the patient.

Since 2010, we use calvarial bone for the augmentation of the maxilla.[10] After a period of 4 months, the dental implants were placed, which in turn, needed to osseointegrate for another 3 months. However, due to the limited resorption that was clinically observed at the time the implants were placed[8], we explored whether the dental implants could be placed simultaneously with the augmentation in a prospective pilot study. By combining the time needed for healing of the graft with the osseointegration of the implants, a reduction in total treatment time to 4 months would be obtained. Here, we present our experience and clinical and radiographic results of 13 patients in which a maxilla augmentation with calvarial bone was performed and the implants were placed at the same time. To assess the results of the augmentation at the microscopic level, a bone biopsy of one healed grafted maxilla was taken for histological evaluation at 4 months, at the time the dental implants were retrieved.

Materials and methods

Medical Ethical Committee

This study was in accordance with the Medical Ethical Committee guidelines of The University Medical Centre Groningen (approval M14157).

Inclusion criteria

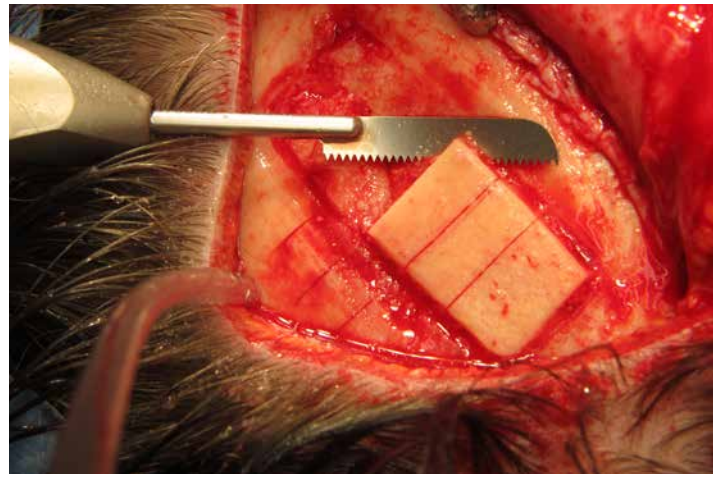
In 2013 and 2014, 13 consecutive patients with a severely resorbed maxilla and problems wearing a denture were identified to be included in the study. Inclusion criteria were the inability to wear a denture due to retention problems caused by maxillary atrophy, and less than 3 mm bone width of the alveolar process in the frontal region, and less than 4 mm bone height under the maxillary sinus as measured using a CT-scan. Exclusion criteria were smoking, immunosuppresive medication, the use of bisphosphonates and/or chemotherapeutic agents.

Surgical procedure

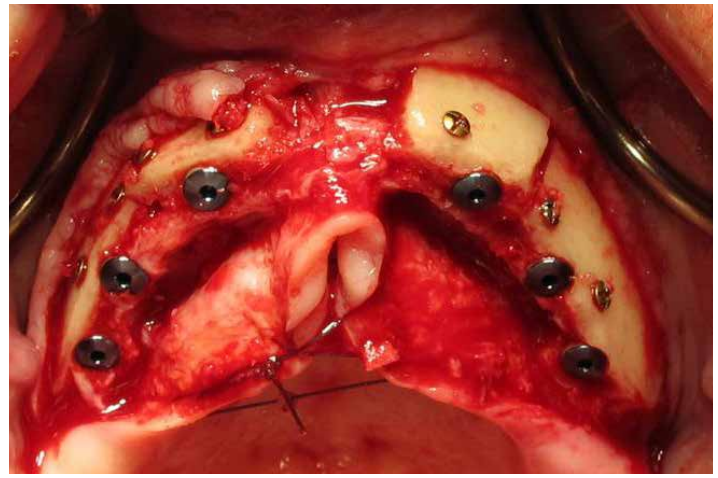
Under general anesthesia, calvarial bone was harvested using a standard technique as described earlier,[10] to remove 4-6 outer table calvarial bone blocks measuring approximately 1.5 x 1.0 x 0.3 cm (length x width x height) each (Fig. 1a).

Intraorally, after reflection of the mucoperiosteum, a sinus augmentation procedure was performed on both sides first. An oval bone window was prepared at each sinus location leaving the sinus membrane intact. After reflexion of the Schneiderian membrane, calvarial bone mass was used to fill up the space created. After this, the calvarial bone blocks could be fixed buccally with 1.3 mm diameter microscrews (Synthes, Wolhusen, Switserland) .The implant was inserted on top to achieve primary stability. When the thickness of the alveolar process in the maxillary sinus region was only as thin as an egg-shell, a calvarial graft was placed onto the palatal wall via the sinus window, and fixed by microosteosythesis screws inserted from palatally.

In the frontal knife edge region, the calvarial bone blocks were fixed onto the buccal side. Before fixation, possible soft tissue remnants were meticulously removed from the alveolar process. Care was taken to ensure that the bone blocks had a nice 'fit' onto the alveolar process, i.e. the bone graft was in full contact with the remaining process. When needed, the grafts were contoured and/or "hollowed" in the center area (removing part of the diploe) using pliers. During



A



B

Fig 1. Immediate dental impant placement in calvarial bone grafts.
The calvarial bone blocks were harvested from the tabula externa (A) and fixed onto the alveolar process (buccal plating) with microscrews (B). Between the screws, the dental implants were placed.

fixation of the graft, the screws were inserted mesially and distally near the edges allowing dental implant placement between the screws (Fig. 1b).

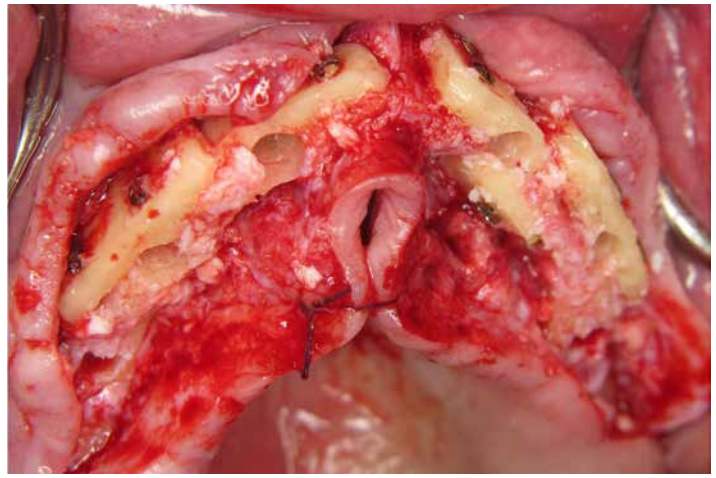
When needed, grafts were placed on both the buccal and the palatal side (Fig. 2). At least 2, but mostly 3 or 4 screws were used per bone block for fixation. After fixation of the grafts, the sharp edges along the entire calvarial grafts were carefully rounded with a round carbide burr to prevent mucosal perforation due to sharp graft edges. Thereafter, the implant bed was drilled. The location of the start of the pilot drill was usually on top of the knife edge ridge or at the interface of the graft and the ridge. The drill was carefully but firmly stabilised during preparation of the implant bed to ensure that the drill only moved vertically, and to prevent tilting of the drill as a result of a lack of stabilization. When drilling the implant bed, the buccal plates did not come loose when properly fixed.

After drilling the implant beds, the bone level dental implants were placed manually. The holes were not tapped. Four or 6 implants (diameter 4.0 mm, length 11.5 mm; Biomet Nanotite Certain Tapered Implant, Biomet 3i, Dordrecht, The Netherlands) were placed in the grafted maxilla (Fig.1b, 2). After ensuring primary stability, healing caps were placed, and the remaining bone mass was placed around the grafts. After periosteal release, the mucosa was closed tensionless using resorbable 4-0 mattress sutures. No membrane was used.

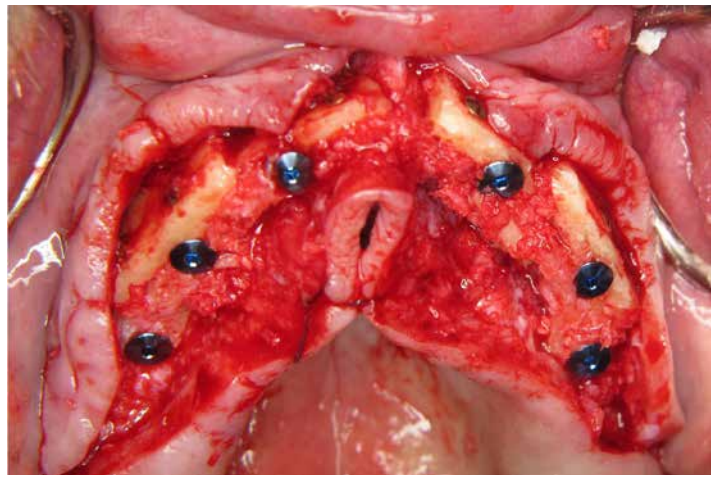
After 4 months the implants were uncovered using the same incision as during the augmentation, the microscrews removed, and the healing abutments placed. In 1 patient a 1 mm wide slice-biopsy was taken of the alveolar process (Fig 3).

After dehydration of the bone biopsy in descending alcohol series, the tissue was embedded without prior decalcification in low temperature polymerizing methylmethacrylate (MMA, Merck Schuchardt OHG, Hohenbrunn, Germany). Histological sections of 4 µm thickness were prepared using a Jung K microtome (R. Jung, Heidelberg, Germany). Sections were stained with Goldner's Trichrome method to distinguish mineralized bone tissue (green) and unmineralized osteoid (red). When the palatal mucosa was very thick, thinning of the mucosa was performed to prevent pseudo pocket formation around the suprastructure. After healing of the gingiva the suprastructure and denture were made.

During follow-up patients were instructed to visit the dental hygienist and to visit control appointments.

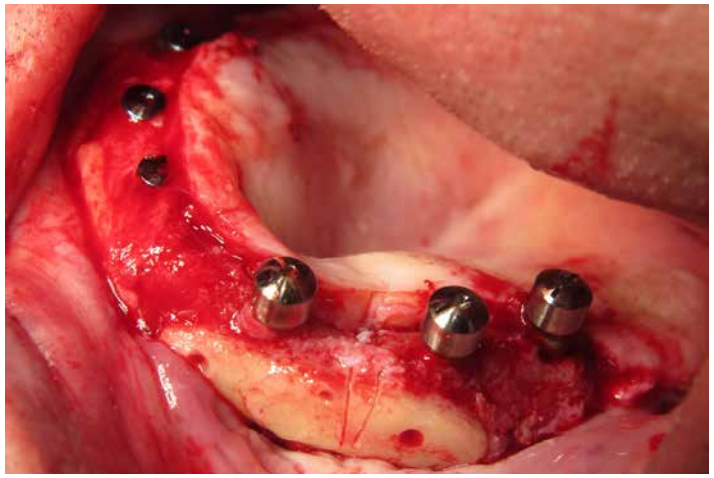


A

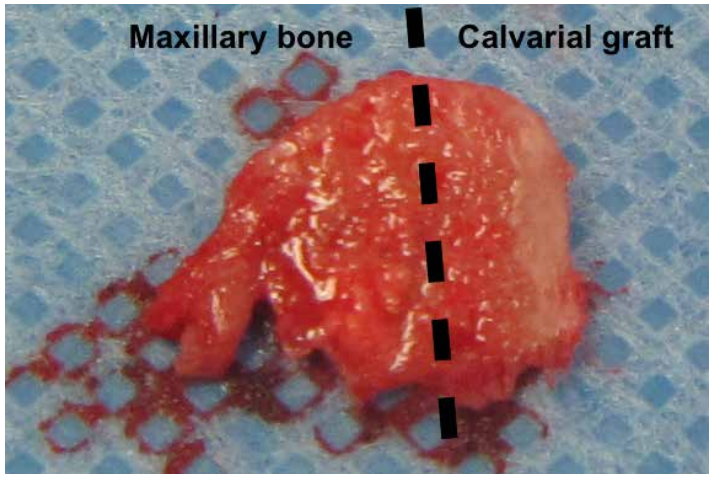


B

Fig 2. An extreme thin knife edge was double plated with calvarial bone.
(A) Just before implant insertion.
The implant bed consisted mostly of calvarial bone.
(B) After placement of implants.
Scraped calvarial bone mass was used to fill up the gaps.



A. The cavarial graft seemed well integrated with the alveolar bone and did not show signs of resorption.



B. Biopsy on the table. The right side consisted of calvarial graft.

Fig 3. At 4 months, when the implants were retrieved, the healing abutments were placed and a bone slice biopsy was taken of the augmented maxilla in which calvarial graft as well a native maxillary bone was present.

Follow-up

Per-operatively, the following items were scored: perforation of sinus mucosa, and primary stability of implants.

Post-operatively, the patients were asked to monitor pain levels daily for both the scalp and intraoral wound using a 10 cm Visual Analogue Score (VAS) list, which ranges from 0 (no pain) until 10 (worst pain ever experienced). Clinical and radiological follow-up was at least 1 year in all patients. During regular follow up visits the following items were scored: intraoral wound dehiscence, and signs of infection (swelling, redness, fistulae).

During implant retrieval at four months the following items were scored signs of peri-implant bone loss, signs of resorption around screw heads, and signs of inflammation (granulomatous tissue, bone graft loss). In one patient without signs of bone loss or resorption, a 1.5 mm thick bone biopsy of the maxilla was taken and fixed in buffered formaline for further histological processing.

After retrieval of the implants the following items were scored: peri-implant mucositis, peri-implantitis, loss of implants, gingival hyperplasia under the bar construction, additional surgical procedures (correction hyperplasias, bone re-contouring, removal of implants).

Peri-implant mucositis and peri-implantitis was scored at patient level. As definition for peri-implant mucositis and peri-implantitis, the consensus reached at the Seventh European Workshop on Periodontology was used,[3] i.e. peri-implant mucositis (radiographic bone loss <2 mm) with bleeding on probing and/or suppuration, and peri-implantitis with bleeding on probing and/or suppuration in combination with marginal bone loss of at least 2 mm.

Radiographic follow-up

Peri-implant bone levels were measured radiologically on orthopantomograms at the time of implant retrieval just before the denture was made, and after 1 year of functional loading. The orthopantomograms were made using a planmeca device (Planmeca Promax, Planmeca, Helsinki, Sweden), in which the head of the patient was positioned using laser guidance beams. Using calibrated imaging software (Planmeca Romexis, version 4.2.1, Helsinki, Sweden) implant bone levels were measured from the implant margin to the bone level both mesial and distal of the implant. The average values of the implants were calculated in mm.

Results

A total of 13 patients (4 male, 9 female, mean age 68 ± 9 years) were included in the study. All patients were operated on by JS and TP.

Peri-operative course

Augmentation of the maxilla[10,8] with calvarial bone was uneventful in all patients. A total of 68 implants was placed. In five patients 4 implants were placed, and in eight patients 6 implants. In two patients it was neccesary to double plate the very thin knife edge in the frontal region (Fig. 2). There were no significant perioperative complications, i.e. o sinus membrane perforations were observed, calvarial bone blocks could be fixed properly, and all implants could be inserted with primary stability.

During surgery the following experiences are of note. First, the calvarial bone pieces can be handeled easily and contoured to fit the alveolar process. Microscrews can be inserted into the calvarial bone with ease, and a remarkable tight "fit" onto the remaining alveolar process can be obtained. During drilling of the implant bed, the calvarial graft remains in place and does not become dislodged due to the pressure of the drill or the implant insertion.

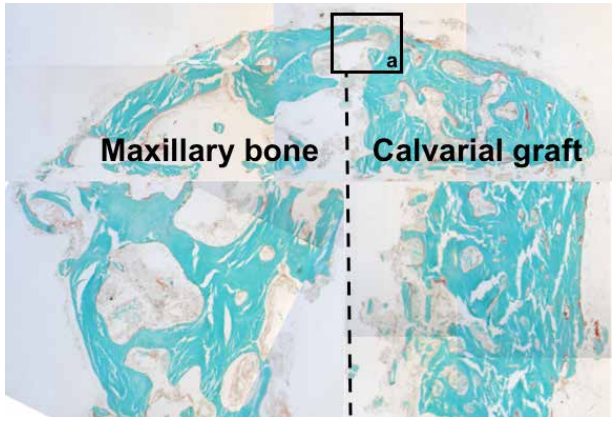
All patients were dismissed from the hospital the next day, except 1 patient suffering from a hypersensitivity reaction to the antibiotics used. This patient was dismissed after two days.

Post-operative course

The average intraoral pain levels were low. At the first postoperative day, the average score on the Visual Analogue Scale was 0.3±0.8 (mean ± SD). After 6 days, all patients were pain-free. The follow-up was 30±11 (mean±SD) months. During the first 4 months after augmentation no wound dehiscences occurred. Four months postoperatively the implants were retrieved. The calvarial bone did not show signs of resorption. The implants were all covered with bone, and no signs of peri-implant bone loss were observed. The calvarial bone around the screw heads did not show resorption. After placing the healing abutments on the implants and subsequent healing of the mucosa, the suprastructures were placed and the dentures made. During further follow-up, no implants were lost. In 5 patients, progressive gingival hyperplasia under the suprastructure limited dental hygiene and resulted in peri-implant mucositis. This was resolved by diathermic correction of the gingiva and extra visits to a dental hygienist.

Radiographically, the average peri-implant bone loss was 0.23±0.44 mm (mean±SD) from the time of retrieval of the implants until one year of functional loading.

The bone biopsy was taken at 4 months between two retrieved implants (Fig. 3). In this biopsy, the calvarial graft could be clearly identified by eye. Histologically both the calvarial graft and the remaining alveolar bone showed signs of active remodelling as could be observed by the presence of non-mineralized (red) areas of newly deposited osteoid. The calvarial bone part was vital, as assessed by the presence of living osteocytes. Osseous contact was observed between the graft and the alveolar bone (Fig. 4).



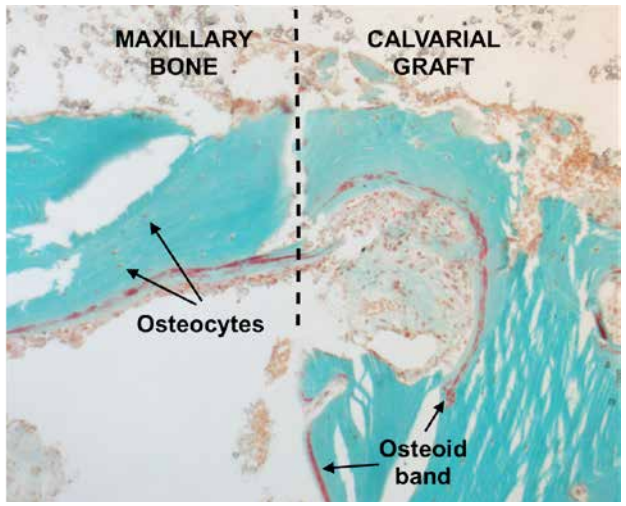


Fig 4. Histological section of a biopsy of the healed grafted maxilla. Combined image, Goldner's Trichrome stain, magnification x25. Histology shows presence of mineralised bone tissue throughout the biopsy (green). The right half side represents calvarial graft, the left side maxillary bone (dotted line).

Insert (a). Detail image of the healed grafted maxilla. Goldner Trichrome stain, magnification x 100. Interface between calvarial graft (right) and maxillary bone (left). An osseous bridge is present indicating osseous integration of the calvarial bone (dotted line). Both the maxillary bone as well as the calvarial bone are vital as indicated by the presence of osteocytes (visible as tiny black "dots" inside the green mineralised tissue), and by the presence of osteoid bands (red).

Discussion

In this pilot study, we decribe and evaluate an alternative approach to rehabilitate the severely resorbed maxilla with dental implants. The results in this study indicated that it was technically possible to place dental implants in the same procedure as the augmentation of the maxilla with calvarial bone. In addition, the results showed that the dental implants will osseointegrate during the same time period as the integration of the calvarial bone graft with the maxillary bone takes place.

The concept of augmenting and placement of implants at the same time is not new; it has been and is still current practice in sinus lift procedures where dental implants are placed in the remaining maxillary bone.[12] This concept is also performed in cases where implants are placed in combination with guided bone regeneration techniques, for example in single tooth replacement situations.[1] Here, the implants are placed first, and then they are covered with bone mass. Presumably these techniques are successful, since the implants receive their primary stability from the tight anchorage in the vital bone of the alveolar process.

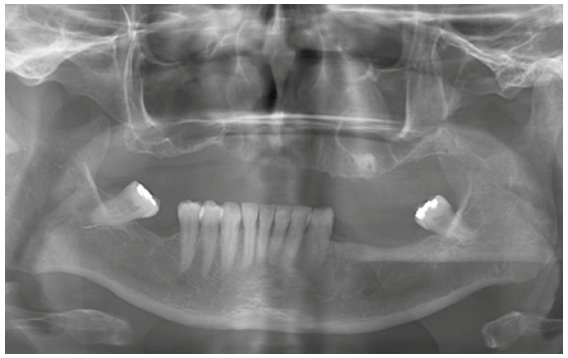
An important difference with our study is that we placed implants that received their primary stability by anchorage in the calvarial bone graft, and less in the thin alveolar process. In our patients, it would not be possible to place the implants in the remaining alveolar bone first, and then cover the dental implant with bone.

The implant surface is mostly surrounded by calvarial bone graft. It seems therefore that osseointegration of implants and healing of calvarial grafts occurs simultaneously and succesfully.

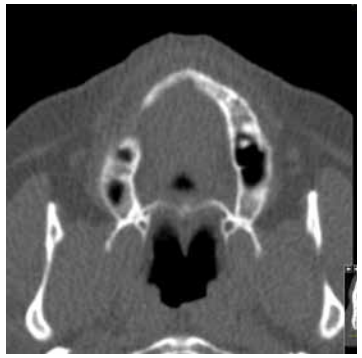
Augmentation of the maxilla with calvarial bone and simultaneous placement of implants has been performed by others.[4] Here, 6 temporary implants were placed simultaneously with the augmentation to provide a base for a fixed resin denture. After 6 months the temporary implants were removed and the definitive dental implants were placed. A high success rate of the temporary implants placed at the time of augmentation was found, which is in accordance with our findings.

In contrast to anterior iliac crest bone, the calvarial bone seems to resorb only to a minimal extent during the healing phase.[5] Calvarial bone is much denser than iliac crest bone as graft[6], and this may explain why we observed no signs of bone resorption at the time of implant retrieval.

The average peri-implant bone loss in our pilot study was limited, suggesting that the calvarial bone graft functioned well as implant supportive bone. By using

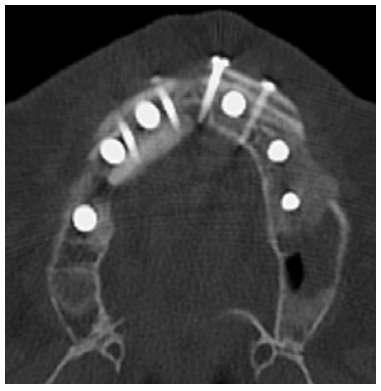


A



B

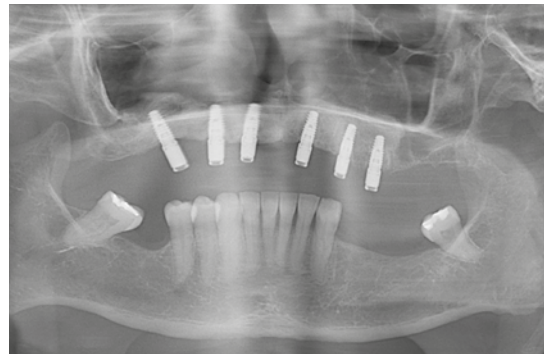
Preoperative OPG (A) and CT scan (B) demonstrating a severely resorbed irregular maxilla.



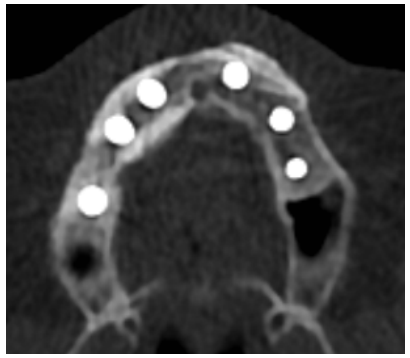
C

Postoperative CT scan of a grafted maxilla with placed implants. The right side of the maxilla is plated with calvarial bone on the buccal and palatal side. The implants are placed between the osteosynthesis screws.

Fig 5. Illustration of preoperative situation and postoperative result after 4 years and 10 months of functional loading.

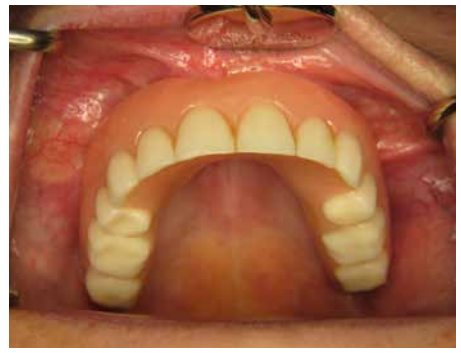


D

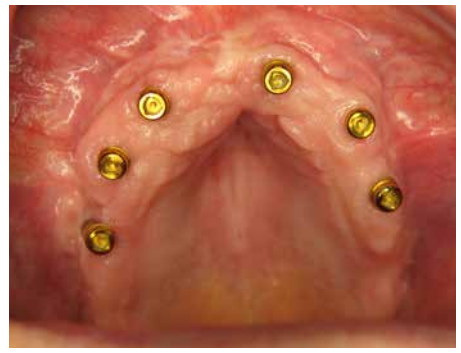


E

OPG (D) and CT scan (E) after 4 years and 10 months follow-up indicating succesfull osse-ointegration of both the calvarial grafts and the implants.



F



G

Final prosthetic result after 4 years of functional loading (F). No signs of peri-implant inflammation or bone loss are present (G).

calvarial bone and simultaneous placement of implants, we reduced the total treatment time with approximately 4 months by combining the healing period of the grafts with the duration of osseointegration of the implants. Usually, dental implants are placed after the graft has healed. In case of iliac crest bone, this process takes about 3-6 months. Then, the implants are placed, which in turn need to osseointegrate for an additional period of 3 months, before the suprastructure can be made.

As compared to anterior iliac crest grafts, calvarial bone grafts seem to have a long long term low morbidity, and less pain postoperatively on the short term.[2]

The bone biopsy revealed vital bone with active remodelling and close contact between the graft and the alveolar process. This indicates that the graft was healing well and that a "new, vital" maxillary process was formed. This is in accordance with results by others who performed histological evaluation of calvarial bone grafts for intraoral grafting.[7,13] During osseointegration, vital bone is formed around the implant. It seems that the calvarial bone graft has become vital within a period of 4 months enabling osseointegration. However, a more elaborate study involving more bone biopsies is needed to make a more evidence-based assessment of the bone density, vitality and remodeling of the calvarial bone graft.

A limitation of this study is the radiographic evaluation. We only measured mesial and distal bone loss around the implant, and not on the buccal or palatal side. However the clinical evaluation (bleeding on probing, bone loss) did not indicate progressive bone loss on the buccal or palatal sides. In one patient CT scans were made of the grafted maxilla postoperative and 4 years and 10 months afterwards for evaluation of sinus complaints. No peri impant bone loss was present and there were no signs of resorption of the calvarial grafts (Fig. 5).

In this pilot study, a small number of patients have been evaluated. The results obtained were positive, i.e. an uneventful surgical procedure and high implant survival rate; and give an incentive to study a larger series of patients to reproduce and confirm our results in the near future.

Conclusion

This prospective pilot study reveals that immediate placement of dental implants in calvarial bone grafts to rehabilite a severely resorbed maxilla is technically feasible, seems to have a high success rate, and may reduce total treatment time.

Acknowledgements

Mr. Joost Tiddens, dental student, is greatly acknowledged for his help in the data acquisition and processing, and Ms. Marion A. van Duin for the histological processing of the biopsy.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Jung RE, Herzog M, Wolleb K, Ramel CF, Thoma DS, Hammerle CH: A randomized controlled clinical trial comparing small buccal dehiscence defects around dental implants treated with guided bone regeneration or left for spontaneous healing. Clin Oral Implants Res 2017:28:348-354.
2. Kuik K, Putters TF, Schortinghuis J, van Minnen B, Vissink A, Raghoebar GM: Donor site morbidity of anterior iliac crest and calvarium bone grafts: A comparative case-control study. J Craniomaxillofac Surg 2016:44:364-368.
3. Lang NP, Berglundh T: Periimplant diseases: where are we now? Consensus of the seventh workshop on periodontology. J Clin Periodontol 2011:38:178-181.
4. Lenssen O, Barbier L, De Clercq C: Immediate functional loading of provisional implants in the reconstructed atrophic maxilla: preliminary results of a prospective study after 6 months of loading with a provisional bridge. Int J Oral Maxillofac Surg 2011:40:907-915.
5. Mertens C, Decker C, Seeberger R, Hoffmann J, Sander A, Freier K: Early bone resorption after vertical bone augmentation. A comparison of calvarial and iliac grafts. Clin Oral Implants Res 2013:24:820-825.
6. Monje A, Monje F, Galindo-Moreno P, Montanero-Fernandez J, Suarez F, Wang HL: Microstructural and densiometric analysis of extra oral bone block grafts for maxillary horizontal bone augmentation: a comparison between calvarial bone and iliac crest. Clin Oral Implants Res 2014:25:659-664.
7. Orsini G, Bianchi AE, Vinci R, Piatelli A: Histologic evaluation of autogenous calvarial bone in maxillary only bone grafts: a report of 2 cases. Int J Oral Maxillofac Implants 2003:18:594-598.
8. Putters TF, Schortinghuis J, Vissink A, Raghoebar GM: A prospective study on the morbidity from calvarial bone harvesting used for intraoral reconstruction. Int J Oral Maxillofac Surg 2015:44:513-517.
9. Raghoebar GM: Maxillary bone grafting for insertion of endosseous implants: results after 12-124 months. Clin Oral Implants Res 2001:12:279-86.
10. Schortinghuis J, Putters TF, Raghoebar GM: Safe harvesting of outer table parietal bone grafts using an oscillating saw and a bone scraper: a refinement of technique for harvesting cortical and 'cancellous'-like calvarial bone. J Oral Maxillofac Surg 2012:70:963-996.
11. Smolka W: Calvarial grafts for alveolar ridge reconstruction prior to dental implant placement: an update. Oral Maxillofac Surg 2014:18:381-385.
12. Ting M, Rice JG, Braid SM, Lee CYS, Suzuki JB: Maxillary sinus augmentation for dental implant rehabilitation of the edentulous ridge: a comprehensive overview of systematic reviews. Implant Dent 2017:26:438-464.
13. Vinci R, Rebaudi A, Cappare P, Gherlone E: Microcomputed and histologic evaluation of calvarial bone grafts: a pilot study in humans. Int J Periodontics Restorative Dent 2011:31:29-36.

Chapter 7

General discussion

General discussion

The PhD research described in this thesis was performed to assess whether calvarial bone serves as a reliable alternative for anterior iliac crest bone to augment severely resorbed maxilla in pre-implant surgery. The results of the studies described in this thesis indicate that calvarial bone can indeed serve as a sound alternative for anterior iliac crest bone. Calvarial bone can be harvested safely, with low donor site morbidity and high implant survival in the grafted sites. Furthermore, preliminary studies suggest that dental implants can be placed immediately in the maxilla augmented with calvarial bone.

Operative technique: safety of the harvesting procedure

The potential severe complications of calvarial bone harvesting[1-6] often restrain maxillofacial surgeons from using the calvarium as a donor site. Accidental perforation of the inner table of the calvarium can result in laceration of the dura and leakage of cerebrospinal fluid. Moreover, a forceful impact of the hammer on the chisel used to harvest the bone can lead to coup/contra-coup brain damage or displaced otoliths.[7] The possibility of these complications occurring can be minimized by using the technique described in this thesis (Chapters 2, 3) composed of six sequential steps:

1. Pre-operative CT scans with frontal plane reconstructions.

A CT scan with frontal reconstructions allows the surgeon to measure the skull thickness as well as identify the indentations i.e., the sites where the inner and outer table are fused. A calvarial graft should not be harvested from the sites with such indentations (Fig. 1). The thickness of the cavarial bone varies between 6 and 8 mm whereby the parietal bone is the thickest[8] and this, therefore, is the best grafting source site.[1]

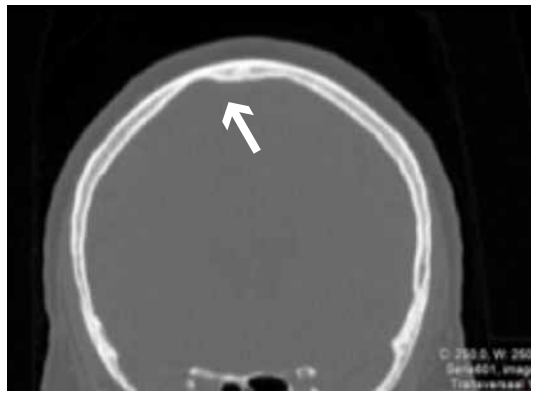


Fig 1A. Coronal CT slide: indentation (white arrow).

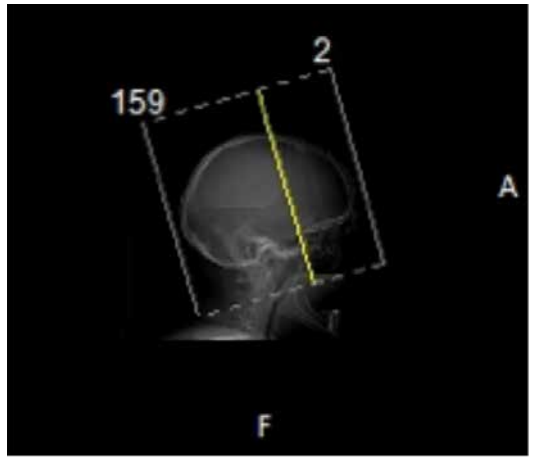


Fig 1B. Position of slide shown in Fig 1A.

2. Marking the outline of the graft.

Before harvesting the calvarial outer table, the outline of the graft has to be marked with a 2.8 mm diameter carbide burr (Fig. 2). The outline is drilled at high speed (40000 rpm) and low manual force. The outline is at the correct depth on seeing spot bleeding at the bottom of the drill slot, which usually occurs on entering the more vascularized diploe at about a depth of 3 mm. When the 2.8 mm diameter drill is just submerged in the external table, the appropriate depth is reached and perforation of the inner table is avoided.

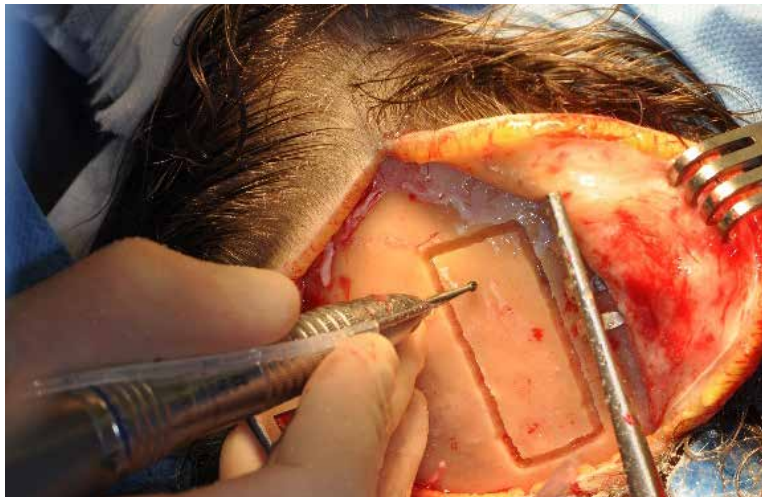


Fig 2. Making the outline.

3. Scraping a trough (bevel) around the marked graft.

After completing the outline, a bevel is made with a bone scraper outside the outline to the depth of the diploic space (Fig. 3). The scraped bone can be used to fill up the space underneath the elevated sinus membrane and to fill up the gaps between the fixed calvarial bone grafts.

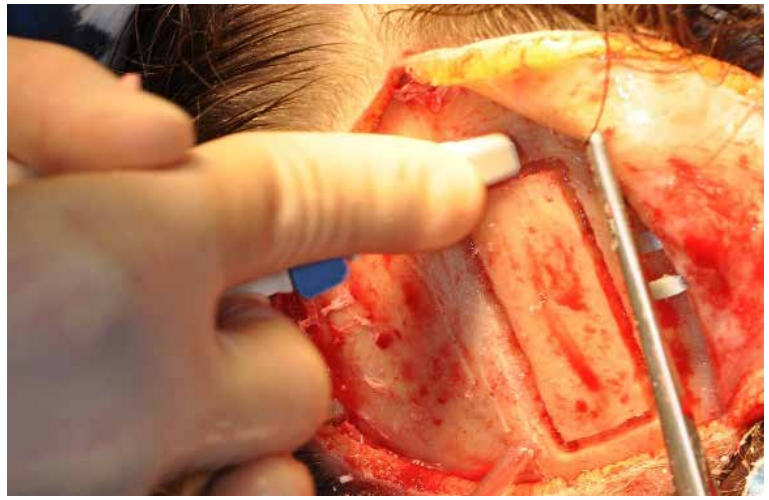


Fig 3. Scraping a trough.

4. Applying vertical parallel saw cuts.

Originally, we removed the total calvarial bone graft in one piece by undermining the corners with the saw in a horizontal plane (Chapter 2). When applying this method, we had to use a chisel to cut through the middle of the graft that was still attached to the inner table, resulting in breaking 5 out of 36 of the grafts, and exposing the dura in 4 out of 36 patients (Chapter 3).

To overcome these problems, the technique was modified by first making vertical saw cuts 10 mm apart from each other on the graft to be harvested (Fig. 4) and removing the graft piece-by-piece. Because the calvarial surface is rounded, a saw can be introduced vertically to access the diploic space, while keeping the saw-tip in view, thereby preventing the saw from entering intracranially. This modification resulted in no breakage of the graft or exposure of the dura in subsequent series.

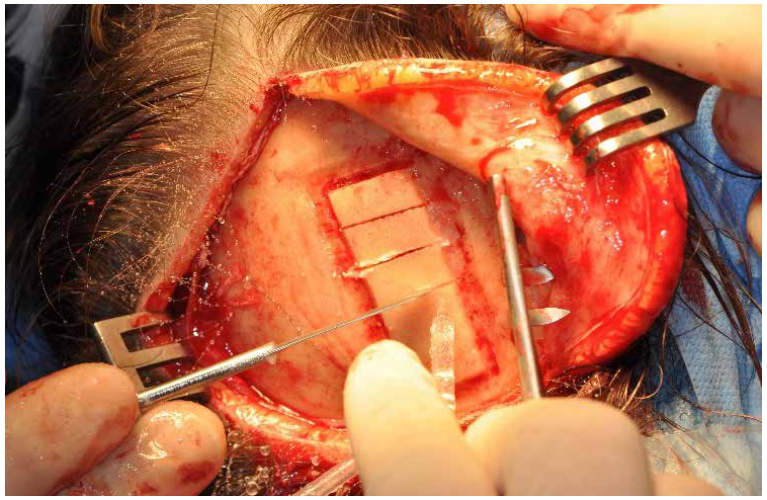


Fig 4. Vertical parallel saw cuts.

5. Horizontal saw cuts.

By holding the saw in a horizontal plane, the pieces of the graft are sawn within the diploic space at the corners while keeping the saw-tip in sight (Fig. 5). An Obwegeser chisel enables detachment of the pieces from the skull with almost no force having to be applied to the chisel.

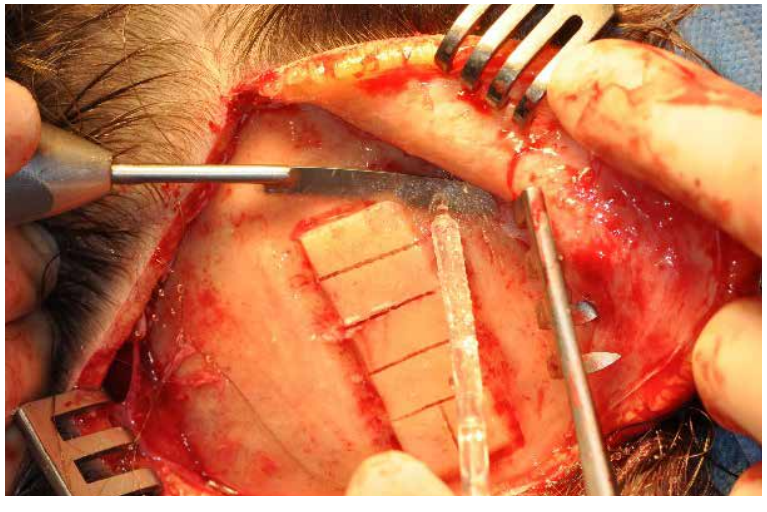


Fig 5. Horizontal saw cuts.

6. Reconstruction of the donor site.

The resulting defect of the outer table can be reconstructed with a bone cement (Fig. 6) such as an autopolymerising acrylic (Palacos®, Heraeus Medical GmbH, Haarlem, The Netherlands), which was used in this study. Other authors have used osteoconductive biomaterials.[9] The usefulness of autopolymerising acrylic based bone cement was proven in cranioplasty. Acrylic resins are stable, chemically inert, unaffected by temperature, are easy to handle and are well tolerated by tissue. However, their lack of porosity interferes with osteoconduction and vascularization and so does not stimulate bone formation at the defect. The contour of the reconstruction is stable.[9] Using osteoconductive biomaterials may enhance newly formed bone with time, but the reconstruction is not predictable during the remodelling process.[9] Moreover, it is debatable to even reconstruct the defect of the outer table. Although an obvious contour deficit remained present in a few of our patients where no reconstruction was performed, the contour deficit was never bothersome for these patients (Chapter 3).

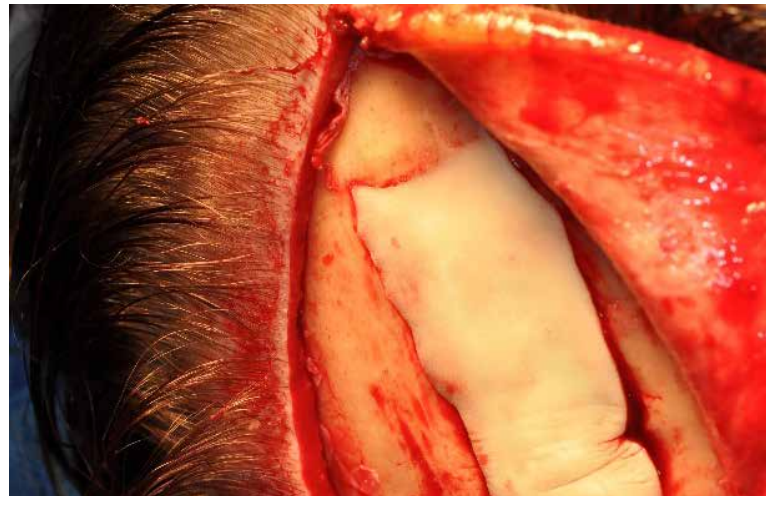


Fig 6. Reconstruction with bone cement.

By adhering to the above 6 principles, calvarial grafts can be harvested in a safe, elegant way, without force. With the techniques described by other authors [1,2,6,10] chisels are used to detach the calvarial graft from the scull. All the authors report complications due to perforation of the inner cortex. Dural exposures, dural tears, intracerebral injury and subdural hematoma are mentioned. With our technique,

by the use of a reciproque saw and keeping the tip of the saw in sight throughout the complete procedure, entering of the intracranium does not occur. Furthermore, the use of a bonescraper to make a trough not only creates an entrance for the saw to undermine the outer cortex, it also provides copious amounts of "cancellous" bone that can be used to fill up the space underneath the elevated sinus membrane and to fill up the gaps between the fixed calvarial bone grafts. In the techniques described by other authors[1,2,5,6], part of the outer table taken from the parietal bone has to be ground with a bone mill for this purpose. Here, a larger piece has to be harvested to give enough bone for the augmentation. This results in a bigger wound surface and longer surgical operation time.

Donor site related comorbidity

Pre-implant augmentation surgery is needed when insufficient bone volume is present for adequate implant placement. A variety of augmentation techniques has been described, either using human bone, animal bone, synthetic materials, or a combination of these. Autogenous bone is currently still considered to be the golden standard[11], because it contains undifferentiated mesenchymal cells, osteoblasts, cytokines and growth factors.[12] These cells and factors enhance revascularisation and remodelling of the graft.[13] Augmenting solely with bone substitutes seems an attractive alternative, because no donor site is needed and thus eliminates donor-site morbidity. However, graft remodelling is much slower when using only bone substitutes[14,15] and these are less suitable for the reconstruction of large defects. To gain proper vertical and horizontal dimensions in extensive surgery, autogenous bone still is needed.[16]

As discussed in this thesis, both iliac crest and calvarial autologous bone sources are highly suitable for reconstructing larger bone defects notwithstanding their inherent early and late donor site comorbidities.

Early donor site related comorbidity

Severe early complications on harvesting carvarial bone include entering the superior sagittal sinus as well as dural tears, intracranial lesions, coup/contra coup lesions, epidural hematoma and infection.[1-4] The modified technique for harvesting cranial bone, as described in this thesis (Chapters 2 and 3), has the potential to greatly reduce the risk of developing such severe complications. Severe complications were absent in our study, compared to the significant complications described by other authors on applying different techniques.

Early complications of harvesting from the anterior iliac crest are fracture of the iliac crest, haematoma, nerve injury, contour deficits and bicortical perforation of the iliac crest.[17,18] It is unclear how common these, usually less severe, complications are, in comparison with the severe complications of harvesting cranial bone occur, but the rate varies from 19.4 %[17] to 63.6%.[19] In our studies, early complication rates in the iliac crest group varied from 0% (Chapter 5) in the randomized controlled trial to 40.7 % (Chapter 4) in the case control study. In the studies described in this thesis (Chapters 4 and 5) the iliac cortical bone blocks were harvested by making two horizontal and five vertical saw cuts and removed piece by piece. Therefore, the risk of perforation of the lateral iliac cortex was minimized and perhaps, because of this, fewer fractures and less haematoma occurred. The absence of early complications in the randomized controlled study may have been due to the small patient sample.

As shown in our studies (Chapters 4 and 5), there is no significant difference in short-term donor site morbidity when autologous bone is harvested from the calvaria or anterior iliac crest, with the exception of early postoperative pain. Early postoperative pain is significantly higher after anterior iliac crest harvesting. This can be explained by the anatomy of the region. Several muscle attachments are present at the anterior iliac crest location. The iliac muscle is partially stripped off the interior blade of the iliac crest, and the iliac crest is reached through the external and internal oblique abdominal muscle. Postoperatively, muscle movements put tension around the donor site, creating pain. Subgroup analysis revealed that postoperative pain after anterior iliac crest harvesting was especially high in subjects with a higher body-mass index (BMI, $p<0.001$). An explanation could be that subjects with a higher BMI create higher forces that need to be dissipated around the donor site, resulting in more pain.

By contrast, the calvarial donor site is a region with much less muscle activity, and the surgical approach does not transverse muscle tissues, only the layers of the scalp. This may logically explain the less postoperative pain at the donor site after harvesting calvarial bone.

Late donor site related comorbidity

Late donor site related comorbidity was low for both the iliac crest and calvarial groups. The patients in the calvaria group did not complain about difficulties in daily functioning or headache during either the early postoperative phase or the long-term follow-up. Contour deficit sensory disturbance and alopecia did, however, occur and are discussed below (Chapters 3-5).

Contour deficits were apparent along the calvarial scar. It is unlikely that irregular application of bone cement was the cause, since great care was taken to prevent over-contouring or irregular borders at the bevel. A more reasonable explanation may be subcutaneous fat atrophy along the scar. Peroperatively, diathermy is used for coagulation in and around the vessels in the subcutaneous tissue. Surrounding perivascular fat may be unintentionally coagulated as well. Finally, the scalp is closed using a tight running suture through the galea and subcutaneous tissue, which might compromise the vascularity to the subcutaneous tissue leading to fat atrophy.

Sensory alterations caused by transection of nerve fibres can be minimized by using a parasagittal incision following the course of the nerves supplying the scalp[2,3] (Fig. 7). The occurrence of sensory disturbances was low in our series (10%), compared to a coronal incision which resulted in higher rates of dysesthesia (15.4%).[2,18]

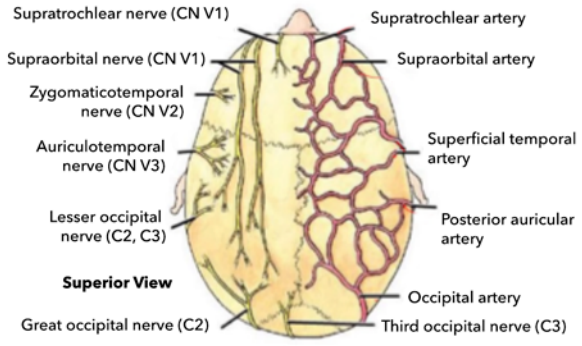


Fig 7A. Sensory nerves of the scalp.
Incision has to be made parallel to the direction of the sensory nerves.

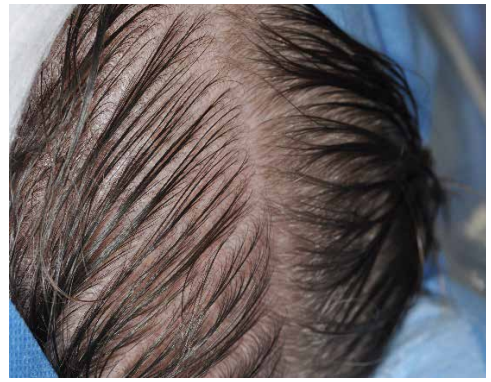


Fig 7B. Hair line that indicates the location of the incision.

In our comparative case-control study, we encountered 2 cases of alopecia (Chapter 4). This late complication can be avoided by using a 30° angle incision to the follicles[19], a very low use of electrocoagulation[20], and the use of low tension sutures.[21-23] Whether such an approach can indeed prevent alopecia was not a subject of our study.

The literature reports more persistent pain and gait disturbances within the iliac crest group[15-17] than our findings. Our low complication rate may have also been due to the small group we investigated. If underreporting is indeed the case, calvarial bone grafting could even be more advantageous than we presume according to our own data.

Intra-oral related comorbidity and complications.

Dehiscence of the maxillary bone, implant loss (1-year implant survival rate of 97.7 %) and infection at the recipient site were rarely encountered. There was no significant difference in occurrence in these complications between the cavarial group and the iliac crest group (Chapters 3 and 5). This could be expected because the intra-oral surgical procedure is the same in both groups. The intra-oral complication rates are also similar to those reported by other authors.

Augmentation surgery combined with implant placement

At the time of placing the implants, 4 months after maxillary augmentation with calvarial bone, we hardly observed any clinical resorption of the calvarial bone.

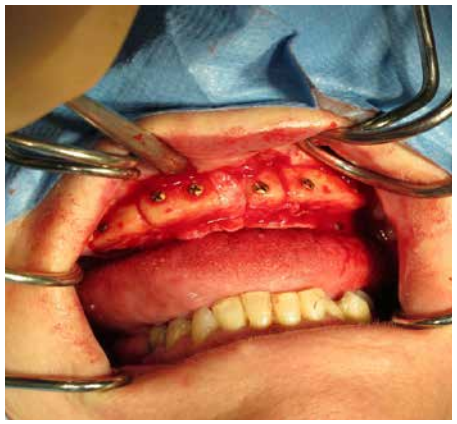


Fig 8A. Four months after augmentation with calvarial bone. Only the screw heads are visible.

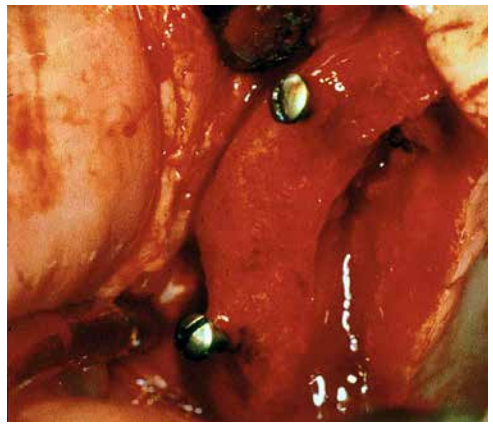


Fig 8B. Four months after augmentation with iliac bone. A significant portion of the screws is visible.

This was new because we commonly observed resorption of the grafted area on applying anterior iliac crest grafts. Also, the screw heads of the screws fixating the calvarial grafts became less exposed during graft healing (Fig. 8a) compared to those used with iliac grafts (Fig. 8b). In other words, minimal surface resorption occurs when calvarial grafts are applied.

When calvarial bone is used to augment the maxilla in preimplant surgery, the bone volume does not really reduce during the first 4 months of remodelling. Therefore, we presumed that dental implants can be placed simultaneously with the augmentation in some of our patients. The total healing time can be reduced to 4 months by combining the time needed for graft healing with the osseointegration of the implants and thereby, a second surgical intervention can be avoided, thus speeding up prosthodontic rehabilitation (Chapters 2-5).

The concept of augmenting and placement of implants at the same time is not new[25]. Placing implants with a dehiscence larger than 2/3 of the buccal implant surface combined with covering of the dehiscent surface with autologous bone has been shown to be accompanied by favourable 5-year peri-implant results. A prerequisite to using this technique is that primary stability in the native maxillary bone can be achieved and that only volume and passive implant coverage is added by the grafted bone.[26]

In our patients, we did not attempt to obtain primary stability in the native bone first before placing the implants as that was not possible due to the very thin knife edges (<3 mm) (Fig. 9; Chapter 6). Therefore, in our prospective pilot study, we first augmented the severely resorbed maxilla with calvarial bone. Subsequently, the implant bed was drilled between the osteosynthesis screws whereafter the implants were placed. Next, the implant bed could be drilled easily and the implants could be placed with high primary stability in that they had a nice 'snug' fit within the augmented alveolar process.

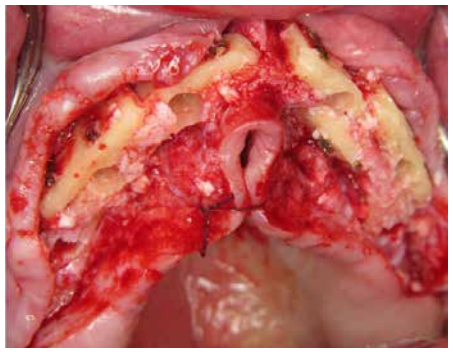
On using our technique to augment the knife edge first and then drill the implant bed between the screws and place the implants, successful osseointegration and no bone resorption was observed at 4 months, when the implants were retrieved. Also, the peri-implant bone height remained stable during follow-up.[27]

This raises an important question whether an implant can osseointegrate when placed with primary stability in mostly calvarial graft, instead of the remaining maxillary process. When a very thin knife edge is augmented with calvarial bone, and the implant is placed in the middle, the implant surface is mostly in contact with calvarial bone, and less with the basal bone. It is possible that the primary stability is mainly obtained by anchoring in the calvarial graft, and not in the thin knife edge (Fig. 9).

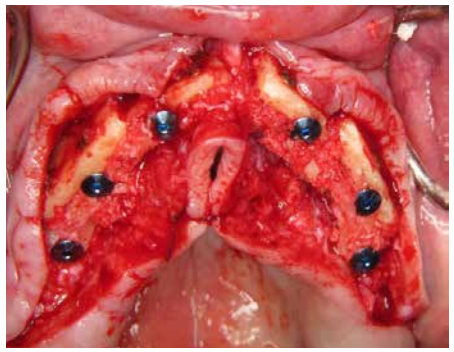
We did not objectify (measure) how much surface contact the implants had with the native maxillary bone and with the calvarial grafted bone after placement but, according to our clinical experience, the implants were mostly covered with calvarial bone. The implants of the particular cases undergoing double plating of the knife edge were almost all placed in calvarial bone (Fig. 9).

In two cases, the alveolar process was between 1 and 2 mm in width, and it was therefore necessary to double plate the alveolar process on the buccal and palatal side with calvarial bone (Figs. 9a, 9b). In these cases, the primary stability of the implants was presumably only achieved by anchoring in the calvarial bone, with minimal contact in the remaining alveolar process. Here, only osseointegration, and no bone resorption, was observed at 4 months, when the implants were retrieved (Fig. 9c). Also successful functional loading of the implants with minimal vertical bone loss after a follow up of one year was observed (Fig. 9d).

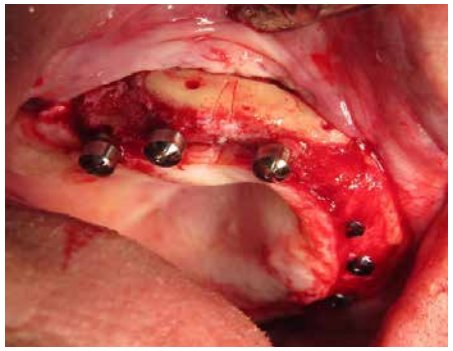
Although further research into immediate implant placement in the extremely resorbed augmented maxilla should address the question of primary stability and bone contact between calvarial grafts and native alveolar process, the above described technique with calvarial bone seems promising.



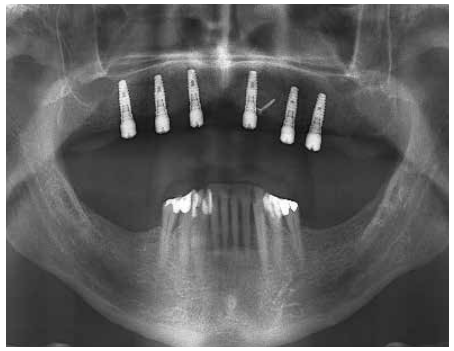
A



B



C



D

Fig 9.
(A) Augmentation of the buccal and palatal alveolar process after implant bed preparation.
(B) After immediate implant placement.
(C) Re-entry after 4 months for abutment connection surgery.
(D) Panoramic radiograph 1 year post implant surgery with stable bone height.

Bone resorption

The observed lower resorption rate of calvarial bone, compared with iliac crest bone, is widely reported in the literature.[24,28,29] Thus, volume maintenance of sites reconstructed with calvarial bone is higher than when reconstructed with iliac crest bone.[30] The observed differences in resorption of the graft may be related to differences in embryologic origin (membranous versus endochondral) and microarchitectural features (composition of cortical and cancellous bone.[31] These 2 differences probably influence the remodelling process.

Membranous bone has, related to its embryologic origin, a different healing mechanism compared to endochondral bone. Membranous bone is formed directly by intramembranous ossification without the intermediate cartilage stage that is observed in the formation of endochondral bone.[32] Therefore, there is less time for osteoclastic activity when intramembranous bone is formed which may underlie the reduced resorption of this type of bone.

Revascularisation in cortical bone is slower than in cancellous bone[31,34] hence initial osteoclastic activity is less with a bigger total bone volume after the initial remodelling.[31,33]

Calvarial bone is membranous and is largely composed of cortical bone and seems therefore to be less susceptible to initial resorption during bone remodelling after grafting compared to iliac bone of endochondral origin.

Future perspectives

The PhD research presented in this thesis focused mainly on clinical results. Important questions that remain are:

- How do calvarial and anterior iliac crest grafts heal after transplantation?
- Why is there a difference in resorption rate between both graft types?
- Does the difference in resorption and bone remodelling of iliac crest and calvarial bone influence long-term implant survival rates?

Although the calvarial bone grafts seem promising for the augmentation of the maxilla as a pre-implant procedure, long term follow-up comparable studies are needed to assess the stability of the calvarial grafts after a few years. Also, the possibility of immediate implant placement in calvarial bone raises important questions. Although the clinical results using this technique are encouraging, elucidation is required as to whether there are differences in implant survival and success when implants are placed in native maxillary bone, including using a combination of calvarial graft/native bone and whether the ratio calvarial bone contact/native bone contact with the implant surface is of influence.

Conclusions

Calvarial bone can be harvested safely and predictably by a piece-by-piece technique using a burr, bone scraper and a micro-saw. The developed technique has

been shown to be accompanied by minor morbidity.

The developed procedure for calvarial bone harvesting is safe. Thus, calvarial bone can serve as an alternative for anterior iliac crest bone to augment the severely resorbed maxilla.

Simultaneous implant placement after the augmentation with calvarial bone is technically feasible. Preliminary results are promising.

When extensive augmentation is needed in severely resorbed maxilla to allow for future preimplant surgery, the choice between crista iliac anterior or the calvarium as a donor site depends on several factors, including BMI, boldness, gait problems and patient preference.

References

1. Tessier P, Kawamoto H, Posnick J, Raulo Y, Tulasne JF, Wolfe SA. Taking calvarial grafts, either split in situ or splitting of the parietal bone flap ex vivo. Tools and Techniques: A9650-case experience in craniofacial and maxillofacial surgery. Plast Reconstr Surg. 2005: 116: 54-71.
2. Tessier P, Kawamoto H, Posnick J, Raulo Y, Tulasne JF, Wolfe SA. Complications of harvasting autogenous bone grafts: a group experience of 20,000 cases. Plast Reconstr Surg. 2005: 116: 72-74.
3. Cominic M, Cannella MD, Hopkins. Superior sagittal Sinus laceration. Complicating an autogenous calvarial bone graft harvest: report of a case. J Oral Maxillofac Surg. 1990: 40: 741-743.
4. Young VL, Schuster RH, Harris LW. Intracerebral hematoma complicating split calvarial bone-graft harvesting. Plast Reconstr Surg. 1990: 86: 763-765.
5. Kline RM Jr, Wolfe SA. Complications associated with the harvesting of cranial bone grafts. Plast Reconstr Surg. 1995: 95: 5-13.
6. John L. Frodel Jr, MD; Lawrence J. Marentette, MD; Vito C. Quatela, MD; et al Gregory S. Weinstein, MD. Calvarial Bone Graft Harvest Techniques, Considerations, and Morbidity. Arch Otolaryngol Head Neck Surg. 1993: 119: 17-23.
7. Lenssen O, Barbier L, De Clercq C. Immediate functional loading of provisional implants in the reconstructed atrophic maxilla: preliminary results of a prospective study after 6 months of loading with a provisional bridge. Int J Oral Maxillofac Surg. 2011: 40: 907-915.
8. Moreira-Gonzalez, Andrea M.D. Papay, Francis E. M.D. Zins, James E. M.D. Calvarial Thickness and Its Relation to Cranial Bone Harvest. Plast Reconstr Surg. 2006: 117: 1964-1971.
9. Zanotti B, Zingaretti N, Verlicchi A, Robi-ony M, Alfieri A, Parodi PC. Cranioplasty: review of materials. J Craniofac Surg. 2016: 27: 2061–2072.
10. Zouhary KJ.Bone graft harvesting from distant sites: concepts and techniques. Oral Maxillofac Surg Clin North Am. 2010: 22: 301-316.
11. Nkenke E, Neukam FW. Autogenous bone harvesting and grafting in advanced jaw resorption: morbidity, resorption and implant survival. Eur J Oral Implantol. 2014: 7: 203-217.
12. Carano RA, Filvaroff EH. Angiogenesis and bone repair. Drug Discov Today. 2003: 8: 980-989.
13. Chen NT, Glowacki J, Bucky LP, Hong HZ, Kim WK, Yaremchuk MJ. The roles of revascularization and resorption on endurance of craniofacial onlay bone grafts in the rabbit. Plast Reconstr Surg. 1994: 93: 714-722.
14. Zerbo IR, de Lange GL, Joldersma M, Bronckers AL, Burger EH. Fate of monocortical bone blocks grafted in the human maxilla: a histological and histomorphometric study. Clin Oral Implants Res. 2003: 14: 759-766.
15. Rickert D, Slater JJ, Meijer HJ, Vissink A, Raghoebar GM. Maxillary sinus lift with solely autogenous bone compared to a combination of autogenous bone and growth factors or (solely) bone substitutes. A systematic review. Int J Oral Maxillofac Surg. 2012: 41: 160-167.
16. Troeltzsch M, Troeltzsch M, Kauffmann P, Gruber R, Brockmeyer P, Moser N, Rau A, Schliephake H. Clinical efficacy of grafting materials in alveolar ridge augmentation: A systematic review. J Craniomaxillofac Surg. 2016: 44: 1618-1629.

17. Dimitriou R, Mataliotakis GI, Angoules AG, Kanakaris NK, Giannoudis PV. Complications following autologous bone graft harvesting from the iliac crest and using the RIA: a systematic review. Injury. 2011: 42 Suppl 2: S3-S15.

18. Marx RE, Morales MJ. Morbidity from bone harvest in major jaw reconstruction: a randomized trial comparing the lateral anterior and posterior approaches to the ilium. J Oral Maxillofac Surg. 1988: 46: 196-203.

19. Scheerlinck LM, Muradin MS, van der Bilt A, Meijer GJ, Koole R, Van Cann EM.Donor site complications in bone grafting: comparison of iliac crest, calvarial, and mandibular ramus bone. Int J Oral Maxillofac Implants. 2013: 28: 222-229.

20. Xia DL, Gui L, Zhang ZY, Teng L, Lu CS, Niu F, Jin J. Complications of scalp coronal incision: analysis, prevention, and treatment. Zhonghua Zheng Xing Wai Ke Za Zhi. 2005: 21: 255-262.

21. Burm JS, Oh SJ. Prevention and treatment of wide scar and alopecia in the scalp: wedge excision and double relaxation suture. Plast Reconstr Surg. 1999: 103: 1143-1151.

22. Papay FA, Stein J, Luciano M, Zins JE. The microdissection cautery needle versus the cold scalpel in bicoronal incisions. J Craniofac Surg. 1998: 9: 344-347.

23. Touzet S, Ferri J, Wojcik T, Raoul G. Complications of calvarial bone harvesting for maxillofacial reconstructions. J Craniofac Surg. 2011: 22: 178-181.

24. Lizuka T, Smolka W, Hallerman W, Mericske-stern R. Extensive augmentation of the alveolar ridge using autogenous calvarial split bone grafts for dental rehabilitation. Clin Oral Implants Res. 2004: 15: 207-615.

25. Boronat A, Carillo C, Penarrocha M. Dental implants placed simultouneously with bone grafts in horizontal defects: a clinical retrospective study with 37 patients. Int J Oral Maxillofac Implants. 2010: 25: 189-196.

26. Boven GC, Meijer HJA, Slot W, Vissink A, Raghoebar GM. Does a large dehiscent implant surface at placement affect the 5- year treatment outcome? An assessment of implants placed to support a maxillary overdenture. J.Craniomaxillofac Surg. 2015: 43: 1758-1762.

27. Putters T. F. Raghoebar G. M. Klein-Nulend J. Vissink, A. Schortinghuis J. Immediate dental implant placement in calvarial bone grafts to rehabilitate the severely resorbed edentulous maxilla: A prospective pilot study. Journal of maxillofacial surgery. 2019: 47: 23-28.

28. Donovan MG, Dickerson NC, Hellstein JW, Hanson LJ. Autologous calvarial and iliac onlay bone grafts in miniature swine. J Oral Maxillofac Surg. 1993: 51: 898-903.

29. Smolka W. Calvarial grafts for alveolar ridge reconstruction prior to dental implant placement: an update. Oral Maxillafac Surg. 2014: 18: 381-386.

30. Mertens C, Decker C, Seeberger R, Hoffmann J, Sander A, Freier K. Early bone resorption after vertical bone augmentation. A comparison of calvarial and iliac grafts. Clin Oral Implants Res. 2013: 24: 820-825.

31. Crespi R, Vinci R, Capparè P, Gherlone E, Romanos GE. Calvarial versus iliac crest for autologous bone graft material for a sinus lift procedure: a histomorphometric study. Int J Oral Maxillofac Implants. 2007: 22: 527-532.

32. Kusiak JF, Zins JE, Whitaker LA. The early revascularization of membranous bone. Plast Reconstr Surg. 1985: 76: 510-515.

33. Wong RWK, Rabie ABM. Quantitative assessment of the healing of intramembranous and endochondral autogenous bone grafts. Eur J Orthod. 1999: 21: 119-126.

34. Chen NT, Glowacki J, Bucky LP, Hong HZ, Kim WK, Yaremchuk MJ. The roles of revascularisation and resorption one endurance of craniofacial onlay bone grafts in the rabit. Plast Reconstruc surg. 2002: 93: 714-720.

Chapter 8

Summary

Summary

To improve oral functioning and denture satisfaction in patients with an edentulous maxilla, fabrication of an implant-supported overdenture is shown to be a valuable treatment. However, the amount of bone needed for reliable implant placement can be limited or insufficient in case of alveolar ridge resorption and maxillary sinus pneumatization. In such cases bone pre-implant bone augmentation surgery is needed. When the maxilla is severely resorbed, extensive pre-implant placement augmentation surgery is needed composing of bilateral sinus floor augmentation surgery and extensive buccal plating. In these cases the anterior iliac crest is most commonly used as donor site for such reconstructive surgery. As harvesting anterior iliac crest has its inherent, occasionally disturbing, morbidity, there is a need to consider alternatives. Calvarial bone might serve as an alternative because of its presumed low morbidity. Therefore, the general aim of the PhD research described in this thesis was to assess whether calvarial bone serves as a reliable alternative for anterior iliac crest bone when applied for augmentation of the severely resorbed maxilla in pre-implant placement augmentation surgery.

In **Chapter 2**, a safe surgical technique for harvesting calvarial bone is described. Calvarial bone has been used as a source of bone for intra-oral pre-implant augmentation procedures. The calvaria consists mostly of cortical bone, while to amount of cancellous bone in the diploeic space is usually scarce. We used a bone scraper (Safescraper) to create a beveled trough around the calvarial outer table graft to facilitate safe removal of the bone grafts by an oscillating saw. Using the scraper copious amounts in excess of 10 cc of 'cancellous'-like bone could be collected. This new application of the Safescraper avoided the need for milling down additional cortical pieces.

In **Chapter 3**, a prospective study is described. The aim of this study was to assess the morbidity of calvarial bone grafts used to reconstruct the maxilla and mandible. In consecutive 36 patients (14 men, 22 women, mean age: 59±8.2 years), the per- and postoperative complications related to harvesting of calvarial bone were scored, as well as the occurrence of intraoral complications (average follow-up 25±12 months). The results revealed that peroperative the dura (n=4) was exposed, and the graft (n=5) broke during harvesting. These complications did not occur anymore when the refined the technique was used (see also chapter 2): instead of removing the calvarial outer table graft bone in one piece, we switched to piece-by-piece in situ removal. Postoperative, pain levels of the calvarial donor site were low (VAS, 1.9±2.0 at day 1), and of short duration (5.2±4.7 days until pain free). In all cases sufficient bone could be harvested to enable the placement of implants. The exposure of the dura did not occur after refinement of the technique and the intraoral complications were of no clinical consequence. Therefore, calvarial bone grafts seem promising to be used for pre-implant intraoral reconstruction.

To obtain more insight in the above described method of calvarial bone harvesting in comparison with iliac bone harvesting two studies were executed. These studies are described in **Chapters 4 and 5**. In **Chapter 4**, a case control study is described in which donor site morbidity of calvarial bone and anterior iliac crest harvesting was compared. Twenty-seven edentulous patients who had been subjected to calvarial bone harvesting were matched with 27 edentulous patients in which anterior iliac crest bone was harvested. All patients were treated between March 2011 and December 2013. Patients were matched according to age, sex and duration of follow-up. Donor site morbidity was assessed by medical records, patient questionnaires and physical examination. In addition, patients were recalled to assess persisting morbidity of the harvesting procedure. Exposure of the dura occurred in three patients in the calvarial group. Post-operative pain (VAS) after harvesting was significantly higher in the anterior iliac crest group. Scars were significantly longer and contours deficits were significantly more prominent after calvarial harvesting, although not bothersome to the patients. Long-term pain was negligible in both groups and there were no differences in satisfaction with the procedure between both groups. It was concluded that both harvesting techniques were accompanied by low long-term donor site morbidity and high patients' satisfaction.

In **Chapter 5**, a randomized controlled study is described. This study compared morbidity of calvarial and iliac crest donor sites after harvesting. Twenty edentulous patients with an insufficient volume of maxillary bone for reliable implant placement were assigned randomly to either calvarial (n=10) or anterior iliac crest (n=10) bone harvesting groups. All patients underwent a maxillary sinus floor elevation procedure combined with broadening of the alveolar process using buccal bone blocks. Donor site morbidity was assessed before, during and at 1 year after the surgery through patient questionnaires, physical examination and medical records. No perioperative complications occurred. The anterior iliac crest group reported minor postoperative pain after harvesting. Pain seemed to be higher in the iliac crest group with an increase in body mass index. The scars after calvaria harvesting were significantly longer (p=0.003), but this was not bothersome for the group of patients. Long-term pain was negligible and satisfaction was high in both groups. Both the calvaria and anterior iliac crest are associated with low long-term donor site morbidity and high patient satisfaction. Thus, patient-centred decision-making is appropriate when selecting the preferred harvesting method for that patient.

In **Chapter 6**, the surgical technique of immediate dental implant placement in calvarial grafs for augmentation of the severely resorbed maxilla is described. In 13 patients the maxilla was augmented with calvarial bone followed by simultaneous dental implant placement (total: 68 implants). In the frontal "knife edge" region, implants were inserted in the buccal plated area. In the maxillary sinus area, implants were inserted into alveolar bone that was plated buccally or palatally. After 4 months, the implants were retrieved and subsequently loaded. Per-operative and post-operative variables were scored. One bone biopsy was taken for histological analysis. The surgical procedure and wound healing were uneventful. During abutment connection 4 months after implant placement, all implants appeared to be osseointegrated with no signs of graft resorption. Radiographically, the average peri-implant bone loss after 1 year of functional loading was 0.23±0.44 mm. No implants were lost. Histological examination revealed vital calvarial and maxillary bone with active remodelling. It was concluded that immediate dental implant placement in calvarial bone grafts as a first step to prosthodontically rehabilitate a severely resorbed maxilla is technically feasible and seems to have a high success rate.

The results of the various studies are discussed in a broader context in Chapter 7. It can be concluded that:

- Calvarial bone can be harvested safely and predictably by a piece-by-piece technique using a burr, bone scraper and a micro-saw. The developed technique has been shown to be accompanied by minor morbidity. Direct postoperative pain levels seem lower than with anterior iliac crest grafting.
- Calvarial bone can serve as an alternative for anterior iliac crest bone for augmentation of the severely resorbed maxilla.
- Simultaneous implant placement after the augmentation with calvarial bone is technical feasible. Preliminary results are promising.
- When extensive augmentation is needed in severely resorbed maxilla to allow for future preimplant surgery, the choice between crista iliac anterior or the calvarium as donor site depends on several factors, including BMI, boldness, gait problems and preference of the patient.

Chapter 9

Samenvatting

Samenvatting

De vervaardiging van een implantaat-gedragen overkappingsprothese voor patiënten met een tandeloze bovenkaak die problemen ondervinden met het houvast van hun prothese is een effectieve behandeling gebleken. Ten opzichte van een conventionele gebitsprothese kunnen patiënten met een implantaat-gedragen overkappingsprothese in de bovenkaak beter oraal functioneren en zijn zij tevredener over hun prothese.

Vanwege voortgeschreden resorptie van de kaak en/of een sterk lucht houdende neusbijholte kan er te weinig bot resteren om implantaten betrouwbaar en met voldoende stabiliteit te plaatsen. Wanneer het aanwezige botvolume ontoereikend is, is het noodzakelijk eerst bot aan te brengen op die plaatsen in de kaak waar de implantaten moeten worden aangebracht. Soms kan worden volstaan met een kleine aanvulling van het bot, zeker wanneer de implantaten nog met voldoende primaire stabiliteit kunnen worden geplaatst. Als er sprake is van ernstige resorptie van de bovenkaak moet eerst bot worden aangebracht op die plaatsen in de kaak waar de implantaten worden geplaatst. Meestal is dan een zogenaamde dubbelzijdige verhoging van de bodem van de neusbijholte, een zogenaamde sinusbodemelevatie, nodig. Wanneer de kaak ook te smal is, wordt deze ingreep gecombineerd met ook het aan de buitenzijde van de bovenkaak aanbrengen van bot.

Voor een sinusbodemelevatie en het verbreden van de bovenkaak wordt vaak een bottransplantaat uit het voorste deel van de bekkenkam, de zogenaamde crista iliaca anterior, gebruikt. Het is bekend dat deze ingreep, in ieder geval in de eerste periode na het oogsten van het bot, gepaard gaat met pijn en problemen met lopen. Vandaar dat is gezocht naar een alternatieve donorlocatie. Een donorlocatie waarvan wordt aangenomen dat het oogsten met een lagere morbiditeit gepaard gaat, is een bottransplantaat uit de buitenste laag van de schedel, een zogenaamd schedeldakbottransplantaat. De algemene doelstelling van het in dit proefschrift beschreven promotieonderzoek was om te onderzoeken of schedeldakbot een betrouwbaar alternatief is voor een bottransplantaat uit de bekkenkam wanneer dit bottransplantaat wordt toegepast voor reconstructie van de sterk geslonken bovenkaak ten behoeve van het plaatsen van implantaten.

In **hoofdstuk 2** wordt een chirurgische techniek voor het oogsten van schedeldakbot beschreven. Het bot van de schedel bestaat voornamelijk uit corticaal bot. De hoeveelheid spongieus bot in de diploe, het gebied tussen de tabula externa (buitenste botlaag van de schedel) en tabula interna (binnenste botlaag van de schedel), is meestal beperkt. Om toch een bottransplantaat veilig te kunnen oogsten uit de tabula externa werd een botschraper (safescraper) gebruikt om een bevel rond het met een boor gemarkeerde uit de schedel te nemen bottransplantaat te maken. Hierdoor was het mogelijk het transplantaat op een veilige manier met een oscillerende zaag te verwijderen. Door vervolgens, na het verwijderen van het corticale schedeldakbot, opnieuw de schraper te gebruiken kon gewoonlijk een grote hoeveelheid 'spongieus'-achtig bot worden verzameld, vaak meer dan 10 cm^3. Wanneer deze nieuwe techniek werd toegepast, was het ook niet meer nodig om corticaal bot te vermalen om aan te kunnen brengen in de neusbijholte en rond de botstukjes waarmee de bovenkaak was verbreed.

In **hoofdstuk 3** wordt een prospectief onderzoek beschreven naar de morbiditeit van het oogsten van schedeldakbot voor reconstructie van de bovenkaak en/of onderkaak. Bij 36 patiënten (14 mannen, 22 vrouwen, gemiddelde leeftijd van 59±8,2 jaar) werden de per- en post operatieve complicaties van het oogsten van schedelbot en de intra-orale complicaties (gemiddelde follow-up 25±12 maanden) na het aanbrengen van het bottransplantaat vastgelegd. Peroperatief bleek de dura, de buitenste laag van het hersenvlies, bloot te liggen bij 4 patiënten en brak het transplantaat bij 5 patiënten. Nadat de techniek voor het oogsten van schedeldakbot was gewijzigd naar de in **hoofdstuk 2** beschreven techniek, traden deze complicaties niet meer op. Het niveau van de post-operatieve pijn op de plaats van oogsten van het bottransplantaat was gering (VAS, 1,9±2,0 op dag 1, op een schaal van 1-10), en van korte duur (5,2±4,7 dagen tot pijnvrij). In alle gevallen kon een voldoende hoeveelheidbot worden geoogst om het plaatsen van de implantaten mogelijk te maken. Intra-orale complicaties traden nauwelijks op en hadden geen consequenties voor de vervolgbehandeling. Met andere woorden, het oogsten van schedelbot is een veelbelovende techniek voor reconstructie van de bovenkaak ten behoeve van het plaatsen van implantaten.

Om meer inzicht te verkrijgen of schedeldakbot een goed alternatief is voor bekkenkam bot werd een tweetal onderzoeken uitgevoerd (hoofdstukken 4 en 5). In **hoofdstuk 4** wordt een case-control studie beschreven waarin de morbiditeit van het oogsten van schedeldakbot wordt vergeleken met de morbiditeit van het oogsten van bekkenkambot. 27 tandeloze patiënten, bij wie schedeldakbot was geoogst, werden vergeleken met 27 vergelijkbare patiënten bij wie bekkenkam bot was geoogst. Alle patiënten waren behandeld tussen maart 2011 en december 2013. Patiënten werden gematched op basis van de hand van leeftijd, geslacht en de duur van de follow-up. De morbiditeit van de donorplaats werd vastgesteld aan de hand van de in de status aanwezige medische gegevens, een vragenlijst voor patiënten, en lichamelijk onderzoek. De post-operatieve pijn (VAS) gedurende de eerste periode na het oogsten van bekkenkambot was significant hoger dan die na het oogsten van schedeldakbot. De littekens waren significant langer en contourdefecten significant prominenter aanwezig op de donorplaats na het oogsten van schedeldakbot. Patiënten ervoeren deze litte-

kens en contourdefecten echter niet als storend. Op langere termijn was in beide groepen nauwelijks tot geen pijn meer aanwezig op de donorplaats en waren beide groepen vergelijkbaar tevreden over de ingreep. Met andere woorden, beide technieken voor het oogsten van bot gaan gepaard met een lage morbiditeit op de lange(re) termijn en een hoge patiënttevredenheid.

In **hoofdstuk 5** wordt een gerandomiseerd, gecontroleerd onderzoek beschreven waarin de morbiditeit van het oogsten van schedeldakbot vergeleken met de morbiditeit van bekkenkam bot. 20 tandeloze patiënten met een onvoldoende botvolume in de bovenkaak voor het plaatsen van implantaten werden willekeurig ingedeeld in een groep waarbij schedeldakbot (n=10) of bekkenkam bot (n=10) werd geoogst. In alle patiënten werd het bottransplantaat gebruikt voor een sinusbodem elevatie gecombineerd met verbreding van de bovenkaak. De morbiditeit van de beide ingrepen werd perioperatief en 1 jaar na de ingreep vastgesteld op basis van de medische gegevens in de status, vragenlijsten en lichamelijk onderzoek. Perioperatieve complicaties waren niet opgetreden. Het oogsten van bekkenkambot ging gepaard met pijn t.h.v. de donorplaats, opmerkelijk was dat deze pijn heviger was in patiënten met een hogere body mass index. Na het oogsten van schedeldakbot waren de littekens langer (p=0.003), deze langere littekens werden niet als storend ervaren. De pijn verdween snel. Op lange(re) termijn was de pijn in beide groepen verwaarloosbaar. Voorts waren beide groepen even tevreden met de ingreep. Met andere woorden, de lange(re) termijn morbiditeit van zowel schedeldakbot als bekkenkambot is verwaarloosbaar en de tevredenheid van de patiënt met beide ingrepen is vergelijkbaar. Dit gegeven houdt in dat de keuze van de donorlocatie kan worden bepaald op basis van voorkeur van de patiënt en voorkeur van de chirurg.

In **hoofdstuk 6** wordt een chirurgische techniek beschreven voor het immediaat plaatsen van implantaten in een met schedeldakbot opgebouwde bovenkaak. In 13 patiënten werd tijdens dezelfde ingreep zowel de bovenkaak gereconstrueerd met schedeldakbot als dat implantaten werden geplaatst (totaal: 68 implantaten). Vier maanden later werden de implantaten vrij gelegd en belast. De chirurgische procedure en wondgenezing verliepen zonder complicaties. Tijdens het vrijleggen van de implantaten en het aanbrengen van de abutments bleken alle implantaten te zijn vastgegroeid. Bovendien viel het op dat er nauwelijks tot geen resorptie van het bottransplantaat was opgetreden. Ook het botverlies rond de implantaten was een jaar na het belasten van de implantaten gering, gemiddeld 0,23±0,44 mm. Geen van de implantaten was verloren. Met andere woorden, het immediaat plaatsen van implantaten in de een met schedeldakbot gereconstrueerde bovenkaak is technisch goed mogelijk en heeft een grote slagingskans.

De resultaten van de diverse onderzoeken worden in een breder kader bediscussieerd in **hoofdstuk 7**. Uit dit promotieonderzoek kan worden geconcludeerd dat schedelbot veilig en voorspelbaar kan worden geoogst met een chirurgische techniek waarbij een boor, botschraper en zaag worden gebruikt en het transplantaat in delen wordt verwijderd. De morbiditeit van deze ingreep is verwaarloosbaar. Ook is aangetoond dat schedelbot een betrouwbaar alternatief is voor een bottransplantaat uit de bekkenkam ten behoeve van reconstructie van een sterk geresorbeerde bovenkaak. Bovendien kan, mits een goede primaire stabiliteit van de implantaten kan worden bereikt, het plaatsen van implantaten worden gecombineerd met de reconstructie van de bovenkaak met schedeldakbot.

Dankwoord

Mijn proefschrift is klaar. Of eigenlijk moet ik zeggen “ons proefschrift”. Velen hebben hier namelijk een steentje aan bijgedragen. Zonder gebruik te maken van alle expertise op verschillende niveaus was het maken van dit proefschrift niet mogelijk. Iedereen die hier aan bij heeft gedragen was opbouwend, welwillend en aardig. Een aantal mensen wil hiervoor in het bijzonder bedanken.

Alle deelnemers van de studie ben ik dankbaar. Het ondergaan van een forse operatieve medische ingreep is al geen sinecure. Als je daarnaast dan ook nog VAS score lijsten moet invullen, tevredenheidsvragen moet beantwoorden en extra onderzoeken moet ondergaan krijg je het nogal voor je kiezen. Jullie waren alle dapper, coöperatief en vol vertrouwen. Door jullie hoop ik dat de gezondheidszorg in de toekomst weer een beetje beter wordt. Uiteindelijk is het daar ook om te doen..

Prof. dr. G.M. Raghoebar, hooggeleerde eerste promotor, beste Gerry. Ondanks mijn eigenwijsheid weet je me altijd te enthousiasmeren, te overtuigen en te onderwijzen. Tijdens mijn specialisatie en tijdens dit promotieonderzoek heb je me laten zien hoe belangrijk het is hoofdzaken en bijzaken te scheiden zonder focus te verliezen voor belangrijke details. Als er mensen zijn die denken dat hoogleraren, stoffige, saaie humorloze mensen zijn, moeten ze een dagje met jou mee lopen. Heel erg bedankt.

Prof. Dr. A. Vissink, hooggeleerde tweede promotor, beste Arjan. Ook ik ben je natuurlijk dankbaar voor je befaamde razendsnelle correcties en feedback. De donkerrode teruggestuurde versies zouden je tot wanhoop kunnen drijven maar bij mij werkte het verhelderend voor lichaam en geest. Ik denk dat je een sieraad bent voor de wetenschap. Het is echter wel vervelend dat ik geen kerstkaart meer kan schrijven zonder dat ik denk “klopt dit wel?”.

Dr. J. Schortinghuis, weledelzeergeleerde co-promotor, beste Jurjen. Het combineren van hoogstaand academisch werk en het verzorgen van reguliere gezondheidszorg is volgens menig vakbroeder niet mogelijk. Jij bewijst elke dag dat het kan. Juist deze combinatie zorgt voor een waardevolle nalatenschap in de gezondheidszorg. Ik heb hier veel van geleerd en ben je hier erg dankbaar voor. Op persoonlijk vlak ben je voor mij van onschatbare waarde geweest. Samenwerken met jou is een synergie.

Geachte prof. dr. A.J.W.P. Rosenberg, prof. dr. H.JA. Meijer en prof. dr. E.A.J.M. Schulten, hooggeleerde leden van mijn beoordelingscommissie. Mijn proefschrift zal een epistel geweest zijn tussen de vele andere werken op jullie bureau welke lagen te wachten op deskundig oordeel. Ik ben jullie dankbaar dat jullie mijn proefschrift kritisch hebben bekeken.

Geachte prof. dr. F.K.L. Spijkervet, beste Fred, afdelingshoofd. Bedankt dat ik de mogelijkheid heb gekregen om als perifeer werkend specialist promotieonderzoek te doen. Onze contactmomenten ervaar ik altijd als zeer hartelijk. Binnenwandelen in “jouw winkel” voelt als thuiskomen.

Geachte prof. dr. L.G.M.de Bont, beste Lambert. Bedankt dat ik de mogelijkheid heb gekregen om me na mijn opleiding tandheelkunde te specialiseren tot MKA chirurg. Ik was de eerste die de specialisatie combineerde met de opleiding geneeskunde. Ondanks mijn spelfouten in mijn sollicitatie brief kreeg ik het voordeel van de twijfel wat resulteerde in een erg leerzame, innerverende en leuke tijd.

Geachte leden van het dagelijks bestuur van de afdeling Mondziekten, Kaak- en Aangezichtschirurgie van het UMCG. Bedankt dat ik altijd gebruik kon maken van de faciliteiten die deze mooie afdeling te bieden heeft

Dr. B. van Minnen, K. Kuik, D.E. Wortmann, Dr. C. Boven, beste Bauke, Karel, Dagmar en Carina, bedankt alle voor de samenwerking. Jullie visie en inzet als professionals in jullie vakgebied zijn onontbeerlijk gebleken voor het slagen van de verschillende onderzoeken die de basis vormen van dit proefschrift.

Geachte prof. dr. Klein Nulend, beste Jenneke. In het prille begin van ons onderzoek bezochten Jurjen en ik je in Amsterdam. De inzichten die je me toen gaf daalden pas in bij het schrijven van de discussie en is voer voor volgende studies.

Beste Ans, je aandeel in het verzamelen van de gegevens en het organiseren van de patiëntenstroom is van onschatbare waarde geweest. Tijdens het promotietraject maar ook tijdens mijn opleiding heb je me altijd gesteund en waren we partners in crime. Het is niet eerlijk dat jij geen soort van titel krijgt die je verdient. Triple A topzuster Ans.

Beste dames-assistentes en heer-assistent Gert van de MKA UMCG. In het bijzonder de “ppc groep”: Ingrid, Ria, Tanja, Ans en Karien. Bedankt voor jullie inzet en hulp bij het volgen van mijn patiëntengroep. Ik zelf was natuurlijk met mijn werkzaamheden elders niet in de buurt als aanspreekpunt. Mijn vertrouwen in jullie is niet voor niets. Dit weet ik al sinds mijn opleiding. Altijd als ik weer terugkom voelt het weer vertrouwd aan. In de toekomst probeer ik weer wat vaker op de poli te komen.

Beste dames van de medische administratie en het secretariaat. Bedankt voor het aanhoren van al mijn telefoontjes en mij doorverbinden naar alle uithoeken van het UMCG. Als ik iemand nodig had of een van mijn patiënten door wilde verwijzen, koos ik altijd maar jullie nummer. Ik kreeg dan de indruk dat ik een voorkeursbehandeling kreeg. Jullie vrolijkheid en persoonlijke interesse klaart je dag

echt op als je in een drukke poli “even” iets tussendoor wil regelen. Lisa, bedankt voor je hulp als ik de weg weer kwijt was in de UMCG machine.

Beste dames van de röntgenafdeling, beste Mariëlle, Liliane, Anne, Yvonne en Charlotte. Bedankt voor de mooie “plaatsjes”. Uit ervaring weet ik dat het soms moeilijk is om maar weer uit zo’n summiere verwijzing van een dokter de juiste vraagstelling te distilleren. Kaakchirurgie is, zo zei eens iemand: “tellen, kieken en foto’s maken”. Wel nu, een derde van het werk nemen jullie uit handen.

Beste stafleden van het CBT en het CTM met in het bijzonder Wim Slot en Charlotte Jensen-Louwerse. Bedankt voor het aanmeten van de prothetiek bij al de geïncludeerde patiënten. Aan een augmentatie met schedelbot en implantaten hebben patiënten helemaal niets zonder goed functionerend fraai oraal gereedschap.

Beste Anne Wietsma en Ashwin Beekes. Hartelijk dank voor alle hulp bij de vervaardiging van de prothetiek.

Beste Gerrit van Dijk en alle medewerkers van het tandtechnisch laboratorium Gerrit van Dijk. Hartelijk dank voor het vervaardigen van de suprastucturen en protheses. Ook ik was een patiënt van jullie. Ik geniet nog dagelijks van de 25 jaar geleden door jullie vervaardigde kroon wanneer ik mijn voedsel aan mijn tractus digestivus presenteer.

Beste OK teams van het UMCG, Scheper ziekenhuis en het Refaja ziekenhuis. Beste Guzide, Ewa, Angelique, Engelina, Ellen, Marleen, Wendy, Honey, Pieter, Peter en Nancy. Bedankt voor jullie ondersteuning tijdens de toch wel nieuwe ingreep. Het was best pionieren. Al snel werd het routine en dankzij jullie een veilige, leuke ingreep.

Beste dames van de MKA Refaja ziekenhuis. Beste Jannet, Willeke, Roelien, Tanja, Josephien, Marika, Agnes en Koba Bedankt voor jullie begrip en geduld op de momenten dat er weer wat moest gebeuren in het kader van het onderzoek. Onze wegen zijn gescheiden. Toch koester ik de 10 jaar samenwerken met jullie.

Beste Marika. Wat een fantastische kundige en enthousiaste vrouw ben je. Je niet aflatende inzet voor het onderzoek heeft me enorm geholpen. Ik hoop dat we contact blijven houden.

Beste Koba. 10 jaar lang mijn rechter hand. Bedankt!

Geachte collegae van de tandartsenkring van de Kanaalstreek. Bedankt voor het vertrouwen die jullie mij gaven door het verwijzen van patiënten. We hebben altijd prettig samengewerkt. Nadat de diensten waren verdeeld, was het altijd heel gezellig in “het Boschhuis” ;-)

Beste paranimf, R.P Wiewel, Beste Roeland. Je bent niet alleen een fijne collega in een vak waar we elkaar vakkundig goed aanvullen maar ook een goede vriend. Bedankt voor je vriendschap en je “ludieke” filmpjes.

Beste paramimf, B.J. Melenhorst, Bart-Jan. Ondanks dat we elkaar niet zo veel meer zien gaat onze vriendschap nooit meer over. Tsja, als je 5 jaar Feithstraat met elkaar overleefd dan maakt een gemist verjaardagje niet zo veel meer uit.

Beste medewerkers van de afdeling MKA Gelre ziekenhuizen, Apeldoorn. Beste Karen, Ingeborg, Monique, Salie, Magreet, Meryem, Inneke, Manon, Mariet. Ik ben dankbaar dat ik in de mooiste best draaiende afdeling MKA van Nederland mag werken.

Beste S. Heinsbroek, beste Steven. Bedankt voor de samenwerking en vriendschap in Apeldoorn. Tijdens onze gezamenlijke sportuurtjes zijn we het griezelig vaak eens over eigenlijk alles. Ik wilde je vragen of je mijn paranimf wilde zijn, maar ik denk dat je die taak had gedelegeerd. En daar zou ik het mee eens zijn.

Beste P. Kraaij, beste Peter. We kennen elkaar al vanaf dag een van onze opleiding tot MKA chirurg. Bedankt voor je collegialiteit, vertrouwen en vriendschap.

Lieve Ilse. We hebben mooie jaren gehad samen. Onze uitmuntende nalatenschap timmert aan de weg (al weten ze dat zelf nog niet).

Lieve Catherine, lief zusje. Bedankt dat je er onvoorwaardelijk voor me bent. Je raakt mensen kwijt in je leven, relaties vervagen maar onze band wordt alleen maar sterker. Gyles, bedankt dat je mijn schoonbroer bent. Ik kan me geen betere man voorstellen voor mijn zus. Ik denk trouwens dat er verder niemand door de eerste sollicitatie ronde heen zou komen.

Lieve vader en moeder, Harrie en Paula. Bedankt voor alle vrijheid die jullie me gegeven hebben om mij te ontwikkelen. Sorry dat ik zo ver van jullie af ben gaan wonen. Ik weet dat jullie dat veel verdriet doet. Wellicht dat we komende jaren wat dichter bij elkaar komen.

Lieve familie Bekkering, Gerard, Janneke, Eyelien en Gerben (ja ok, ook Jeroen.). Jullie hebben mij geleerd wat “boerenslimheid” echt betekent. Zonder jullie was dit proefschrift er niet geweest.

Allerliefste, Danielle, Daantje, op het moment dat ik dit schrijf heb je een zeer moeilijke tijd doorgemaakt waardoor ik me nog meer besef hoeveel jij in mijn DNA bent gekropen. Ik hou van je voor de rest van mijn leven. De manier waarmee je omgaat met tegenslag is een groot voorbeeld en een voorrecht om te aanschouwen. Wij hebben het vreselijk getroffen om bij elkaar te horen. En geen enkele dokter weet wat alles beter kan maken en wij stiekem wel.

Lieve Maria, lieve Salomon, mijn allerbelangrijkste in dit melkwegstelsel. Alles vernauwd zich tot geluk in zijn eenvoud als ik bij jullie ben. Ik hoop dat ik jullie promotor des levens mag zijn en blijven.

Curriculum Vitae

Thomas Franciscus Putters was born in Tilburg, the Netherlands, on February 2th, 1976. After finishing secondary school at the “Odulphus Lyceum” in Tilburg in 1995, he completed Dentistry school at the University of Groningen, Groningen, the Netherlands in 2000. In 2000, he started medical school at the University of Groningen, Groningen, the Netherlands, combined with his residency in Oral and Maxillofacial Surgery at the department of Oral and Maxillofacial Surgery of the University Medical Centre Groningen, the Netherlands (head: prof. dr. L.G.M.de Bont). After his registration as a maxillofacial surgeon in 2007, he founded the department of Oral and Maxillofacial Surgery at the Refaja hospital in Stadskanaal, the Netherlands. In 2011 he was founder of the Department of Dentistry at the Refaja hospital in Stadskanaal. In 2013, he started his PhD project at the department Oral and Maxillofacial surgery of the University Medical Centre Groningen (head: prof. dr. F.K.L. Spijkervet). From 2018, he works at the department of Oral and Maxillofacial surgery of the Gelre hospitals, Apeldoorn, the Netherlands. Thomas is an amateur triathlete, windsurfer and ice speed skater. Thomas lives together with Danielle Bekkering and his daughter Maria and son Salomon.