J Clin Periodontol 2011; 38: 95–101 doi: 10.1111/j.1600-051X.2010.01630.x

Journal of Clinical Periodontology

Soft tissue expansion with self-filling osmotic tissue expanders before vertical ridge augmentation: a proof of principle study

Doğan Kaner[1] and Anton Friedmann[2]

[1]Department of Operative Dentistry and Periodontology, CharitéCentrum 3, Charité – Universitätsmedizin Berlin, Berlin, Germany; [2]Department of Periodontology, University of Witten/Herdecke, Witten, Germany.

Kaner D, Friedmann A. Soft tissue expansion with self-filling osmotic tissue expanders before vertical ridge augmentation: a proof of principle study. J Clin Periodontol 2011; 38: 95–101. doi: 10.1111/j.1600-051X.2010.01630.x.

Abstract

Introduction: Post-surgical graft exposition and loss of grafted bone are a common complication of vertical bone augmentation. Soft tissue expansion (STE) by implantation of osmotic self-filling tissue expanders before reconstructive surgery is an effective method for generation of soft tissue. The aim of this study was to investigate the feasibility of STE before bone augmentation with regard to clinical and histological outcomes and complications.

Methods: Tissue expanders were implanted in patients requiring vertical bone augmentation. Onlay grafting was carried out after 2 months of STE. Implants were placed 4–6 months after augmentation. Vertical bone gain was analysed with cone-beam computed tomography (CBCT). Bone biopsies were investigated with micro-computed tomography (micro-CT).

Results: Twenty-four sites in 12 patients were treated with STE. Complications of STE were perforation (two sites) and infection (two sites). At augmentation after STE, primary wound closure was easily achieved and the incidence of graft expositions was low (4%). At implant placement, high vertical bone gain of 7.5 ± 2.4 mm was found. Micro-CTs of bone revealed a good ratio of bone volume/tissue volume (mean BV/TV = 0.1614 ± 0.0582). All implants were osseointegrated.

Conclusions: The combination of STE and subsequent vertical augmentation provided high gain of well-structured bone for further successful implant therapy and was accompanied by minimal complications.

Key words: bone graft; dental implants; tissue expansion; vertical bone augmentation

Accepted for publication 9 September 2010

Placement of dental implants often requires reconstruction of resorbed alveolar ridges and a variety of bone augmentation techniques is used to improve the horizontal and vertical dimensions of the implant site. When applied for lateral ridge augmentation, autogenous bone block grafts or guided bone regeneration (GBR) techniques provide a predictable volume of generated bone after healing (McAllister & Haghighat 2007). On the other hand, the outcome of vertical ridge augmentation appears less clear. Clinical and histological data support the feasibility of vertical augmentation procedures such as onlay grafting, inlay grafting, distraction osteogenesis or GBR (Rocchietta et al. 2008, Esposito et al. 2009). However, these surgical procedures are considered highly technique sensitive and the findings are difficult to extrapolate (Rocchietta et al. 2008, Esposito et al. 2009). Although the reported incidence of post-operative complications varies highly among studies, it is apparent that soft tissue dehiscence and exposure of bone grafts to the oral cavity are common complications of vertical ridge

Conflict of interest and source of funding statement

D. K. lectures for Osmed and A. F. lectures for Institut Straumann AG.
This study was supported by unrestricted research grants and donation of clinical materials by Osmed (Ilmenau, Germany) and Institut Straumann AG (Basel, Switzerland).

augmentation, compromising the outcome and leading to partial or complete loss of the graft in up to 40% of the cases (Verhoeven et al. 1997, Bahat & Fontanesi 2001, Chiapasco et al. 2004, 2007, Roccuzzo et al. 2004, 2007, Proussaefs & Lozada 2005, Barone & Covani 2007, Merli et al. 2007, Canullo & Malagnino 2008, Felice et al. 2009, Urban et al. 2009).

Exposure of grafts is mainly attributed to difficulties in achieving tension-free closure of the flap (Lundgren et al. 2008). Generally, the elevation of a flap disturbs perfusion and causes ischaemia (McLean et al. 1995). Preservation of sufficient blood flow is important for tissue survival (Nakayama et al. 1982). Conversely, reduction of blood supply and ischaemia-reperfusion injury may affect the operated tissue and may cause complications such as necrosis of the flap. The severity of tissue damage relates to the duration and intensity of ischaemia (Morris et al. 1993, Carroll & Esclamado 2000). Accordingly, a direct relation between the extent of surgical trauma and concomitant disturbance of perfusion has been shown for periodontal surgical procedures with different degree of tissue traumatization (Retzepi et al. 2007). Given that tissue mobilization for achieving tension-free primary wound closure for vertical augmentation is considerably more traumatic compared with a straightforward lateral augmentation procedure, soft tissue quality and quantity appear as key factors for predictable success.

Notwithstanding complications, volume maintenance during healing is another major concern, as up to 60% of graft volume may be resorbed during healing (McAllister & Haghighat 2007). Again, compromised vascularization and tension of the flap caused by soft tissue movement and subsequent limitation of regenerative space have been considered as causes for limited outcomes in vertical augmentation in animals (Rothamel et al. 2009) and in humans (Lundgren et al. 2008). Thus, it may be concluded that an antecedent improvement of soft tissue quality and quantity could enhance the outcome of vertical bone regeneration.

Generation of soft tissue by using subcutaneous tissue expanders before reconstructive procedures is an established method in plastic surgery. After implantation, the increase of expander volume over time causes tension on the surrounding tissues and results finally in tissue gain (Bennett & Hirt 1993, Bascom & Wax 2002). Osmotic self-filling tissue expanders consist of a polymer of methylmethacrylate/vinylpyrrolidone and expand due to absorption of body fluids. Presently, these expanders are used for a variety of indications, such as breast reconstruction, defect coverage after excisions and preparation of tissue donor sites (Berge et al. 2001, Ronert et al. 2004). Here, we report for the first time on the application of osmotic tissue expanders to improve soft tissue before vertical augmentation of severely resorbed ridges. The aim of this study was to evaluate the feasibility of a combined soft tissue expansion (STE) and vertical augmentation procedure with regard to gain of bone and complications.

Material and Methods

Patients

Patients were recruited from patients seeking implant treatment at the Department of Periodontology, Charité – Universitätsmedizin Berlin. Resorbed edentulous or partially edentulous ridges class C or D (Misch & Judy 1987) and the need of vertical bone augmentation of >3 mm before placement of dental implants were criteria for inclusion.

Exclusion criteria were untreated periodontal disease; caries; insufficient oral hygiene; previous radiation therapy; smoking; systemic disorders potentially affecting the outcome in implant therapy (e.g. uncontrolled diabetes mellitus, haemorrhagic disorders) and medications putatively affecting implant therapy (e.g. bisphosphonates). Written informed consent has been obtained from each patient. The study protocol has been approved by the institutional Ethics Committee of the Charité – Universitätsmedizin Berlin (EA2/117/07).

Implantation of tissue expanders

Expander type and size (hemisphere with 0.35 ml final volume; round-ended cylinders with 0.24, 0.7, 1.3 or 2.1 ml final volume; "Dental Cupola slow" and "Dental cylinder slow", Osmed, Ilmenau, Germany) appropriate for the edentulous site and with a swelling time of 60 days (Fig. 1a and b) were selected with surgical templates corresponding to the final expander volume (Fig. 2a and b). A submucosal pouch was prepared with scalpel and scissors without elevation of the periosteum (Fig. 2c). The size of the pouch was controlled with the surgical template (corresponding to the initial expander volume) that should easily fit into the pouch (Fig. 2d). The expander was placed into the pouch and fixed with a bone fixation screw (Fig. 2e). A meticulous two-layer wound closure was performed using fine monofilament sutures. Administration of antibiotics (amoxicillin 750 mg or clindamycin 600 mg) was started 1 h before surgery and continued for 7 days. Ibuprofen (400 mg) was prescribed as analgesic. Patients were followed up weekly and were advised to rinse with 0.2% chlorhexidine for 2 weeks until suture removal. Abstention from removable prostheses was required. Fixed provisional prostheses were adjusted regularly according to the increasing soft tissue volume. Bone augmentation was carried out after 6–8 weeks of expansion, when the expander had reached its final volume (Figs 1a and 2f).

Expander removal and bone augmentation

Depending on the needed graft volume and the availability of intra-oral donor bone, bone grafts were harvested either

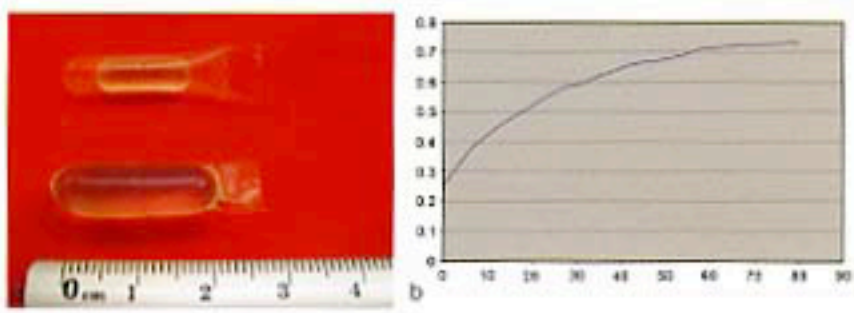

Fig. 1. (a) Cylindrical tissue expander before and after swelling. (b) Volume increase over time of a tissue expander in vitro (0.9% saline). The final volume (here: 0.7 ml) is reached after approx. 60 days.

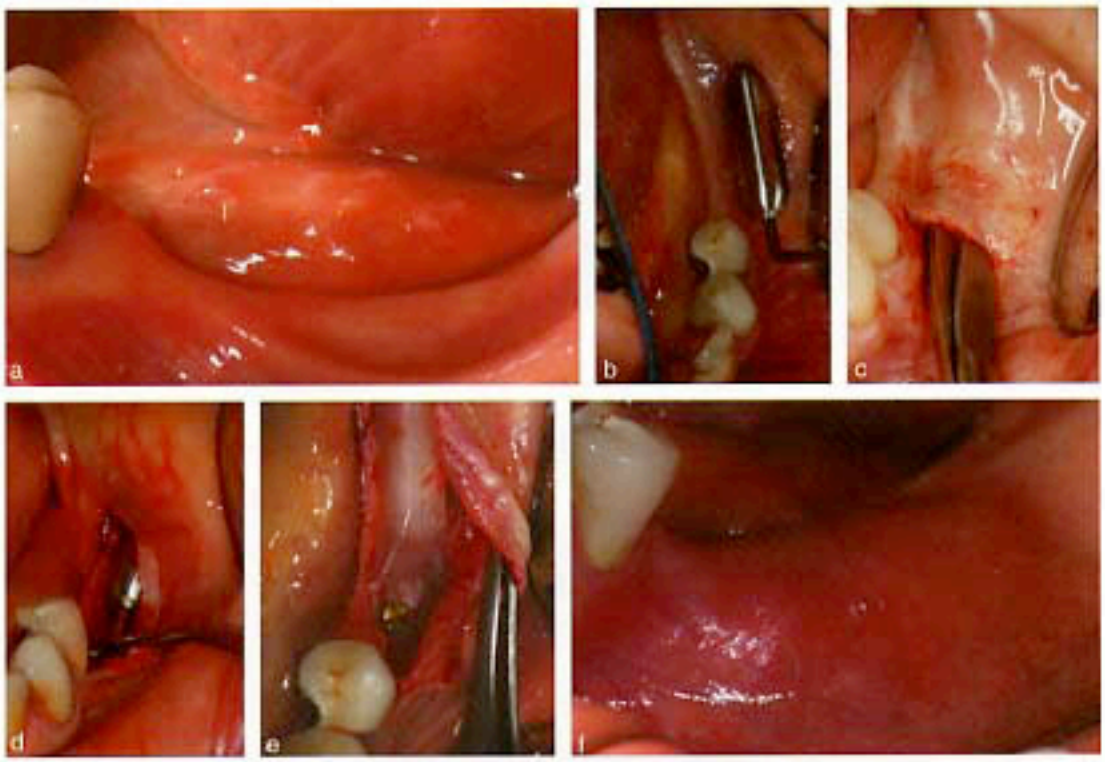

Fig. 2. (a) Resorbed edentulous ridge (class C) requiring vertical bone augmentation of approx. 5 mm. (b) The appropriate expander size is selected using the surgical template (final expander volume). (c) A supraperiosteal mucosal pouch is prepared using scalpel and scissors. (d) The preparation is controlled with the surgical template (initial expander volume). (e) The tissue expander is inserted into the pouch and fixed with a bone fixation screw. (f) After 8 weeks of tissue expansion (1.3 ml expander), a considerable gain of soft tissue can be observed.

from the mandibular ramus or the posterior ilium.

Bone augmentation with ramus grafts was carried out under local anaesthesia, under sedation, anti-phlogistic medication with prednisolone and antibiotic coverage. Ibuprofen 600 mg was prescribed as analgesic and patients rinsed with 0.2% chlorhexidine for 2 weeks.

At the donor site, a mucoperiostal flap was reflected distally of the second molar, exposing the lateral aspect of the ramus along the external oblique ridge. Block grafts were prepared with a piezoelectric device (Piezosurgery II, Mectron, Köln, Germany).

After midcrestal incision at the recipient site, a mucoperiostal flap was reflected. The expander was removed and the bone was exposed. Generally, vertical releasing incisions were avoided; in case of adjacent teeth present, the incision was extended into the gingival sulcus for ease of reflection. The local bone was perforated and the block graft was secured with screws (Institut Straumann AG, Basel, Switzerland). The graft was covered with a granular bone substitute (BioOss, Geistlich, Wolhusen, Switzerland) and a collagen membrane (Ossix plus, Colbar, Hertzelia, Israel). The incision was closed with modified vertical mattress sutures and single interrupted sutures, using fine monofilament sutures. Sutures were removed after 2 weeks.

Bone augmentation with grafts from the posterior ilium was performed under general anaesthesia and under antibiotic coverage. The patient was placed in a prone position and an incision was placed extending cranially from the posterior iliac spine. Grafts were harvested from the external wall of the posterior iliac crest with an oscillating saw and a chisel.

At the recipient sites, mucoperiostal flaps were elevated (Fig. 3a). Again, releasing incisions were avoided. After removal of the expanders, the local bone was exposed and perforated, and onlay grafts were fixed with screws (Fig. 3b). Patients were mobilized after 24 h and sutures were removed after 1 week.

The expanders were weighed after removal and a biopsy was taken from the expanded soft tissue.

Implant placement

In patients treated with ramus grafts and GBR, implants (Standard Plus, SLActive surface, Institut Straumann AG) were placed 6 months after bone augmentation, following the standard protocol for non-submerged healing. In patients treated with iliac grafts, implants of the same type were placed 4 months after augmentation. Sutures were removed after 1–2 weeks.

Radiographs

Cone-beam computed tomographies (CBCT, Galileos, Sirona, Bensheim, Germany) were taken before implantation of tissue expanders, and 4–6 months after bone grafting, before placement of dental implants. Digital panoramic radiographs (Sirona) were made after bone augmentation and after implant surgery. The mean vertical bone gain/surgical site was calculated to the nearest millimetre by subtraction of bone height before grafting from bone height before implantation, using the CBCT software measurement tool after aligning the

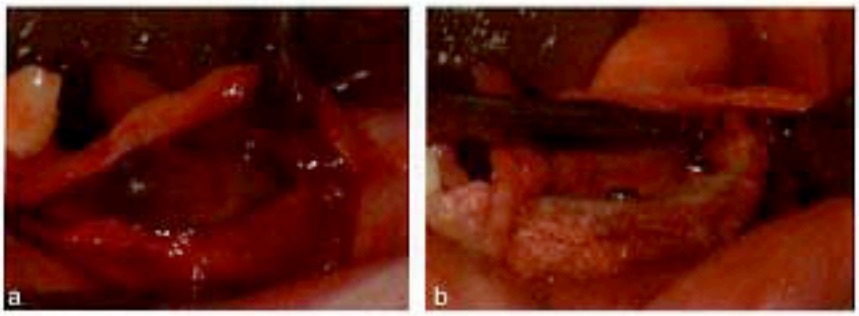

Fig. 3. (a) The tissue expander is explanted in the course of bone augmentation surgery. (b) After fixation of the bone graft, primary closure of the flap is easily achieved without further mobilization.

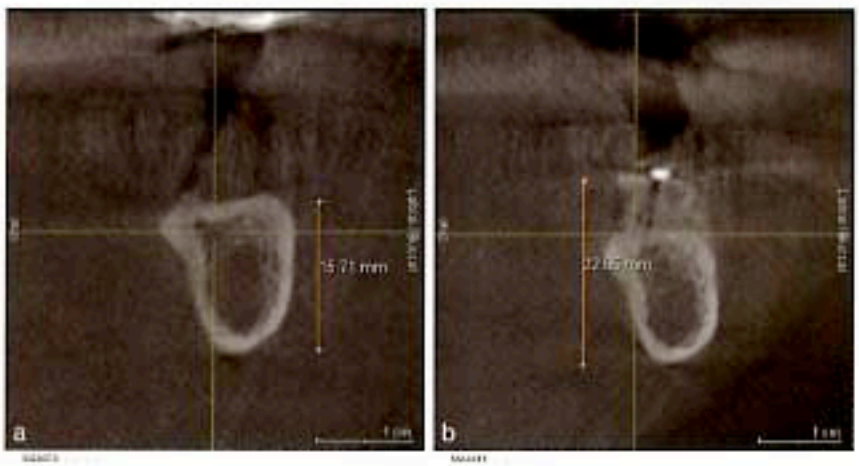

Fig. 4. (a) Cone-beam computed tomographic cross section of a resorbed mandible before augmentation. Mandibular height: 15.7 mm. (b) Same section of the same patient, 6 months after augmentation. Mandibular height: 22.6 mm, radiographic bone gain approx. 6.9 mm.

investigation window at reproducible anatomical landmarks (Fig. 4a and b).

Biopsies

At the time of bone augmentation, biopsies were taken from the expanded soft tissue surrounding the expander, fixed in 4% formalin, embedded in paraffin, stained with haematoxylin/eosin and investigated with a light microscope.

Bone core biopsies were harvested at the time of implant placement using a trephine drill (inner diameter 2.2 mm) for preparation of the implant site, and fixed in formalin. The bone biopsies were investigated with micro-computed tomography (micro-CT), using an experimental cone-beam micro-CT scanner with a micro-focus tube (voxel size 20 μm).

Results

Twelve patients (three men, nine women, mean age 45 years, range 21–73 years) were included in the study since November 2007. Treatment was concluded in October 2009.

Expanders were placed in 24 surgical sites. Post-operative sequelae were minor edemata and slight pain; generally, the treatment was well tolerated.

Healing and expansion period were uneventful in 10 patients. In two patients, expanders perforated through the mucosa and were removed. Reasons for perforation were seroma formation and infection after 4 weeks (one site), and probably, the use of an oversized expander type (one site). These sites were allowed to heal for 6 weeks and were successfully retreated with smaller expanders. In two sites, fistulae developed after seroma formation shortly before bone augmentation. These sites were treated with instillation of a tetracycline/cortisol paste until augmentation surgery.

Augmentation with ramus grafts and GBR was carried out in 12 sites in nine patients. In three patients (12 recipient sites), corticocancellous bone grafts from the posterior ilium were placed as onlay grafts onto the resorbed mandible, or in the maxilla, onlay grafting was combined with a sinus lift procedure with granular bone substitute. In all cases, wound closure at the recipient sites was easily achieved without further mobilization of tissue beyond the incision for the removal of the tissue expanders (Fig. 3b).

Paraesthesia of the mental region occurred in one patient after ramus grafting, but resolved spontaneously after 4 months. One minor exposition occurred after vertical augmentation in the posterior maxilla, but healed spontaneously after debridement and repeated application of chlorhexidine gel.

In all other cases and augmented sites, wound healing was uneventful. Weighing of the expanders after explantation showed that all expanders had reached their expected final volume (data not shown). Histological analysis of the soft tissue capsule surrounding the expander showed dense connective tissue and absence of infiltration (Fig. 6a).

After the designated healing time of 4 and 6 months, respectively, analysis with the CBCT measurement tool revealed a mean vertical bone gain of 7.5 ± 2.4 mm (range 3–12 mm) before implant surgery. In all patients, the desired height of augmentation was reached and 53 implants (1–19 implants per patient, length 8–12 mm) could be placed as intended (Fig. 5a and b) without additional grafting. In 22 of 24 sites, the width of keratinized gingiva was increased with free gingival grafts (20 sites) or connective tissue grafts (two sites) simultaneously with placement of the implant (six sites) or after healing (16 sites). All implants were osseointegrated and were used for fixed partial dentures, crowns or bar-retained removable prostheses.

Eleven bone biopsies were analysed by micro-CT (Fig. 6b and c; supporting information Video S1) and a mean BV/TV (bone volume/tissue volume) of 0.1614 ± 0.0582 was found.

Discussion

The use of tissue expanders before intraoral bone graft surgery has been occasionally described in case reports (Lew et al. 1988, Wittkampf 1989, Bahat & Handelsman 1991). In these studies, "classical" types of tissue expanders

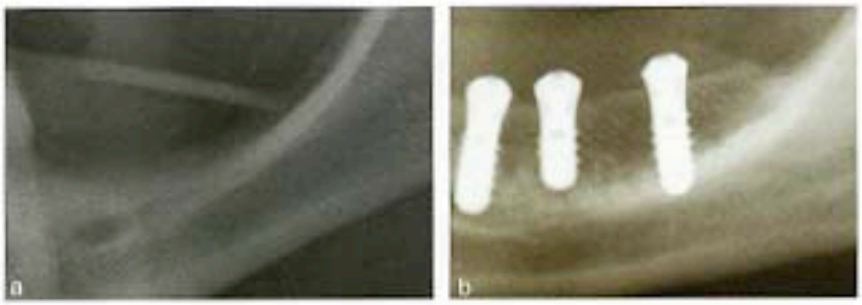

Fig. 5. (a) Panoramic radiograph before bone augmentation. Minimal bone height over the mandibular canal. (b) Panoramic radiograph after implant surgery. Vertical bone gain of approx. 8 mm.

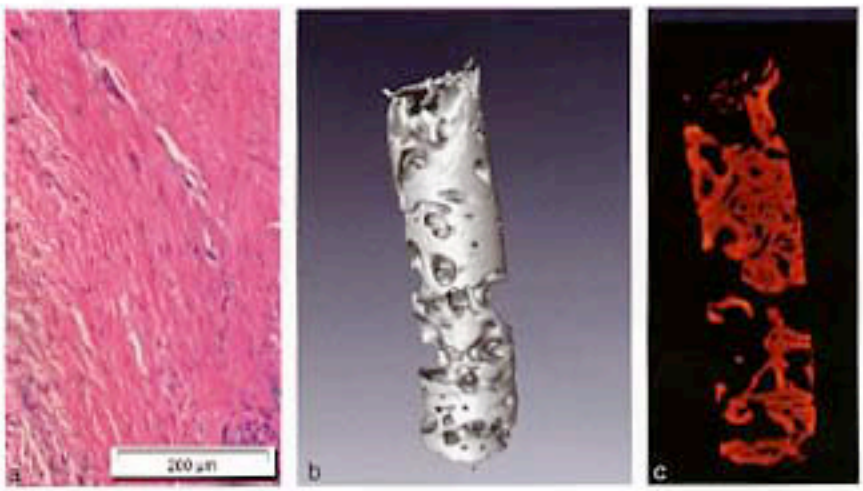

Fig. 6. (a) Biopsy of the tissue capsule surrounding the expander. After 8 weeks of tissue expansion, a fibre-rich dense connective tissue without the presence of inflammatory cells can be seen. (b and c) Micro-CT of a bone core biopsy taken at implant site preparation 4 months after grafting from the posterior ilium shows distinct trabecular structures (BV/TV 0.237). A supplemental movie file shows the full volume of the scan.

were used, i.e. variations of inflatable silicone balloons. Usually, these expanders are filled once a week by injection of saline into subcutaneous filling ports or percutaneous valve constructions to the extent until the skin over the expander appears blanched. However, decreased tissue perfusion and hypoxia are caused by intra-luminal pressure spikes that result from the intermittent filling technique (Pietila 1990), and may lead to tissue necrosis and subsequent perforation of the balloon expander through skin or mucosa (Wiese 1993). Generally, percutaneous injections into subcutaneous ports require local anaesthesia, while percutaneous valve constructions that penetrate the skin increase the risk of infection (Wiese 1993). These disadvantages may become even more relevant in the oral environment and may have as yet impeded the systematic application of tissue expanders for ridge augmentation.

In our study, we used for the first time osmotic tissue expanders before vertical ridge augmentation. Complications such as perforation and seroma formation occurred in four of 24 sites, similar to the use of osmotic expanders in other indications (Ronert et al. 2004). In two sites, expander implantation was successfully repeated using a smaller expander type. Seroma formation in two sites shortly before bone augmentation was treated with a local antibiotic and did not interfere with bone augmentation surgery. Osmotic expanders increase their size by absorption of body fluids and the need for external fillings is eliminated, which may explain the low incidence of infectious complications during osmotic tissue expansion in our study and in other indications (Ronert et al. 2004).

Further, this type of expander is ensheathed with a silicone shell; perforations in the impermeable shell allow influx of tissue fluid, while the rate of influx over time (and therefore speed of volume increase) is controlled by the number of perforations. Unlike balloons, osmotic expanders with suchlike silicone shells swell slowly and continuously, and injection-dependent pressure peaks are avoided (Anwander et al. 2007). The expanders used in our study reach their final volume after 60 days. Slow and continuous expansion results in safe and effective generation of soft tissue (Wiese 1993, Wiese et al. 2001), as experienced during bone augmentation surgery and confirmed by the absence of infiltration in soft tissue biopsies (Fig. 6a).

The expanders were placed in a submucosal pouch without elevation of the periosteum. Expansion of the periosteum is not to be expected, as it is replaced by fibrous connective tissue after subperiosteal implantation of tissue expanders (Tominaga et al. 1993), while a new periosteum is formed underneath the expander. Further, subperiosteal implantation causes significant resorption of the underlying bone (Stoelinger et al. 2009), a finding that was not observed in our patients. In addition, a submucosal pouch is easily and quickly prepared and well tolerated by the patient; hence, supraperiosteal implantation appears preferable over subperiosteal implantation of osmotic tissue expanders.

After expansion, major bone augmentation procedures were carried out. The quality of expanded tissue was excellent and the space created by tissue expansion permitted easy primary closure without the need for additional flap advancement. Accordingly, the incidence of post-operative graft expositions was very low (one in 24 sites, 4%), when compared with studies of vertical bone augmentation without previous tissue expansion (mean incidence of expositions 21.4%, up to 50%, Table 1) (Verhoeven et al. 1997, Proussaefs et al. 2002, Roccuzzo et al. 2004, 2007, Chiapasco et al. 2004, 2007, Proussaefs & Lozada 2005, 2006, Barone & Covani 2007, Merli et al. 2007, Canullo & Malagnino 2008, Fontana et al. 2008, Felice et al. 2009, Urban et al. 2009).

Before implant surgery, after 4–6 months of healing, standardized CBCT measurements showed a mean vertical bone gain of 7.5 ± 2.4 mm. These results compare favourably with the mean bone gain of 4.13 ± 1.05 mm

Table 1. Overview of studies reporting on vertical ridge augmentation using variations of guided bone regeneration (GBR) techniques and/or onlay grafts, illustrating the incidence of post-surgical graft expositions, and radiographic vertical gain of bone 4–6 months after augmentation

References	Method of augmentation	Vertical bone gain (mm)	Incidence of expositions, *n* (%)
Barone and Covani (2007)	Onlay graft	Not reported	4/37 (11)
Camullo and Malagnino (2008)	GBR	5.3 ± 1.9	1/10 (10)
Chiapasco et al. (2004)	GBR	3.87 ± 1.05	3/11 (27.3)
Chiapasco et al. (2007)	Onlay graft	5.0 ± 1.07	1/8 (12.5)
Fontana et al. 2008	GBR	4.7 ± 0.48	0/5 (0)
	GBR	4.1 ± 0.88	1/5 (20)
Merli et al. (2007)	GBR	2.2 ± 1.1	4/11 (25)
	GBR	2.5 ± 1.2	5/11 (22)
Proussaefs and Lozada (2005)	Onlay graft	4.75 ± 1.29	3/12 (25)
Proussaefs and Lozada (2006)	Granular autologous bone and bone substitute, titanium mesh	2.59 ± 0.91	6/18 (33)
Roccuzzo et al. (2004)	Granular autologous bone, titanium mesh	4.8 ± 0.9	3/18 (17)
Roccuzzo et al. (2007)	Onlay graft	3.4 ± 1.4	6/12 (50)
	Onlay graft and titanium mesh	4.8 ± 1.5	4/12 (33.3)
Urban et al. (2009)		4.7 ± 1.67	0/12 (0)
		5.1 ± 2.13	1/16 (6.25)
Verhoeven et al. (1997)	Onlay graft	Not reported	3/13 (23)
Mean		4.13 ± 1.05	45/211 (21.3)
Present investigation	Onlay graft/GBR subsequent to soft tissue expansion	7.5 ± 2.4	1/24 (4)

(range 2.2–5.1 mm) reported in the aforementioned studies after similar healing periods (Table 1) and to data similarly aggregated in a systematic review (mean vertical bone gain: 4.8 mm, incidence of graft expositions: 18.8%; Jensen & Terheyden 2009).

Bone biopsies were investigated with micro-CT (Fig. 6b and c; supporting information Video S1). Three-dimensional micro-CT gives a better estimation of bone regeneration than classical two-dimensional histomorphometry using histologic sections, because the histologic processing results in loss of biopsy material (Muller et al. 1998, Stiller et al. 2009). As microarchitecture reflects bone quality (Majumdar 2003), an appropriate ratio of BV/TV and the distinct trabecular structure found in biopsies of regenerated bone further illustrate the good outcome after vertical bone augmentation subsequent to STE.

In conclusion, our findings demonstrate the feasibility of tissue expansion using osmotic expanders before vertical bone augmentation. STE was accompanied by minimal complications and the incidence of graft expositions after augmentation surgery was very low. The combined treatment resulted in comparably high vertical gain of well-structured bone and may help to further improve the outcome and predictability of implant therapy of patients showing severe bone resorption.

Acknowledgements

We thank Ms Nannette Richter, DMD, for dental care of the patients and Dr Thomas Bauer, MD, DMD (Clinic for Maxillofacial Surgery, Dessau, Germany) for his cooperation. Micro-CTs were kindly provided by Dr. Zully Ritter and Prof. Dr. Dieter Felsenberg, Center for Bone and Muscle Research, Charité – Universitätsmedizin Berlin.

References

Anwander, T., Schneider, M., Gleger, W., Reich, R. H., Appel, T., Martini, M., Wenghoefer, M., Metka, M. & Berge, S. (2007) Investigation of the expansion properties of osmotic expanders with and without silicone shell in animals. *Plastic and Reconstructive Surgery* **120**, 590–595.

Bahat, O. & Fontanesi, F. V. (2001) Complications of grafting in the atrophic edentulous or partially edentulous jaw. *The International Journal of Periodontics & Restorative Dentistry* **21**, 487–495.

Bahat, O. & Handelsman, M. (1991) Controlled tissue expansion in reconstructive periodontal surgery. *The International Journal of Periodontics & Restorative Dentistry* **11**, 32–47.

Barone, A. & Covani, U. (2007) Maxillary alveolar ridge reconstruction with nonvascularized autogenous block bone: clinical results. *Journal of Oral and Maxillofacial Surgery* **65**, 2039–2046.

Bascom, D. A. & Wax, K. A. (2002) Tissue expansion in the head and neck: current state of the art. *Current Opinion in Otolaryngology & Head and Neck Surgery* **10**, 273–277.

Bennett, R. G. & Hirt, M. (1995) A history of tissue expansion. Concepts, controversies, and complications. *The Journal of Dermatologic Surgery and Oncology* **19**, 1066–1073.

Berge, S. J., Wiese, K. G., van Linden, J. J., Niederhagen, B., Appel, T. & Reich, R. H. (2001) Tissue expansion using osmotically active hydrogel systems for direct closure of the donor defect of the radial forearm flap. *Plastic and Reconstructive Surgery* **108**, 1–5, discussion 6–7.

Camullo, L. & Malagnino, V. A. (2008) Vertical ridge augmentation around implants by e-PTFE titanium-reinforced membrane and bovine bone matrix: a 24- to 54-month study of 10 consecutive cases. *The International Journal of Oral & Maxillofacial Implants* **23**, 858–866.

Carroll, W. R. & Esclamado, R. M. (2000) Ischemia/reperfusion injury in microvascular surgery. *Head & Neck* **22**, 700–713.

Chiapasco, M., Romeo, E., Casentini, P. & Rimondini, L. (2004) Alveolar distraction osteogenesis vs. vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans. *Clinical Oral Implants Research* **15**, 82–95.

Chiapasco, M., Zaniboni, M. & Rimondini, L. (2007) Autogenous onlay bone grafts vs. alveolar distraction osteogenesis for the correction of vertically deficient edentulous ridges: a 2–4-year prospective study on humans. *Clinical Oral Implants Research* **18**, 432–440.

Esposito, M., Grusovin, M. G., Felice, P., Karatzopoulos, G., Worthington, H. V. & Coulthard, P. (2009) Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment. *Cochrane Database of Systematic Reviews* **7**, CD003607.

Felice, P., Marchetti, C., Iezzi, G., Piattelli, A., Worthington, H., Pellegrino, G. & Esposito, M. (2009) Vertical ridge augmentation of the atrophic posterior mandible with interpositional block grafts: bone from the iliac crest vs. bovine anorganic bone. Clinical and histological results up to one year after loading from a randomized-controlled clinical trial. *Clinical Oral Implants Research* **20**, 1386–1393.

Fontana, F., Santoro, F., Maiorana, C., Iezzi, G., Piattelli, A. & Simion, M. (2008) Clinical and histologic evaluation of allogeneic bone matrix versus autogenous bone chips associated with titanium-reinforced e-PTFE membrane for vertical ridge augmentation: a prospective pilot study. *The International Journal of Oral & Maxillofacial Implants* **23**, 1063–1072.

Jensen, S. S. & Terheyden, H. (2009) Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials. *The International Journal of Oral & Maxillofacial Implants* **24** (Suppl.), 218–236.

Lew, D., Ames, E. L. & Shuyer, F. V. III (1998) The use of a subperiosteal tissue expander in rib reconstruction of an atrophic mandible. *Journal of Oral & Maxillofacial Surgery* **46**, 229–232.

Lundgren, S., Sjostrom, M., Nystrom, E. & Sennerby, L. (2008) Strategies in reconstruction of the atrophic maxilla with autogenous bone grafts and endosseous implants. *Periodontology 2000* **47**, 143–161.

Majumdar, S. (2003) Advances in imaging: impact on studying craniofacial bone structure. *Orthodontics & Craniofacial Research* **6** (Suppl. 1), 48–51.

McAllister, B. S. & Haghighat, K. (2007) Bone augmentation techniques. *Journal of Periodontology* **78**, 377–396.

McLean, T. N., Smith, B. A., Morrison, E. C., Nasjleti, C. E. & Caffesse, R. G. (1995) Vascular changes following mucoperiosteal flap surgery: a fluorescein angiography study in dogs. *Journal of Periodontology* **66**, 205–210.

Merli, M., Migani, M. & Esposito, M. (2007) Vertical ridge augmentation with autogenous bone grafts: resorbable barriers supported by osteosynthesis plates versus titanium-reinforced barriers. A preliminary report of a blinded, randomized controlled clinical trial. *The International Journal of Oral & Maxillofacial Implants* **22**, 373–382.

Misch, C. E. & Judy, K. W. (1987) Classification of partially edentulous arches for implant dentistry. *The International Journal of Oral Implantology* **4**, 7–13.

Morris, S. F., Pang, C. Y., Zhong, A., Boyd, B. & Forrest, C. R. (1993) Assessment of ischemia-induced reperfusion injury in the pig latissimus dorsi myocutaneous flap model. *Plastic and Reconstructive Surgery* **92**, 1162–1172.

Muller, R., Van Campenhout, H., Van Damme, B., Van Der Perre, G., Dequeker, J., Hildebrand, T. & Ruegsegger, P. (1998) Morphometric analysis of human bone biopsies: a quantitative structural comparison of histological sections and micro-computed tomography. *Bone* **23**, 59–66.

Nakayama, Y., Soeda, S. & Kasai, Y. (1982) The importance of arterial inflow in the distal side of a flap: an experimental investigation. *Plastic and Reconstructive Surgery* **69**, 61–67.

Pietila, J. P. (1990) Tissue expansion and skin circulation. Simultaneous monitoring by laser Doppler flowmetry and transcutaneous oximetry. *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery* **24**, 135–140.

Proussaefs, P. & Lozada, J. (2005) The use of intraorally harvested autogenous block grafts for vertical alveolar ridge augmentation: a human study. *The International Journal of Periodontics & Restorative Dentistry* **25**, 351–363.

Proussaefs, P. & Lozada, J. (2006) Use of titanium mesh for staged localized alveolar ridge augmentation: clinical and histologic-histomorphometric evaluation. *Journal of Oral Implantology* **32**, 237–247.

Proussaefs, P., Lozada, J., Kleinman, A. & Rohrer, M. D. (2002) The use of intraoral autogenous block grafts for vertical alveolar ridge augmentation and implant placement: a pilot study. *The International Journal of Oral & Maxillofacial Implants* **17**, 238–248.

Retzepi, M., Tonetti, M. & Donos, N. (2007) Comparison of gingival blood flow during healing of simplified papilla preservation and modified Widman flap surgery: a clinical trial using laser Doppler flowmetry. *Journal of Clinical Periodontology* **34**, 903–911.

Rocchietta, I., Fontana, F. & Simion, M. (2008) Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review. *Journal of Clinical Periodontology* **35**, 203–215.

Roccuzzo, M., Ramieri, G., Bunino, M. & Berrone, S. (2007) Autogenous bone graft alone or associated with titanium mesh for vertical alveolar ridge augmentation: a controlled clinical trial. *Clinical Oral Implants Research* **18**, 286–294.

Roccuzzo, M., Ramieri, G., Spada, M. C., Bianchi, S. D. & Berrone, S. (2004) Vertical alveolar ridge augmentation by means of a titanium mesh and autogenous bone grafts. *Clinical Oral Implants Research* **15**, 75–81.

Rosen, M. A., Hotheinz, H., Matassa, E., Asgarouladi, H. & Olbrisch, R. R. (2004) The beginning of a new era in tissue expansion: self-filling osmotic tissue expander – four-year clinical experience. *Plastic and Reconstructive Surgery* **114**, 1025–1031.

Rothamel, D., Schwarz, F., Herten, M., Ferrari, D., Mischkowski, R. A., Sager, M. & Becker, J. (2009) Vertical ridge augmentation using xenogeneic bone blocks: a histomorphometric study in dogs. *The International Journal of Oral & Maxillofacial Implants* **24**, 243–250.

Stiller, M., Rack, A., Zabler, S., Goebbels, J., Dalugge, O., Jorcher, S. & Knabe, C. (2009) Quantification of bone tissue regeneration employing beta-tricalcium phosphate by three-dimensional non-invasive synchrotron micro-tomography – a comparative examination with histomorphometry. *Bone* **44**, 619–628.

Stoetzer, C., Rucker, M., Schumann, P., Bormann, K. H., Hanke, Y., Sinikovic, B. & Gellrich, N. C. (2009) Osseous alterations at the interface of hydrogel expanders and underlying bone. *Journal of Craniomaxillofacial Surgery* **37**, 258–262.

Tominaga, K., Matsuo, T., Kuga, Y. & Mizuno, A. (1993) An animal model for subperiosteal tissue expansion. *Journal of Oral & Maxillofacial Surgery* **51**, 1244–1249.

Urban, I. A., Jovanovic, S. A. & Lozada, J. L. (2009) Vertical ridge augmentation using guided bone regeneration (GBR) in three clinical scenarios prior to implant placement: a retrospective study of 35 patients 12 to 72 months after loading. *The International Journal of Oral & Maxillofacial Implants* **24**, 502–510.

Verhoeven, J. W., Cune, M. S., Terlou, M., Zoon, M. A. & de Putter, C. (1997) The combined use of endosteal implants and iliac crest onlay grafts in the severely atrophic mandible: a longitudinal study. *The International Journal of Oral & Maxillofacial Surgery* **26**, 351–357.

Wiese, K. G. (1993) Osmotically induced tissue expansion with hydrogels: a new dimension in tissue expansion? A preliminary report. *Journal of Craniomaxillofacial Surgery* **21**, 309–313.

Wiese, K. G., Heinemann, D. E., Ostermeier, D. & Peters, J. H. (2001) Biomaterial properties and biocompatibility in cell culture of a novel self-inflating hydrogel tissue expander. *Journal of Biomedical Materials Research* **54**, 179–188.

Witkamp, A. R. (1989) Short-term experience with the subperiosteal tissue expander in reconstruction of the mandibular alveolar ridge. *Journal of Oral & Maxillofacial Surgery* **47**, 469–474.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Video S1. Full volume micro-CT scan of a bone core biopsy taken at implant site preparation 4 months after grafting from the posterior ilium (BV/TV 0.237).

Please note: Wiley-Blackwell are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

Address:
Dogan Kaner
Department of Operative Dentistry and Periodontology
CharitéCentrum 3
Charité – Universitätsmedizin Berlin
Allmannshauser Str. 4–6
14197 Berlin
Germany
E-mail: dogan.kaner@charite.de

Clinical Relevance

Scientific rationale for the study: Post-surgical graft exposition and subsequent loss of grafted bone are common complications of vertical ridge augmentation and are attributed to deficient soft tissue. We investigated clinical and histological outcomes and the feasibility of a procedure combining vertical ridge augmentation and preceding STE using self-filling osmotic tissue expanders.

Principal findings: Implantation of tissue expanders was accompanied by minimal complications. After tissue expansion, primary closure at vertical augmentation was easily achieved without further tissue mobilization and the incidence of graft expositions was low. At implant placement, comparatively high vertical gain of well-structured bone was found.

Practical implications: The combination of STE and subsequent vertical ridge augmentation may be considered for implant treatment of patients with severely resorbed edentulous ridges.