Vertical Distraction of the Severely Resorbed Edentulous Mandible: An Assessment of Treatment Outcome

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Purpose: *To assess the treatment outcome (implant survival, surgical complications, patient satisfaction) of vertical distraction of the severely resorbed edentulous mandible.* ***Materials and Methods:*** *Forty-six patients with severe resorption of the edentulous mandible (bone height 5 to 8 mm, median 6 mm) participated in this study. The anterior segment of the mandible was vertically augmented using the Groningen distraction device. One or 2 months after the last day of distraction, 2 implants (n = 92) were placed. Standardized clinical and radiographic assessments were performed annually, and patient satisfaction was scored on a 10-point rating scale (0 = completely dissatisfied; 10 = completely satisfied).* ***Results:*** *Three implants were lost during the healing phase, but none were lost for the rest of the follow-up period (72 ± 10.3 months), resulting in an implant survival rate of 97%. One patient developed a fracture of the mandible 3 days after the last day of distraction; it healed uneventfully. The mean mandibular bone resorption during follow-up as measured on radiographs in the midline and distal of the implants was 9.8% ± 0.6% and 10.2% ± 0.8%, respectively. In 4 patients radiolucency in the distracted area persisted during the follow-up period. Four patients reported a slight sensory disturbance at the final evaluation visit. All patients functioned well with their prostheses. The mean patient satisfaction score after treatment was 8.1 ± 1.2.* ***Conclusion:*** *Vertical distraction of the anterior segment of a severely resorbed alveolar ridge of the mandible can provide a proper basis for insertion and osseointegration of endosseous load-bearing implants with good implant survival, few surgical complications, and good patient satisfaction.* (Case Series) Int J Oral Maxillofac Implants 2008;23: 299–307

Key words: *augmentation, dental implants, distraction osteogenesis, edentulous mandible*

The field of implant dentistry is dynamic, and many clinicians are searching for simple preimplantation surgical procedures that are more convenient for the patient but can still help create optimal circumstances for implant placement. Various augmentation techniques are currently in use to create sufficient bone volume for reliable insertion of endosseous implants in cases where the mandible is severely resorbed.[1] Although these augmentation techniques, which often utilize the iliac crest as a donor site, have realized good results, the procedures require bone transplantation and may cause significant donor site morbidity.[2]

A recent review indicated that temporary pain and gait disturbances were the most frequent complications of bone harvesting from the iliac crest, although long-term pain/gait disturbances were reported in only 2% of cases.[3] In addition, severe bone resorption of the initial onlay bone grafts, ranging from 12% to 60%, has been observed with this technique.[3] Short implants should be considered as an alternative to advanced bone surgery, since bone augmentation surgeries can involve higher morbidity, require extended treatment periods, and mean higher costs for the patient.[4] A recent structured review evaluating short implants placed in the pos-

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terior region of partially edentulous patients demonstrated a trend toward an increased failure rate with short implants, however.[5] With regard to the anterior region of the edentulous mandible, good results have been reported with the application of short implants,[6,7] but in these studies the lower limit of mandibular height allowing for short implants to support mandibular overdentures was set at 8 mm, or the short implants were used to support fixed partial dentures.[8] Finally, from a prosthodontic point of view, it might be unfavorable to place short implants (< 8 mm) because the soft tissues in such cases (eg, high attachment of the muscle sling and level of the floor of the mouth) might interfere with a satisfactory prosthodontic treatment outcome. Thus, for very severely resorbed mandibles, there might be a need for an appropriate reconstructive method other than a conventional augmentation procedure for restoration with implant-supported overdentures.

Case studies have shown the potential applicability of distraction osteogenesis to create sufficient bone volume for reliable insertion of endosseous implants.[9–14] Distraction osteogenesis is a technique of gradual bone lengthening in which the natural healing mechanisms of the human body are used to generate new bone.[15] The Groningen Group developed a nonvoluminous intraosseous distraction device to solve the problem of inadequate bone height for the insertion of endosseous dental implants.[16] Advantages of the Groningen distraction device are its applicability in cases of severe resorption of the mandible (minimum height of 5 mm in the mandibular canine region), the adjustability of the distraction vector, and the fact that the endosseous implants are inserted in the holes from which the distraction screws are removed.

Preliminary studies in animals have resulted in the generation of bone of very good quality, with adequate potential for implant osseointegration.[17–20] In humans growth of lamellar bone parallel to the distraction vector was visible in the distraction gap.[21] The advantages of distraction osteogenesis compared to grafting procedures are the absence of donor site morbidity, the presence of vital bone in the distraction area, and the gradual gain of soft tissues. Possible complications of the distraction technique for the edentulous mandible are fracture of the mandible, infection, necrosis of the superior fragment, and fracture of the distraction device.[22,23] Furthermore, long-term results of distraction of the edentulous mandible have not yet been described. Therefore, the aim of this study was to evaluate the clinical and radiographic long-term results of distraction followed by placement of endosseous implants in the severely resorbed edentulous mandible.

MATERIALS AND METHODS

Patients

The participants in this study had been referred to the Department of Oral and Maxillofacial Surgery of the University Medical Center Groningen by their dentist. Patients were suffering from severe functional problems with mandibular dentures (ie, poor retention and stability of the mandibular denture), and little or no improvement could be expected from making new conventional dentures. The patients had been edentulous in the mandible for 4 to 24 years, resulting in severe resorption of the mandible (Cawood class VI).[24] A routine intraoral and radiographic examination was carried out. The intraoral examination included an evaluation of the quality of the present set of dentures and the condition of the oral mucosa. Radiographic examination consisted of a panoramic radiograph and a standardized lateral cephalogram. Bone height was measured in the symphyseal area. The mandibular height in symphyseal area, as measured on the standardized lateral cephalogram, ranged from 5 to 8 mm (median, 6 mm); thus, augmentation was considered necessary. Informed written consent was obtained from all patients.

Distraction Equipment

The Groningen distraction device (Martin Medizin Technik, Tüttlingen, Germany) is an intraoral device consisting of 2 distraction screws, 2 extensions, and 1 guide screw (Fig 1a). The distraction screw (diameter, 3.0 mm) has threads with a ridge-to-ridge distance of 0.5 mm. The caudal part of the distraction screw has a smooth surface (length, 4 mm), and the top of the screw is hexagonal. The distraction screw can only be placed in the extensions from a caudal direction because of the lack of threads in the caudal part. The design of the distraction screw prevents the risk of accidental loss of the screw into the mouth and/or upper airway system (aspiration). The extension is fixed with titanium screws (diameter, 1.5 mm; length, 5 mm) on the top of the segmented cranial part of the anterior mandible. The guide screw has a threaded caudal part (length, 3 mm; diameter, 2 mm) for fixation in the caudal part of the mandible. Rotation of the distraction screws "activates" the device (Fig 1b). The result is elevation of the cranial bone segment (the transport segment). The transport segment is connected with the extensions to the distraction screws, while the distraction screws themselves keep their position in the caudal part of the mandible.

Surgical Protocol

The surgeries were carried out under general anesthesia. The mandibular ridge between the mental

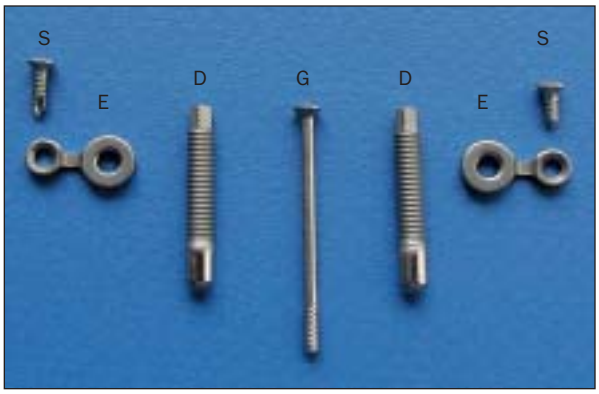


Fig 1a The distraction device consists of 2 distraction screws (D), 2 extensions (E), two 1.5-mm titanium screws (S) for fixation of the distraction screws via the extensions to the segmented cranial part of the anterior mandible, and 1 guide screw (G).

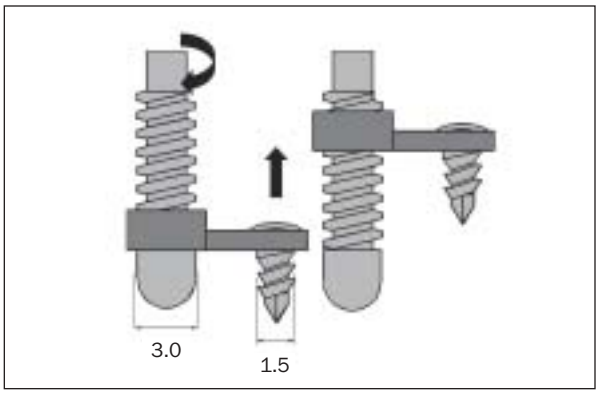


Fig 1b Rotation of the distraction screws results in elevation of the cranial bone segment, which is connected by the extensions to the distraction screws.

foramina, which were carefully localized, was exposed by an interforaminal incision in the buccal fold and the raising of a full-thickness mucoperiosteal flap. In the correct position, sagittal to the opposing occlusion, a vertical hole was made in the midline with a bur, just perforating the basal bone. A direction indicator was placed in the hole. The holes for the distraction screws were prepared 1 cm to the left and right of the midline parallel to the indicator. Care was taken not to perforate the basal cortical bone. These paramedian distraction holes were widened using a standardized bur. Preparation was carried out at high speed, circa 2,000 rpm, with profuse irrigation with sterile saline to prevent overheating of the bone. All sites (distraction screws and guide screw) were parallel with one another. The distraction screws were positioned, and the holes for fixation of the extensions were drilled. Subsequently, all screws were temporarily removed. Lateral to both paramedian holes, but anterior to the mental foramina (minimum distance of 5 mm), vertical cuts were made in the upper third of the mandibular bone with an oscillating saw. These saw-cuts were horizontally connected with an oscillating saw. After all saw-cuts were made, the mobility of the anterior segment was tested. The survival of the transport segment was dependent on the preservation of the lingual mucoperiosteal flap. In the midline the self-tapping guide screw (Martin, Tüttlingen, Germany) was inserted through a small incision in the mucosa. Afterward, the mobility of the transport segment was checked again. Subsequently, 2 Martin distraction screws (Martin, Tüttlingen, Germany), mounted in the extensions were inserted in the paramedian holes through a small incision in the mucosa. Although the distraction screws were only affixed to the cranial fragment (transport segment), their smooth surfaces extended to the nonmobile inferior border of the mandible. This extension to the inferior border was necessary to stabilize the device in the medial-lateral and anterior-posterior directions and to counteract rotational forces. The mobility of the transport segment was checked for the last time by rotating the device to its maximum. Care was taken to preserve the soft tissue pedicle on the lingual surface. The wound was closed in layers. The patient was not allowed to wear a mandibular denture while the distraction device was in place.

The patients received broad-spectrum antibiotics (amoxicillin) intravenously for 48 hours, starting prior to the surgical procedure. Postoperatively, the patients received a 0.2% chlorhexidine mouthrinse for 2 weeks. Distraction was begun 5 days after insertion of the distraction device (1 mm/d). The screws were rotated twice a day. Each revolution represented 0.5 mm cranial movement of the transport segment (Fig 1b). Vertical movement of the transport segment elevated the ridge crest by enlarging the space within the horizontal osteotomy. The space beneath the elevated segment formed the regeneration chamber.

Two months (the first 22 patients; Fig 2) or 1 month (the second 24 patients) after the last day of distraction, the distraction screws were removed, and the area where the implants were to be inserted was placed under local anesthesia. The consolidation time before implant placement was decreased to shorten the overall treatment time. The implants were inserted in the paramedian holes from which the distraction device had been removed after the holes were widened to the required dimensions using the standard burs for the implant system chosen. Finally, the median guide screw was removed. Twelve weeks after implant placement the prosthetic treatment was begun. The patients received new conventional maxillary prostheses and implant-

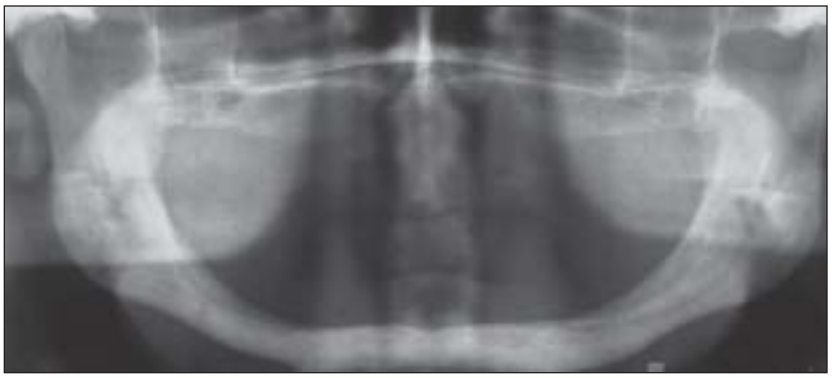


Fig 2 *A 72-year-old female with a severely resorbed mandible. The height of the mandible in the canine region was 6 mm.*

Fig 2a Panoramic radiograph of the extremely resorbed mandible.

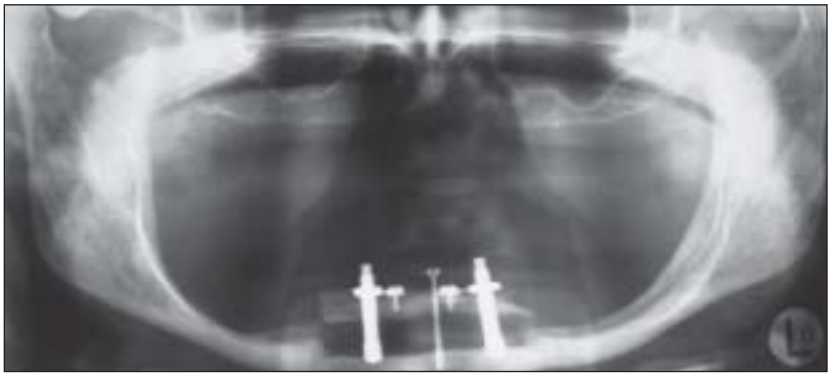
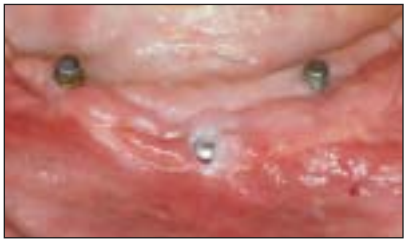


Fig 2b Panoramic radiograph 8 weeks after the distraction period, showing the gain in bone height.



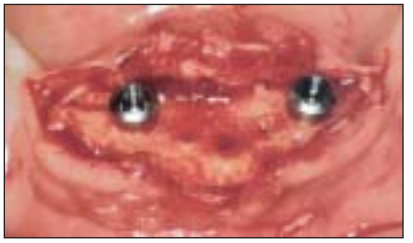


Fig 2c *(Left)* Clinical view of the distraction device after 8 weeks.

Fig 2d *(Right)* Two implants were placed after removal of the distraction device.

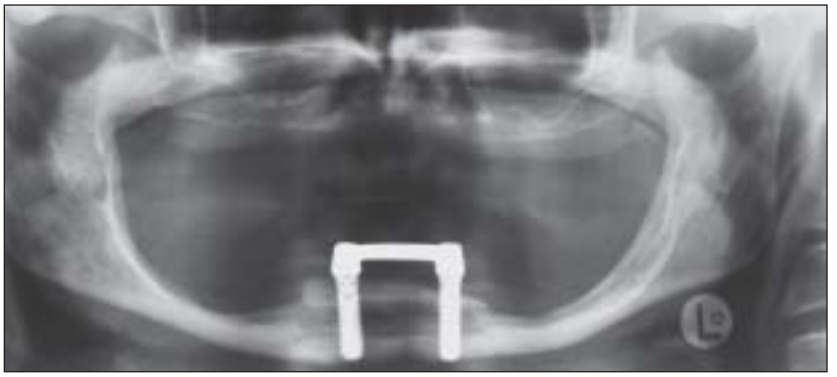


Fig 2e Panoramic radiograph 12 months after delivery of the prosthesis. A slight radiolucency is still visible in the distraction area.

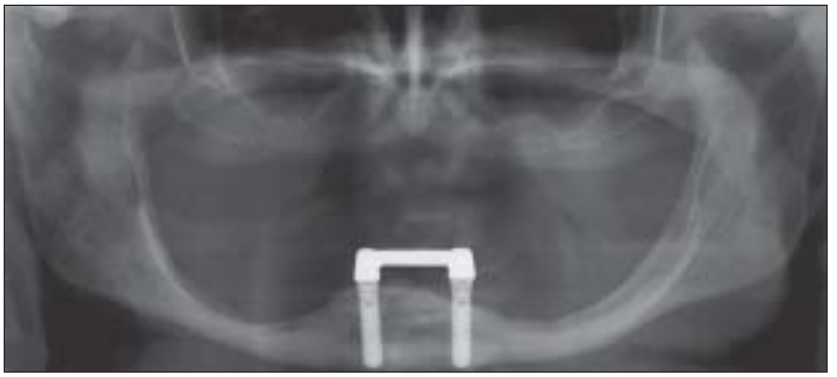


Fig 2f Panoramic radiograph 8 years after delivery of the prosthesis.

retained mandibular overdentures. The overdentures were retained by an ovoid Dolder bar with a clip attachment.

Clinical and Radiographic Examination

All patients were seen for final clinical and radiographic evaluation in 2005, and a questionnaire concerning patient's satisfaction was completed. Patient satisfaction was scored on a 10-point scale ranging from 0 (completely dissatisfied) to 10 (completely satisfied). Sensory changes of lip and chin were noted. In addition, the patient records were reviewed regarding clinical parameters such as inflammation around the screws, loss of distraction screws, and loss of implants.

Because of anatomic limitations periapical radiographs could not be made in all patients (ie, in those with a relatively high level floor of the mouth).[7] Therefore, it was decided to use panoramic radiographs to assess peri-implant bone loss in cases (12 of 46 patients) where standardized periapical radiographs could not be obtained. Since bone loss cannot be assessed as accurately with panoramic radiographs, it was decided to rate peri-implant bone loss using a 4-point rating scale, where 0 indicated no apparent bone loss; 1, < 3 mm of peri-implant bone loss; 2, from 3 to 6 mm of peri-implant bone loss; and 3, > 6 mm of peri-implant bone loss.[25] Moreover, in addition to measurements in the symphyseal area on the standardized lateral cephalograms, the height of the augmented part of the mandible was measured on panoramic radiographs in 3 sites: at the midline and 3 mm distal to each implant. The panoramic radiograph made before the prosthetic procedure was compared with the radiographs obtained at the final evaluation visit (Figs 2a and 2f).

RESULTS

Clinical Results

Notwithstanding the rather low mandibular bone height at the time of surgery (5 to 8 mm in the canine region), all surgical procedures were performed without complications, and few complications were observed thereafter. Wound healing was uneventful, and no problems were observed during the distraction period other than 1 case of wound dehiscence that developed 8 days after surgery. This patient was put on a regimen of rinsing with a chlorhexidine mouthrinse 4 times daily, whereupon the dehiscence healed within 2 weeks. None of the transport segments became necrotic or excessively mobile during the distraction.

In a female patient, a mandibular fracture on the edge of the distraction gap developed 3 days after the last day of distraction (original bone height, 6 mm; increase by distraction, 6 mm; Fig 3). There was a slight mobility of the fractured parts of the mandible. The distraction device was removed, and the patient received instructions not to load the area. The mandibular fracture healed without complications. After 2 months, 2 implants were inserted (Fig 3b). Osseointegration of the implants occurred without complications, and the prosthesis could be fabricated after 2 months.

In 3 patients, the distraction screws used were longer than was needed for the planned increase in bone height. This extension of the distraction screws into the oral cavity during the consolidation phase resulted in a slight loss of distraction height due to backwards rotation of the distraction screws. The patients were urged not to play with the intraorally extending part of the distraction screws. At the time of implant placement, in 4 patients the titanium screw used for fixation of one of the extensions appeared to be mobile.

The increase in bone volume, including the compromised cases (fracture, backwards rotation), was sufficient to insert implants with a length of at least 10 mm in the interforaminal region. The lengths of the implants used were 10 mm (n = 3), 12 mm (n = 63), 13 mm (n = 18), and 14 mm (n = 8). During the osseointegration period, 3 endosseous implants were lost (3 patients). Patients in whom an implant was lost included the patient in whom wound dehiscence occurred. In the same patient the distraction screw had extended a couple of millimeters through the oral mucosa during the consolidation phase. After a healing period of 2 months in all 3 patients a new implant was inserted; this new implant became osseointegrated in all cases. No differences in implant loss or other clinical or radiographic parameters were observed between patients who received their implants 1 month after the last day of distraction and those who received their implants 2 months after the last day of distraction.

Before treatment none of the patients reported sensory disturbances of the mental nerve, while 8 patients reported signs of a disturbed sensitivity of the lip or chin region postsurgery. At the final evaluation, 4 patients still reported a slight sensory disturbance in the distracted region. Objective testing of tactile sensibility (with a cotton pellet) and superficial pain (with a needle) revealed that the symptoms of hypoesthesia could not be confirmed objectively in any of the patients.

No cases of gingival hyperplasia or peri-implantitis were observed during the surgical phase, prosthetic

Fig 3 *A 52-year-old woman with a severely resorbed mandible. The height of the mandible in the canine region was 6 mm.*

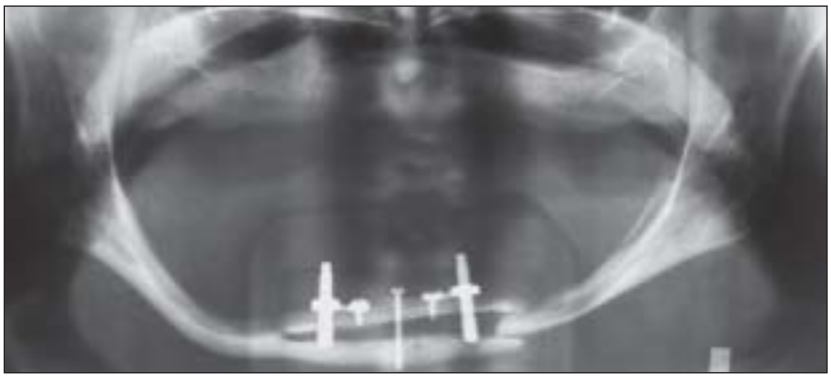


Fig 3a Panoramic radiograph 1 week after the last day of distraction, showing a fracture in the mandible.

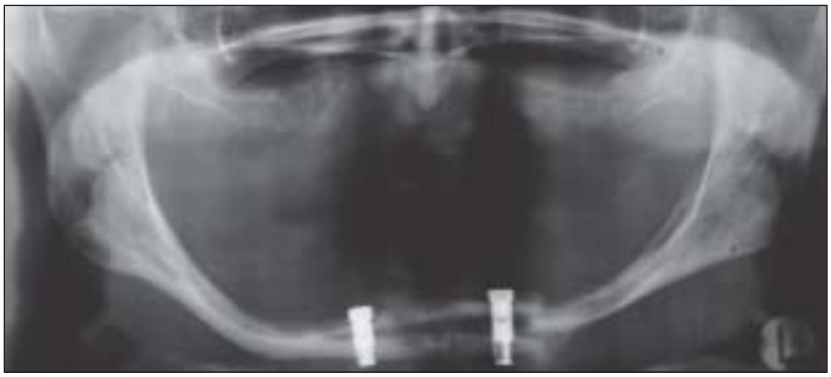


Fig 3b The distraction device is removed. After 8 weeks, 2 implants were placed. Note the callus formation.

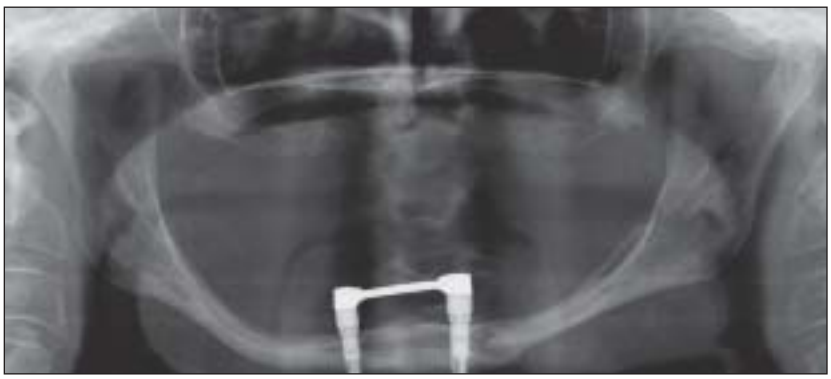


Fig 3c Panoramic radiograph 1 year after delivery of the prosthesis.

phase, or follow-up period. All patients functioned well with their prosthetic restoration. The mean patient satisfaction score was 8.1 ± 1.2.

Radiographic Results

Bone loss was evaluated mesial of and distal to each implant. No apparent bone loss was observed at 164 sites (score 0, 89%). Slight bone loss was seen at 18 sites (score 1, 10%), and serious bone loss was seen at 2 sites (score 2, 1%). No severe bone loss (score 3) was detected.

The height of the augmented mandible was measured at 3 locations: the midline of the augmented segment, 3 mm distal of the lateral implants. Both the height after distraction in the midline and 3 mm distal of the implants were 13.3 ± 0.7 mm (range, 12 to 14 mm). In the midline there was a diminishment in height of 10.2% ± 0.8% (range, 8% to 13%), and distal of the implants there was a diminishment in height of 9.8% ± 0.6% (range, 8% to 12%).

In general, ossification of bone was present in the distraction gap (Figs 2b, 2e, and 2f). In 4 patients a slight radiolucent area was still present at the final evaluation (Fig 4).

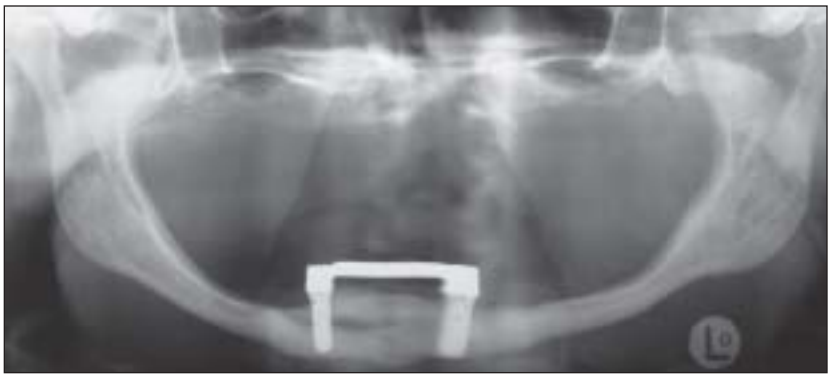


Fig 4 A 48-year-old woman with a severely resorbed mandible. Panoramic radiograph 2 years after delivery of the prosthesis. There is a radiolucent area on the right side of the distraction gap.

DISCUSSION

Vertical distraction of the anterior segment of a severely resorbed alveolar ridge of the mandible can be achieved with the Groningen distraction device, providing a proper basis for insertion and osseointegration of endosseous load-bearing implants. According to the literature, clinicians tend to withdraw distractors as soon as possible to avoid infectious complications and allow early implant placement (ie, before the distraction chamber is completely mineralized).[23] The present study showed that, when using the Groningen distraction device, a consolidation phase of 4 weeks was sufficient to achieve sufficient tissue in the distraction gap to provide primary stability to an implant.

The optimum rate of distraction is a rate that allows for lengthening with bone formation in the distraction gap and a proper soft tissue response. If the distraction rate is too rapid, nonunion will occur, and if it is too slow, premature union will happen.[26] Thus far, a continuous rhythm of distraction is thought to be ideal, with lengthening of approximately 1 mm a day and activation of the distractor 2 times per day.[9,18] In the present day, a rate of distraction of 1 mm/d was used, with distraction beginning 5 days after placement of the distractor. However, the optimum rate of distraction and length of latency before onset of distraction are areas where further research is needed. Moreover, there is a need for consensus regarding the gain in height that is needed for insertion of implants placed to support a mandibular overdenture. Insertion of two 12-mm implants in the mandible is considered sufficient for overdenture treatment in most cases.[27]

As mentioned in the introduction, short implants have been used in the extremely resorbed mandible with good implant survival rates.[7] However, in most studies evaluating treatment outcome in the severely resorbed anterior mandible, implants with a length 8 to 10 mm were placed, while there are very few studies evaluating the treatment outcomes of shorter implants (6 or 7 mm).[8,28] The treatment outcomes of these studies revealed that the placement of short implants in such mandibles might be considered as a good alternative. However, in the present study the height of most mandibles in the symphyseal area was 5 to 6 mm (median, 6 mm), which is at or below the lower limit for reliable placement of short implants in the anterior region of the mandible. Thus, for certain cases, particularly when there are unfavorable conditions of the soft tissues which might interfere with the prosthodontic treatment outcome, there still might be a need for an augmentation or distraction method to create a more favorable condition for both implant and prosthodontic treatment. Thus far, prospective clinical trials are not available comparing the treatment outcome of conventional augmentation procedures and distraction procedures for severely resorbed mandibles (mandibular height < 8 mm). However, the results of this distraction study are comparable to the treatment outcome of a historic patient cohort in whom an augmentation procedure was applied.[7] Implant survival with the distraction method (97%) tended even to be higher than implant survival after augmentation (90%). Finally, Keller[28] stated that short implants can be placed in severely resorbed mandibles when the residual anterior mandible (interforaminal area) is more than 5 mm in height and at least 6 mm in width. Keller[28] also observed, however, that half of the patients in his study had soft tissue problems, such as peri-implant tissue hyperplasia secondary to loose or fractured abutment screws and moveable peri-implant soft tissue. In contrast, the peri-implant tissue in the patient cohort evaluated in the present study was healthy. Short implants are a good treatment option for the severely resorbed mandible, but only in cases where the soft tissue profile does not interfere with the prosthodontic treatment. In patients with an unfavorable soft tissue profile (eg, high attachment of the muscle sling and level of floor of the mouth), a reconstructive procedure should be considered before implant placement.

In the 3 patients who lost some of the height obtained during the consolidation period, the distraction screws extended through the oral mucosa for up to 8 mm. The patients played with the extending part of the distraction screw, which resulted in backward rotation of the distraction screw. In extreme cases this hypothetically could lead to mobility of the distraction screw and a compromised implantation site. To prevent this phenomenon, it is strongly advised to choose distraction screws with a length just sufficient to obtain the needed increase in bone height. The distraction screw should extend into the oral cavity for a maximum of 1 to 2 mm at the end of the distraction period (Fig 2c), and ideally it should be at the level of the oral mucosa. This was the case in the other 43 patients.

At the final evaluation visit, radiographic analysis of the distracted anterior part of the mandible revealed a diminishing of bone height of approximately 10%. Peri-implant bone loss was very moderate. In evaluation of the resorption data, one has to consider that evaluation of peri-implant bone loss was performed on panoramic radiographs when standardized intraoral radiographs could not be made.[25] This approach may have resulted in underestimation of the level of bone resorption. Nevertheless, peri-implant bone loss was shown to be negligible in most cases, suggesting that the level of resorption was comparable to that of implants placed in nonaugmented edentulous mandibles. Moreover, studies describing augmentation procedures using bone onlay procedures report substantially more peri-implant bone loss, up to half of the grafted bone after 10 years.[29] Thus, bone loss after distraction in the present study was substantially less than after onlay procedures in the anterior mandible. One explanation might be that, in contrast to the onlay technique, the distraction technique applied secured the blood supply of the augmented area: the upper part of the mandible is original bone, and the periosteum is lingually attached to this bone fragment.[13]

In comparison with other surgical techniques, distraction osteogenesis also has some disadvantages. The need for absolute compliance of the patient and the family is of utmost importance (for daily rotation of the distraction screws at home), and the need for close and frequent follow-up is obvious. In addition, the patient cannot wear a mandibular prosthesis during the distraction and consolidation phases. Possible complications of the distraction procedure are fracture of the mandible, wound dehiscence, nerve disturbance, osteomyelitis, lack of bone formation, and bone resorption of the superior segment.[14,19,22] Some of these complications may be due to the severely resorbed mandible, with its poor blood supply. None of these complications have occurred with the Groningen distraction device thus far.

Evaluation of the long-term results of the implants and a comparison of the distraction method with other techniques (the use of short implants, augmentation in combination with insertion of implants), and other studies similar to the present study, are needed to determine the treatment of choice for severely resorbed mandibles.

CONCLUSION

Distraction osteogenesis for augmentation of the edentulous mandible resulted in satisfactory clinical and radiographic performance during the follow-up period. Moreover, the morbidity was low, acceptance by the patients was good, and bone harvesting from the iliac crest was not necessary. Thus, the distraction method should be considered as an option for reconstruction of the severely resorbed anterior mandible, particularly in cases where the soft tissues could interfere with the prosthodontic treatment.

REFERENCES

1. Stellingsma C, Vissink A, Meijer HJ, Kuiper C, Raghoebar GM. Implantology and the severely resorbed edentulous mandible. Crit Rev Oral Biol Med 2004;15:240–248.
2. Kalk WWI, Raghoebar GM, Jansma J, Boering G. Morbidity from iliac crest bone harvesting. J Oral Maxillofac Surg 1996;54: 1424–1429.
3. Chiapasco M, Zaniboni M, Boisco M. Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. Clin Oral Implants Res 2006;17:136–159.
4. Das Neves FD, Bernardes SR, do Prado CJ, Neto AJ. Short implants—An analysis of longitudinal studies. Int J Oral Maxillofac Implants 2006;21:86–93.
5. Renouard F, Nisand D. Impact of implant length and diameter on survival rates. Clin Oral Implants Res 2006;17:35–51.
6. Nedir R, Bischof M, Briaux JM, Beyer S, Szmukler-Moncler S, Bernard JP. A 7-year life table analysis from a prospective study on ITI implants with special emphasis on the use of short implants. Results from a private practice. Clin Oral Implants Res 2004;15:150–157.
7. Stellingsma K, Raghoebar GM, Meijer HJ, Stegenga B. The extremely resorbed mandible: A comparative prospective study of 2-year results with 3 treatment strategies. Int J Oral Maxillofac Implants 2004;19:563–577.
8. Friberg B, Grondahl K, Lekholm U, Brånemark P-I. Long-term follow-up of severely atrophic edentulous mandible reconstructed with short Brånemark implants. Clin Implant Dent Relat Res 2000;2:184–189.
9. Chin M, Toth BA. Distraction osteogenesis in maxillofacial surgery using internal devices: Review of five cases. J Oral Maxillofac Surg 1996;54:45–53.
10. Chin M. Distraction osteogenesis for dental implants. Atlas Oral Maxillofac Surg Clin North Am 1999;7:41–63.

11. Hidding J, Lazar F, Zöller JE. Erste Ergebnisse bei der vertikalen Distraktionsosteogenese des atrophischen Alveolarkamms. Mund Kiefer Gesichtschir 1999;3:79–83.
12. Klein C, Papageorge M, Kovács A, Carchidi JE. Erste Erfahrungen mit einem neuen Distraktionsimplantatsystem zur Kieferkammaugmentation. Mund Kiefer Gesichtschir: 1999;3:65–69.
13. Lazar F, Hidding J, Zöller JE. Knöcherne Regeneration des Unterkeiferalveolarfortsatzes mit Hilfe der vertikalen Kallusdistraction. Dtsch Zahnärtzl Z 1999;54:51–54.
14. Gaggl A, Schultes G, Kärcher H. Vertical alveolar ridge distraction with prosthetic treatable distractors: A clinical investigation. Int J Oral Maxillofac Implants 2000;15:701–710.
15. Ilizarov GA. The principles of the Ilizarov method. Bull Hosp Joint Dis Orthop Inst 1988;48:1–11.
16. Raghoebar GM, Heydenrijk K, Vissink A. Vertical distraction of the severely resorbed mandible. The Groningen Distraction Device. Int J Oral Maxillofac Surg 2000;29:416–420.
17. Block MS, Chang A, Crawford D. Mandibular alveolar ridge augmentation in the dog using distraction osteogenesis. J Oral Maxillofac Surg 1996;54:309–314.
18. Block MS, Almerico B, Crawford C, Gardiner D, Chang A. Bone response to functioning implants in dog mandibular alveolar ridges augmented with distraction osteogenesis. Int J Oral Maxillofac Implants 1998;13:342–351.
19. Oda T, Sawaki Y, Ueda M. Alveolar ridge augmentation by distraction osteogenesis using titanium implants: An experimental study. Int J Oral Maxillofac Surg 1999;28:151–156.
20. Oda T, Sawaki Y, Ueda M. Experimental alveolar ridge augmentation by distraction osteogenesis using a simple device that permits secondary implant placement. Int J Oral Maxillofac Implants 2000;15:95–102.
21. Raghoebar GM, Liem RSB, Vissink A. Vertical distraction of the severely resorbed edentulous mandible. A clinical, histological and electron microscopic study of 10 treated cases. Clin Oral Implants Res 2002;13:558–565.
22. Enislidis G, Fock N, Ewers R. Distraction osteogenesis with subperiosteal devices in edentulous mandibles. Br J Oral Maxillofac 2005;43:399–403.
23. Cano J, Campo J, Moreno LA, Bascones A. Osteogenic alveolar distraction: A review of the literature. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:11–28.
24. Cawood JI, Howell RA. A classification of the edentulous jaws. Int J Oral Maxillofac Surg 1988;17:232–236.
25. Meijer HJ, Raghoebar GM, Van't Hof MA, Visser A. A controlled clinical trial of implant-retained mandibular overdentures: 10 years' results of clinical aspects and aftercare of IMZ implants and Brånemark implants. Clin Oral Implants Res 2004;15: 421–427.
26. Davies J, Turner S, Sandy JR. Distraction osteogenesis. A review. Br Dent J 1998;185:462–467.
27. Batenburg RHK, Raghoebar GM, Van Oort RP, Heijdenrijk K, Boering G. Mandibular overdentures supported by two or four endosteal implants. A prospective, comparative study. Int J Oral Maxillofac Surg 1998;27:435–439.
28. Keller EE. Reconstruction of the severely atrophic mandible with endosseous implants: A 10-year longitudinal study. J Oral Maxillofac Surg 1995;53:305–320.
29. Verhoeven JW, Cune MS, Ruijter J. Permucosal implants combined with iliac crest onlay grafts used in extreme atrophy of mandible: Long-term results of a prospective study. Clin Oral Implants Res 2006;17:58–67.