The Extremely Resorbed Mandible: A Comparative Prospective Study of 2-year Results with 3 Treatment Strategies

Kees Stellingsma, DDS[1]/Gerry M. Raghoebar, DDS, MD, PhD[2]/
Henny J. A. Meijer, DDS, PhD[3]/Boudewijn Stegenga, DDS, PhD[2]

Purpose: *The aim of this prospective clinical study was to compare the clinical and radiographic results of 3 modes of implant treatment in combination with an overdenture in patients with extremely resorbed mandibles. The 3 treatment strategies used were a transmandibular implant, augmentation of the mandible with an autologous bone graft followed by placement of 4 endosseous implants, and the placement of 4 endosseous implants only.* ***Materials and Methods:*** *Sixty edentulous patients met the inclusion criteria and were assigned according to a balanced allocation method to 1 of the 3 groups. Postoperative complications, implant survival, periodontal indices, change in mandibular bone height, and prosthetic complications were assessed during a 2-year evaluation period.* ***Results:*** *During the evaluation period significantly more implants were lost in the transmandibular implant and the augmentation groups compared to the group with endosseous implants only. Except for the Bleeding Index and the Periotest values, the periodontal parameters did not differ significantly among the groups. In all 3 groups, there was no significant bone loss at most locations. Minimal prosthetic retreatment was necessary.* ***Discussion:*** *Although implant loss is a frequently used outcome measure for success, the necessity of retreatment seems to be of more relevance for both the patient and the clinician.* ***Conclusions:*** *The results of this study suggested that patients with extremely resorbed mandibles can be treated with implants alone in this patient population.* (More than 50 references.)
INT J ORAL MAXILLOFAC IMPLANTS 2004;19:563–577

Key words: *augmentation, dental implants, edentulous mandibles, overdentures, transmandibular implants*

A substantial percentage of the complete denture–wearing population report shortcomings in the function of their dentures.[1,2] The lack of stability and retention, especially of the mandibular denture, is responsible for the majority of these complaints. Although numerous preprosthetic surgical techniques have been developed to improve the denture-bearing area, it was the widespread use of dental implants that revolutionized prosthetic treatment for edentulous patients.[3] Dental implants can be placed in the edentulous mandible to support a fixed prosthesis or to retain an implant-supported overdenture.[4–6] Because of the relative simplicity, high success rates, and cost-effectiveness of the treatment, the majority of edentulous patients in the Netherlands are treated using 2 to 4 implants in the interforaminal area and an implant-retained mandibular overdenture.[7,8]

This treatment concept, which has been evaluated in several studies,[9–11] can also be applied to patients with extreme resorption of the edentulous mandible. However, only a few studies specifically describe the outcome results of short implants in the interforaminal area of the extremely resorbed mandible.[12–14] Instead of using short implants, augmentation of the extremely resorbed mandible with autologous bone prior to implant placement can

[1]Maxillofacial Prosthodontist, Department of Oral and Maxillofacial Surgery and Maxillofacial Prosthetics, University Hospital, Groningen, The Netherlands.
[2]Oral and Maxillofacial Surgeon, Associate Professor, Department of Oral and Maxillofacial Surgery and Maxillofacial Prosthetics, University Hospital, Groningen, The Netherlands.
[3]Prosthodontist, Associate Professor, Department of Oral and Maxillofacial Surgery and Maxillofacial Prosthetics, University Hospital, Groningen; and Department of Oral Function and Prosthetic Dentistry, Dental School, Faculty of Medical Sciences, University of Groningen, The Netherlands.

Correspondence to: Dr C. Stellingsma, Department of Oral and Maxillofacial Surgery and Maxillofacial Prosthetics, University Hospital Groningen, PO Box 30.001, 9700 RB Groningen, The Netherlands. Fax: +31 50 3611136. E-mail: c.stellingsma@kchir.azg.nl

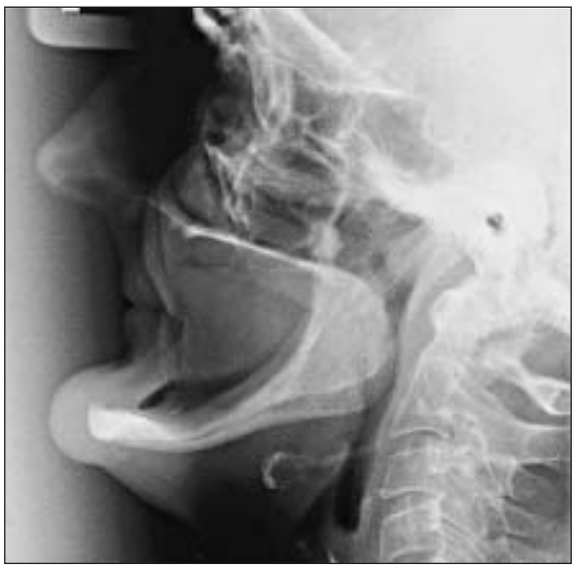

Fig 1 The symphyseal bone height of the mandible was assessed on a lateral radiograph.

restore height of the mandible and make placement of implants of maximal length possible.[15–17] A third option is the transmandibular implant system according to Bosker,[18,19] which was especially developed for the extremely resorbed mandible. These 3 treatment strategies are different in terms of surgical and prosthetic treatment procedures. The aims of this prospective clinical trial were to evaluate and compare clinical outcomes using these 3 implant strategies to treat the extremely resorbed mandible.

MATERIALS AND METHODS

Patient Selection

Edentulous patients with an extremely resorbed mandible and persistent problems with conventional complete mandibular dentures were included in this study. They were referred by general practitioners to the Department of Oral and Maxillofacial Surgery and Maxillofacial Prosthetics of the Groningen University Hospital and screened by an oral and maxillofacial surgeon and a prosthodontist, both with extensive experience in the application of dental implants in patients with persistent problems wearing complete dentures. The criteria for inclusion were:

- The patient had to have been completely edentulous for at least 2 years.
- Mandibular symphyseal height measured on a standardized lateral radiograph had to be between 6 and 12 mm (Fig 1).
- The patient had to have experienced severe functional problems with mandibular dentures, eg, poor retention and stability of the mandibular denture.
- Little or no improvement could be expected from the manufacture of new conventional dentures.
- Patients with a history of radiotherapy in the head and neck region, preprosthetic surgery, or previous oral implants were excluded from the study.

The patients were thoroughly informed about the 3 possible modes of treatment and about study-related procedures associated with the trial (eg, questionnaires, evaluation visits) before they gave their written consent to participate. The study was approved by the Medical Ethical Committee of the University Hospital Groningen.

Study Design and Treatment Procedure

Treatment allocation was made using a balancing procedure to provide for an equal distribution of patients over the treatment groups with regard to age, gender, period of mandibular edentulousness, the number of previous mandibular dentures, the number of years the present mandibular denture had been worn, and the symphyseal bone height of the mandible. A computer program was used for the balanced allocation method of assigning a treatment modality to each patient.[20]

All surgeries were done by 1 experienced oral and maxillofacial surgeon according to protocols that were established in close cooperation with the manufacturers of the implant systems. The prosthetic procedures were performed by 2 experienced prosthodontists following specific protocols for each treatment modality.

Eligible patients were allocated to 1 of the 3 modes of treatment:

- *Group 1:* The 20 patients in group 1 each received a transmandibular implant (TMI) according to Bosker (M+R Haren, Haren, Groningen, The Netherlands) consisting of a baseplate, 4 implant posts, and 5 cortical screws, all made of a gold alloy.[18] The TMI was placed under general anesthesia using an extraoral approach (Fig 2) according to the protocol of Bosker and associates.[21,22] Through the removal of redundant skin and subcutaneous fat and the reconstruction of the facial musculature, the appearance of the lower face can be restored.[23,24] Eight days after the surgery a bar superstructure connecting the 4 implant posts was placed. Patients were advised to follow a soft diet to

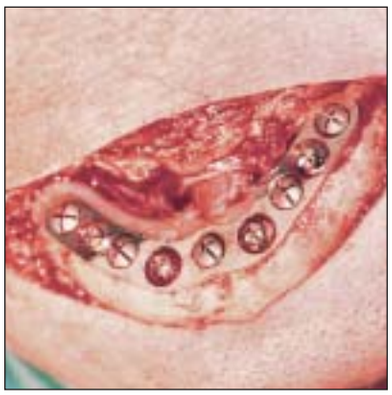

Fig 2 The TMI (group 1) was placed via a submental approach. The baseplate was secured to the inferior border of the mandible by cortical screws; as shown, the implant posts were secured to the baseplate.

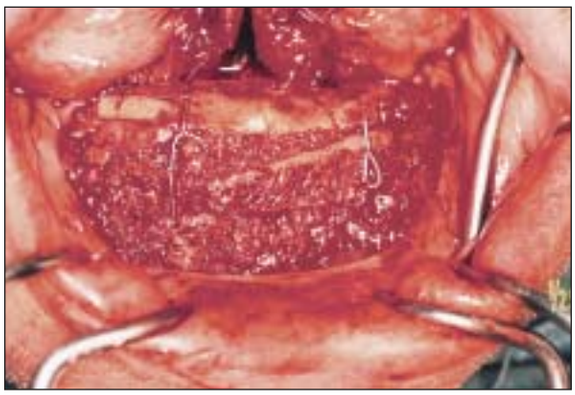

Fig 3 In group 2, the augmentation group, the mandible was sectioned in the interforaminal area, and a corticocancellous bone graft taken from the anterior ilium was positioned between the 2 segments.

Table 1 No. of Implants of Each Length by Treatment Group

	Length (mm)						
Group	8	10	11	12	13	15	18
1	8	16	—	56	—	—	—
2	—	—	—	—	8	52	20
3	56	—	24	—	—	—	—

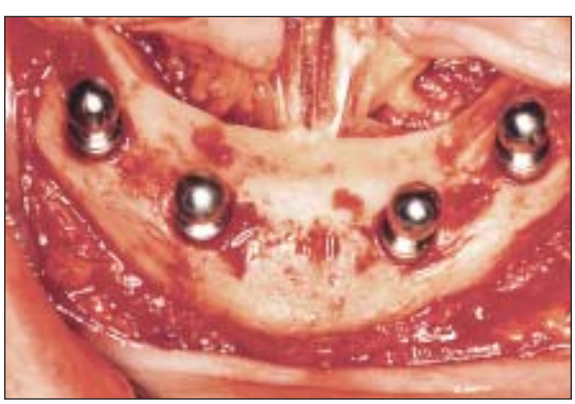

Fig 4 In group 3, four 8-mm implants were placed in the interforaminal area.

minimize loading of the implant system. Three months after placement of the TMI, the prosthodontic treatment began.

- *Group 2:* In the 20 patients in group 2, the mandible was augmented using an autologous bone graft from the iliac crest. This procedure was performed under general anesthesia. The bone graft was placed using the interpositional technique (Fig 3) described by Stellingsma and associates.[15] After 3 months, the osteosynthesis wires were removed, and 4 IMZ apical screw-type implants (Friadent, Mannheim, Germany) were placed under local anesthesia in the interforaminal region. Three months after implant placement, second-stage surgery was performed under local anesthesia. Prosthodontic treatment was started 2 weeks after abutment connection.
- *Group 3:* In the 20 patients in group 3, four 8- or 11-mm Twin Plus IMZ implants (Friadent) were placed in the interforaminal region under local anesthesia (Fig 4) using the surgical procedure previously described by Stellingsma and colleagues.[13] Three months after implant placement, second-stage surgery was performed under local anesthesia. Prosthodontic treatment was started 2 weeks after the abutment connection.

Length of the implants used in the 3 treatment groups is presented in Table 1.

Prosthodontic Treatment

In group 3 the existing mandibular denture was readapted 3 weeks after surgery with a soft liner (Coesoft; Coe Laboratories, Chicago, IL), so the patients were able to wear the mandibular denture during the osseointegration period. In groups 1 and 2 the mandibular denture could not be adjusted because of, respectively, the presence of a superstructure or extensive change in the denture-bearing area.

Patients with the IMZ implant system (groups 2 and 3) were treated with an overdenture supported by an egg-shaped triple bar with a Dolder-clip

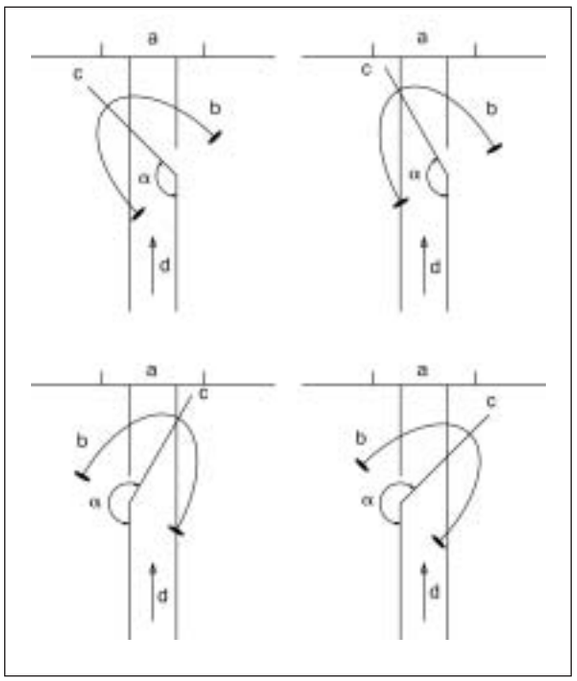

Fig 5 Oblique lateral radiographs made in 4 positions: *(Top left)* right lateral part (135 degrees); *(Top right)* right frontal part (150 degrees); *(Bottom left)* left frontal part (210 degrees); and *(Bottom right)* left lateral part (225 degrees). a = the film; b = the mandible; c = the midsagittal plane; d = the central x-ray beam; α = the angle between the midsagittal plane and the central x-ray beam.

retention system (Cendres et Métaux, Biel-Bienne, Switzerland). The bar superstructure was not provided with cantilever extensions. In case of the TMI system (group 1) an overdenture with 5 clips was fabricated on a bar superstructure (Cendres et Métaux), according to the protocol established in close cooperation with the implant system manufacturers. In contrast to the IMZ implant system, the bar was placed 8 days after implant placement. The bars between the posts were U-shaped, and 5-mm egg-shaped cantilever extensions were used.

In all groups, the overdenture was fabricated after a 3-month osseointegration period. According to the protocol, the edentulous base areas in the TMI group were relieved for 3 to 4 mm to allow possible bone growth distal to the posts. The available space was checked every 3 months during the follow-up period using silicone impression paste (FitChecker; GC Dental, Tokyo, Japan). All patients received a new maxillary denture. The lingualized occlusion concept, using porcelain teeth, was used.[25] All patients were subjected to a strict oral hygiene program.

Data Collection

Postoperative complications, implant survival, and prosthetic complications were recorded from the time of surgery until 2 years after placement of the new prostheses. Periodontal indices and radiographic evaluation were assessed after placing the new dentures (T0), 12 months later (T12), and 24 months later (T24). The periodontal indices included the following parameters: Plaque Index,[26] Bleeding Index,[26] Gingival Index,[27] probing depth, and implant mobility. Probing depth was not measured in group 1 at the insistence of the manufacturer of the TMI system. The depth of the peri-implant "sulcus" was measured distally, labially, mesially, and lingually to the nearest millimeter using a periodontal probe (Merrit B; Hu-Friedy, Chicago, IL) after removal of the bar. The distance between the gingival margin and the tip of the pocket probe was considered the probing depth. For each implant, the deepest pocket was used for data analysis. Mobility of implants (without the bar in place) was quantitatively determined by the Periotest.[28]

The oblique lateral radiographic technique has been used to determine resorption patterns of the edentulous mandible and to study bone (re)modeling processes following the placement of dental implants.[29,30] It is a linear technique with minimal geometric errors.[31,32] Provided the recording technique is clinically standardized, geometric errors are constant in time, which enables longitudinal comparison of mandibular bone height on subsequent radiographs. With this technique it is possible to evaluate bone conditions in the vicinity of the implants as well as in areas distant to the implants. For these reasons the oblique lateral technique was used to evaluate mandibular bone height. At the start of prosthetic loading (T0), 4 oblique lateral radiographs were made to depict the lateral and frontal parts of the mandible.[32] Starting at an angle of 135 degrees between the midsagittal plane of the mandible and the central x-ray beam to depict the right lateral part, the patient was subsequently rotated at angles of 150, 210, and 225 degrees to depict the right frontal, left frontal, and left lateral parts of the mandible, respectively (Fig 5). This procedure was repeated after 12 and 24 months.

All radiographs were made in the same cephalostat (Orthophos; Siemens, Bensheim, Germany) at 60 kV and 0.9 mA. For each patient the optimal exposure time and the individual settings were recorded and repeated on subsequent occasions. The films were automatically processed in a Kodak RP X-Omat M5 processor (Eastman-Kodak, Rochester, NY).

The patient was seated in the cephalostat in a standardized way. Earpins and nose fixation helped to stabilize the position of the patient's head. The positioning of the mandible was enhanced using an individually prepared intraoral resin template (made

Fig 6a Template made for the maxilla. The extension to the superstructure in the mandible can be seen.

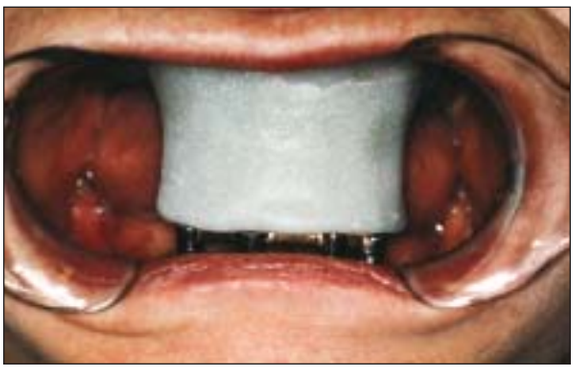

Fig 6b Intraoral view of the template in situ. The superstructure can occlude in only one way to the template, ie, in centric relation in the vertical dimension in which the overdenture was fabricated.

of a light-curing resin during fabrication of the overdenture) that was fabricated so that the superstructure (and thus the mandible) occluded in only 1 reproducible way (Fig 6). By making 4 exposures using the oblique projection technique, it was possible to determine the bone height of the frontal and lateral part of the edentulous mandible (Fig 7).

Bone height was assessed at the following anatomic landmarks.

Group 1 (13 locations):

- Locations 1 and 13: Five millimeters posterior to the distal cortical screw (parallel to the long axis of the lateral implant), right and left, respectively
- Locations 2 and 12: Above the distal cortical screw (parallel to the long axis of the lateral implant), right and left, respectively
- Location 7: Above the median cortical screw
- Locations 3 to 6: On the mesial and distal sides of the right lateral and right frontal implants
- Locations 8 to 11: On the mesial and distal sides of the left frontal and left lateral implants

The mesial/distal bone height was defined as the distance between the baseplate and the marginal bone level at the mesial/distal side of the implant.

Groups 2 and 3 (12 locations):

- Locations 1 and 2: Ten millimeters and 5 mm posterior to the lateral implants, respectively, parallel to the long axis of the lateral implant, on the right
- Locations 12 and 13: Ten millimeters and 5 mm posterior to the lateral implants, respectively, parallel to the long axis of the lateral implant, on the left
- Locations 3 to 6: On the mesial and distal sides of the right lateral and right frontal implants
- Locations 8 to 11: On the mesial and distal sides of the left frontal and left lateral implants

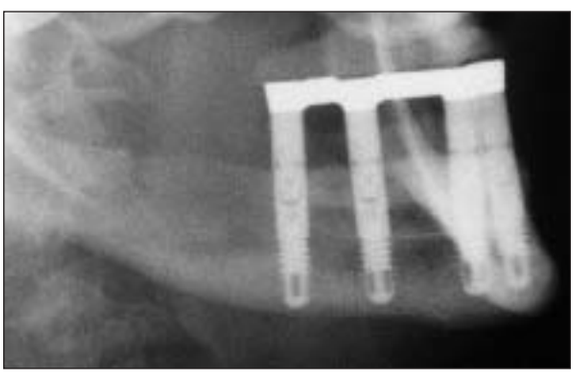

Fig 7 An oblique lateral radiograph of the left lateral part of the mandible of a patient in group 2 at T0.

The mesial/distal bone height was defined as the distance between the apex of the implant and the marginal bone level at the mesial/distal side of the implant.

The measurements were made using a specially made transparent template in which a millimeter ruler was engraved. In this way, bone height could be measured in a reproducible manner in all instances, ie, at fixed distances from, and parallel to, an implant (Fig 8). Distances were assessed to the nearest 0.5 mm. Each point was measured twice by 2 different observers, and measurement was repeated 3 weeks after the initial measurements were made to assess interobserver and intraobserver variability.

Data Analysis

Survival of the implants and surgical retreatment in the 3 groups were analyzed using life table analysis and the log-rank test. Qualitative data were analyzed using the Kruskal-Wallis analysis of variance (ANOVA) between the 3 groups. The Friedman test was used to assess the course of clinical parameters during the evaluation period (T0 to T24) within the

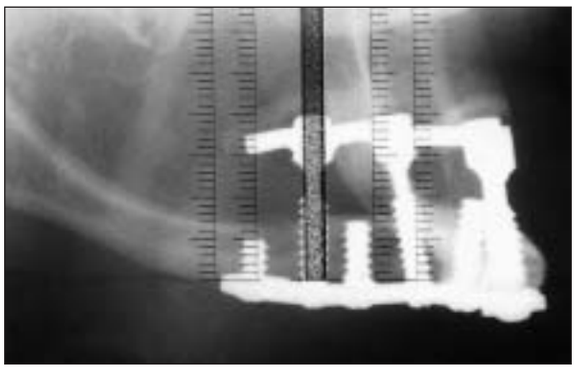

Fig 8 An oblique lateral radiograph of the left lateral part of the mandible of a patient in group 1 with special transparent ruler in place. The bone right above the lateral cortical screw and 5 mm posterior to this screw can be assessed.

groups. To evaluate possible differences between the groups with regard to normally distributed quantitative variables, a 1-way ANOVA was performed; in case of 2 groups, independent *t* tests were performed. When the criteria for using parametric tests were not fulfilled, the Kruskal-Wallis ANOVA, the Mann-Whitney test (independent data), or the Friedman test (dependent data) was applied.

Regarding radiographic evaluation, intraobserver differences were calculated by determining the difference between the first and the second measurements of each pair of data. Interobserver differences were calculated by determining the difference between the first set of measurements made by the 2 observers. The 95% confidence interval (CI) of the mean difference was determined. The statistically significant change between independently obtained measurements, also known as the smallest detectable difference (SDD), was calculated for the 13 locations in the mandible and for the 2 observers for each treatment group.[33]

Changes in radiographic parameters within the groups during the evaluation period were evaluated with the Friedman test. Between-group results were analyzed with 1-way ANOVAs, followed by multiple comparison tests (according to Tukey) in case of significant result. In all analyses, a significance level of .05 was used. Statistical analysis was performed using Statistical Package for the Social Sciences (version 10.0 for Windows; SPSS, Chicago, IL).

RESULTS

The study sample consisted of 60 individuals (50 women and 10 men) with a mean age of 59.4 ± 11.0 years. They had been edentulous for an average of 28.9 ± 10.0 years. The last denture was most frequently their third denture (range 1 to 5 previous dentures) and had been functioning for 6.4 ± 5.8 years. The mean jaw height measured in the symphyseal area on a standardized lateral cephalometric radiograph was 9.7 ± 1.4 mm. The pretreatment characteristics of the 3 groups are summarized in Table 2. Three months after placement of the new dentures, 2 patients had dropped out; 1 patient (group 3) had died, and 1 patient (group 2) had moved out of the region and was lost to follow-up. It was assumed that the dropouts left the study for reasons unrelated to the treatment, and these 2 patients were excluded from the study. Thus, 58 patients were available for evaluation.

The mean hospitalization period for group 1 patients was 3.4 days (range 2 to 5; SD 0.9), which was significantly shorter (independent *t* test, $P < .05$) than the mean for patients in group 2 (5.9 days; range 3 to 9; SD 1.3). All the patients in group 3 were treated in an outpatient clinic setting.

Postoperative Complications and Implant Survival

In the transmandibular group (group 1), 1 implant post failed to osseointegrate in the healing phase and was replaced. At the 1-year follow-up visit, 4 implant posts in 1 patient were found to have lost integration. The TMI was removed shortly thereafter, and the patient was retreated.

In the augmentation-followed-by-implants group (group 2), 1 patient developed a sublingual edema postoperatively, which had to be treated by reintubating the patient in the intensive care unit for 3 days. Two patients had wound dehiscence in the grafted area, which was treated conservatively by debridement, wound closure, and application of 0.2% chlorhexidine mouthwash. Four patients each lost 1 implant during the healing phase. It was decided to use the remaining 3 implants for fabrication of the superstructure. One patient lost all 4 implants during the healing phase and was retreated.

In group 3 (implants alone) 1 patient was treated for bleeding after implant placement. In this group no implants were lost during the evaluation period.

There was a significant intergroup difference (log-rank test, $P < .05$) in implant survival: significantly more implants were lost in groups 1 (5 implant posts lost, 2 retreatments) and 2 (8 implants lost, 1 retreatment) than in group 3 (no implants lost, no retreatments). With respect to surgical retreatment there were no significant differences between the 3 treatment groups after a 2-year follow-up period (log-rank test, $P > .05$). A life table

Table 2 Characteristics of the Patient Population, Classified by Treatment Modality

	Group 1 (n = 20)			Group 2 (n = 20)			Group 3 (n = 20)		
	N	Range	SD	N	Range	SD	N	Range	SD
Mean age (y)	59.4	39 to 78	12.0	57.4	42 to 74	10.0	61.4	43 to 81	11.4
Gender									
Male	3			4			3		
Female	17			15			16		
Mean edentulous period (y)	29.6	5 to 50	11.9	20.8	15 to 40	7.1	30.1	15 to 54	9.9
Median no. of mandibular dentures	3	1 to 5		3	1 to 4		3	1 to 6	
Age of last mandibular denture (y)	6.0	1 to 15	4.5	8.3	1 to 20	5.7	5.0	1 to 31	6.7
Mean jaw height (mm)	9.7	7 to 12	1.4	9.5	6 to 12	1.6	9.8	7 to 12	1.4

Group 1 = patients received TMIs; group 2 = patients received autologous bone grafts prior to implant placement; group 3 = patients received conventional implants alone.

Table 3 Life Table Analysis of Implant Survival and Surgical Retreatment

	Implants					Patients	
Time	No. in function	No. failed	No. withdrawn	Survival rate (%)	CSR (%)	No. retreated	CRR (%)
Group 1							
0 to 6 mo	80	1	0	98.75	98.75	1	5
6 mo to 1 y	79	4	0	94.94	93.75	1	10
1 to 2 y	75	0	0	100.00	93.75	0	10
Group 2							
0 to 6 mo	80	8	0	90.00	90.00	1	5
6 mo to 1 y	72	0	4	100.00	90.00	0	5
1 to 2 y	68	0	0	100.00	90.00	0	5
Group 3							
0 to 6 mo	80	0	0	100.00	100.00	0	0
6 mo to 1 y	80	0	4	100.00	100.00	0	0
1 to 2 y	76	0	0	100.00	100.00	0	0

CSR = cumulative survival rate; CRR = cumulative retreatment rate.

analysis of implant survival and surgical retreatment is presented in Table 3.

Before treatment none of the patients reported sensory disturbances of the mental nerve. After treatment 2 patients in group 1 reported dysesthesia (bilateral in 1 case, unilateral in the other), as did 2 patients in group 2 (unilateral in both cases). One patient in group 3 reported unilateral hypoesthesia of the lip and chin area. During the follow-up period 1 of the group 2 patients reported complete recovery of normal sensibility. Objective testing of tactile sensibility (by a cotton pellet) and superficial pain (by a needle) revealed that the symptoms of hypoesthesia could be confirmed objectively in the group 3 patient.

Periodontal Indices

Frequency distributions of the probing depth and Plaque, Gingival, and Bleeding Indices are presented in Figs 9 to 12. Significant differences between the groups with regard to bleeding scores were found at T0, T12, and T24 (Kruskal-Wallis ANOVA, $P < .05$). Regarding Plaque and Gingival Index scores, no significant differences existed between the 3 groups (Kruskal-Wallis ANOVA, $P > .05$). The difference in probing depth between groups 2 and 3 was not significant (Mann-Whitney test, $P > .05$). During the evaluation period, the probing depth as well as the Bleeding, Plaque, and Gingival Index scores improved or did not deteriorate significantly (Friedman test, $P > .05$). This was consistent in all 3 treatment groups.

Periotest values (PTVs) for all implants ranged from –8 to 46 (Table 4). At T0, there was a significant difference between the 3 groups (ANOVA, $P < .05$). Higher PTVs were reported in group 1 than in group 2; the lowest PTVs were reported in group 3 (multiple comparison test, $P < .05$). During the evaluation period, the PTVs in group 2 improved significantly (paired independent t tests, $P < .05$), while the PTVs in groups 1 and 3 did not change significantly (paired t tests, $P > .05$). In all 3 treatment groups the

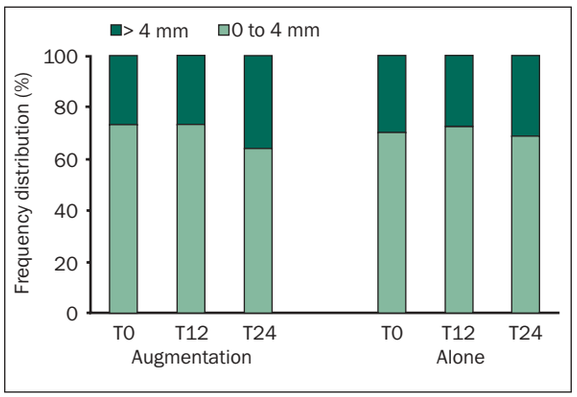

Fig 9 Frequency distribution of the pocket probing depths of groups 2 and 3 at T0, T12, and T24.

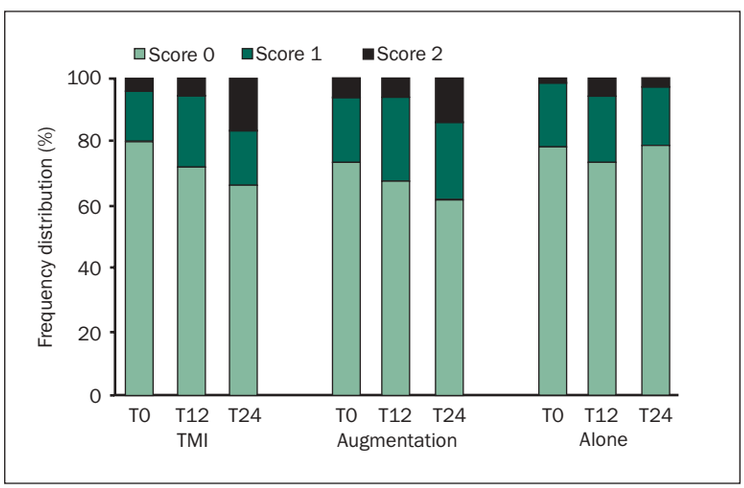

Fig 10 Frequency distribution of Plaque Index scores at T0, T12, and T24. A score of 0 meant no plaque; 1, plaque detected by running a probe across the implant or abutment; 2, plaque was visible to the naked eye; and 3, an abundance of plaque.

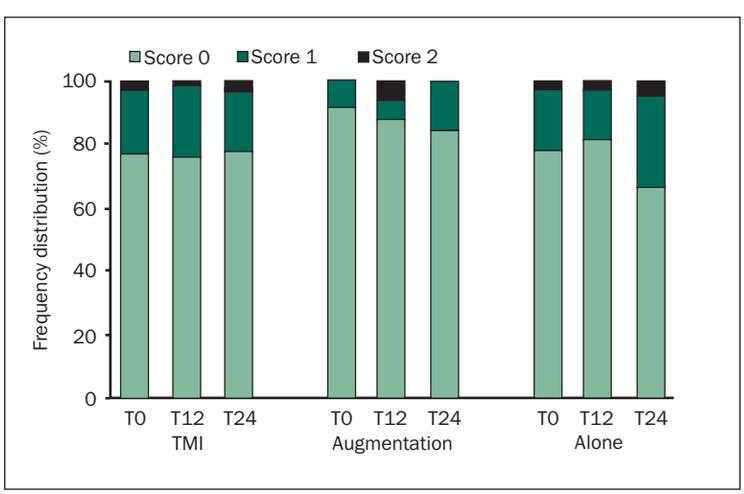

Fig 11 Frequency distribution of the Gingival Index scores at T0, T12, and T24. A score of 0 indicated normal peri-implant mucosa; 1, mild inflammation; 2, moderate inflammation; and 3, severe inflammation.

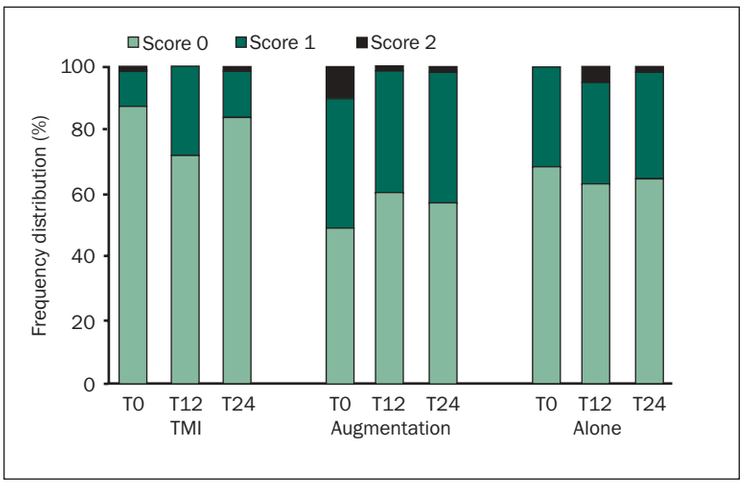

Fig 12 Frequency distribution of the Bleeding Index scores at T0, T12, and T24. A score of 0 indicated no bleeding after probing; 1, isolated bleeding spots; 2, a confluent line of blood; and 3, heavy or profuse bleeding.

Table 4 Mean PTVs of the Treatment Groups at T0, T12, and T24

	Group			
	1	2	3	Significance
T0	6.1	–2.8	–4.5	1 > 2 > 3
T12	6.3	–3.8	–4.7	1 > 2 > 3
T24	5.8	–4.4	–4.6	1 > 2 = 3
Significance	T0 = T12 = T24	T0 > T12 > T24	T0 = T12 = T24	

–8 = minimal mobility; 50 = maximal mobility.

PTVs of the lateral and medial implants did not differ significantly (independent *t* tests, $P > .05$).

Radiographic Evaluation

The mean of the differences of the repeated measurements for observer 1 was 0.16 mm, with 95% CI limits of 0.06 and 0.26 mm. For observer 2, the mean of the differences was 0.20 mm (95% CI 0.06 to 0.35 mm). The mean of the interobserver differences was 0.27 mm (95% CI 0.15 to 0.40 mm). The SDD varied from 0.4 mm (observer 2, location 1, group 2) to 0.9 mm (observer 1, location 9, group 2). The mean of the SDD values of both observers was 0.55 mm (95% CI 0.51 to 0.61 mm).

During the evaluation period, a significant decrease in the mean bone height at the mesial and distal aspects was detected at the right frontal implant (locations 5 and 6) in group 1 (Friedman test, $P < .05$). The decrease in the mean bone height observed at the mesial and distal aspects of the other 3 implants during the evaluation period was not significant (Friedman test, $P > .05$). The increase in the mean bone height (up to 0.6 mm) that occurred during the evaluation period distal to the lateral implants in 4 locations was significant (Friedman test, $P < .05$) for the 2 locations above the distal cortical screw (locations 2 and 12). The mean bone height above the median cortical screw did not change significantly (Friedman test, $P > .05$).

In group 2 there was a significant decrease (up to 0.9 mm) in the mean bone height at the 4 locations distal to the lateral implants (Friedman test, $P < .05$). The mean bone height at the mesial and distal aspects of the 4 implants decreased up to 0.6 mm (Friedman test, $P < .05$) at 3 locations (locations 3, 8, and 10). The mean bone height at the other 5 locations (locations 4, 5, 6, 9, and 11) did not change significantly (Friedman test, $P > .05$).

The mean bone height at the mesial and distal aspects of the implants in group 3 did not change significantly during the evaluation period (Friedman test, $P > .05$). The increase in bone height (up to 0.8 mm) observed during the evaluation period at the 4 locations distal to the lateral implants was only significant for location 1 (Friedman test, $P < .05$). The results of the 3 treatment groups are presented in Fig 13.

Differences in bone height between the 3 groups were not significant in the evaluation period (ANOVA, $P > .05$) for 7 locations at the mesial and

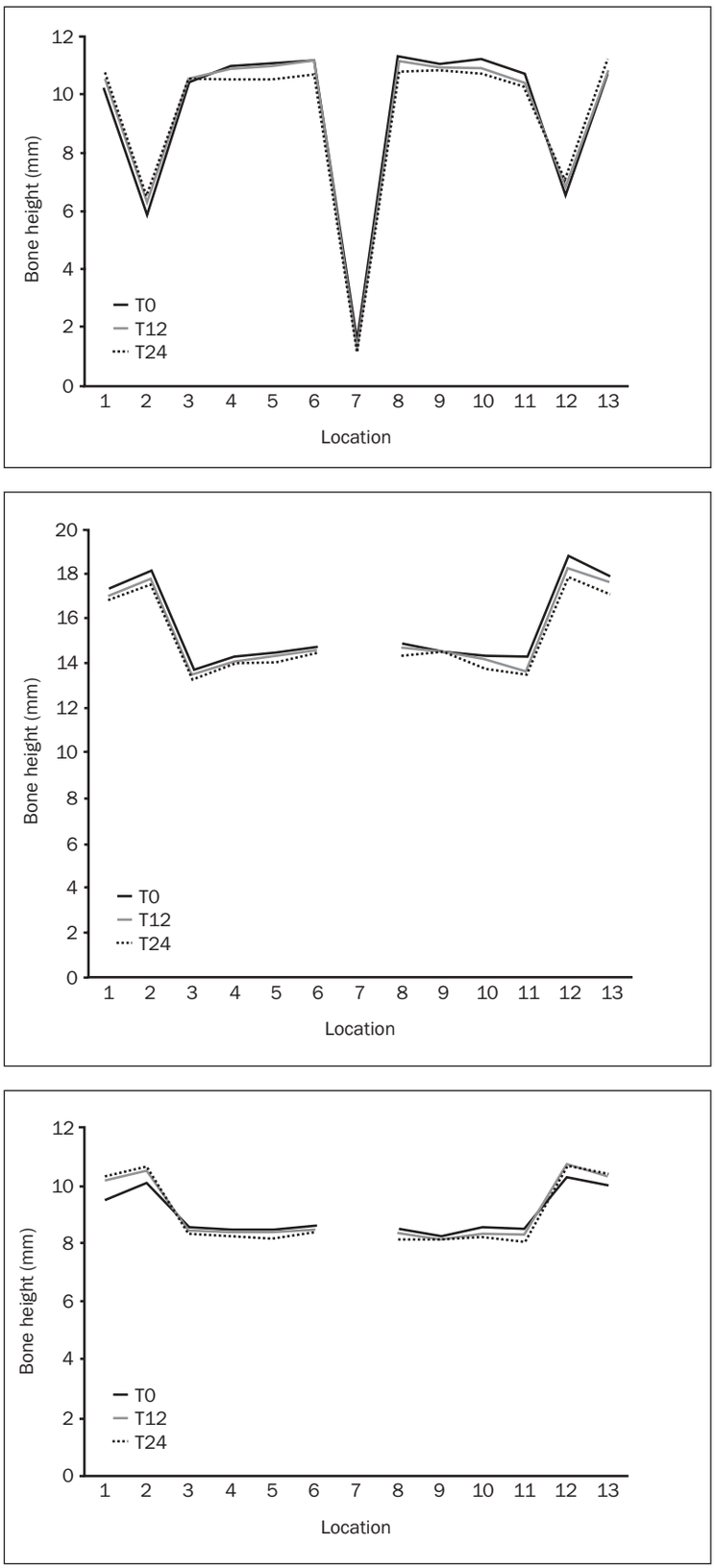

Fig 13 Bone height in at T0, T12, and T24 in *(top)* group 1, *(center)* group 2, and *(bottom)* group 3.

distal aspects of the implants. At the distal aspect of the left lateral implant the differences between the 3 groups were significant (ANOVA, $P < .05$); a post hoc Tukey test revealed significant differences ($P > .05$) for group 2 versus groups 1 and 3.

At the 4 locations distal to the lateral implants there were significant differences (ANOVA, $P < .05$) between the 3 groups. Post hoc tests revealed significant differences (Tukey test, $P < .05$) for group 2 (decrease of bone height) versus groups 1 and 3 for all 4 locations.

Prosthetic Complications

Prosthetic complications encountered during the 2-year evaluation period are presented in Table 5.

Table 5 Prosthetic Aftercare During the Evaluation Period, Classified to Treatment Modality

	Group			
	1	2	3	Total
Repair denture base/teeth	1	4	0	5
Adjustment/repair bar	4	3	1	8
Readjustments occlusion	1	1	2	4
New retention clip(s)	0	1	0	1
Relining mandibular overdenture	1	0	1	2
Relining maxillary denture	0	1	0	1
Remake mandibular overdenture	2	0	0	2
Remake maxillary overdenture	1	0	0	1

DISCUSSION

Three mandibular overdenture strategies used to treat the extremely resorbed mandible were compared. During a prospective clinical trial, serious postoperative complications such as life-threatening sublingual edema were seen in the augmentation group (group 2). The protocol used for this group necessitated 2 wound areas (the mandible and the iliac crest), each with its own specific morbidity,[34] which made hospitalization and treatment under general anesthesia necessary. Although placement of a TMI took place under general anesthesia as well, major postoperative complications were not encountered, and the hospitalization period was significantly shorter. Placement of a TMI is possible in a single day even under local anesthesia, but in this study an inpatient procedure was preferred to ensure optimal pre- and postoperative care. All patients in group 3 could be treated in an outpatient clinic setting under local anesthesia. Only relatively minor complications (ie, subsequent bleeding) were experienced, which makes this modality an attractive option, especially in an older population, which is more likely to include patients with systemic diseases and in whom general anesthesia for elective surgery is unwarranted.

Although the mental foramina were always identified in all 3 types of operation, postsurgical sensory disturbances of the mental nerve were seen in 5 patients (8%). In these patients, there was a partial sensory disturbance of the mental nerve, suggesting prolonged tension or pressure on the nerve bundle during or following the operation, a complication that has been reported in other studies.[35,36]

During the evaluation period, significantly more implants were lost in groups 1 (TMI) and 2 (augmentation) than in group 3 (implants alone). In group 2, 8 implants were lost in the healing phase, 4 of which were lost in 1 patient, possibly due to necrosis of the osteotomized cranial fragment of the mandible. This illustrates that adaptation of the graft and circulation in the augmented mandible are essential. Especially in the extremely resorbed mandible, where there is hardly any cancellous bone in the interforaminal area, the blood supply is jeopardized, which compromises successful integration of the graft, especially in certain situations.[37] In group 1, 1 implant post was lost during the healing phase, possibly due to thermal trauma during preparation of the implant site; this patient was retreated. Four implant posts in 1 patient were found to be mobile during the 1-year follow-up visit and had to be removed. This patient was known to nocturnally grind and clench, but could not be persuaded not to wear her mandibular and maxillary dentures during the night. This could be the cause of loss of osseointegration of the 4 implant posts.

From other studies it is known that relatively short implants can be applied in the extremely resorbed mandible. The healing period is the most critical factor for long-term survival of the implants.[13,38] Because of the dense cortical structure of the bone in the interforaminal area of the extremely resorbed mandible, overheating of the bone during preparation of the implant site can easily take place, thus undermining the potential for successful integration of endosseous implants. Although the placement of 4 endosseous implants in the interforaminal area of an extremely resorbed mandible seems like a relatively simple surgical procedure, especially in this type of bone, the use of sharp instruments and delicate surgical handling of the oral tissues are prerequisites for successful implant osseointegration. In the subsequent evaluation period none of the implants were lost, which has also been reported in other studies.[13,14]

A major disadvantage of the TMI system is that if an individual implant post is lost, surgical retreatment is necessary, because the system, 4 implant

posts connected to a baseplate, is designed to act as a rigid box frame.[22] By contrast, in protocols such as those used for groups 2 and 3, loss of an individual endosseous implant in most cases does not preclude continuation of the treatment with the remaining 3 implants. Although implant survival rate is often used to define treatment outcome, treatment outcome based on objective success and retreatment criteria, as postulated by Payne and coworkers,[39] is perhaps more relevant.

The favorable periodontal outcome in this study is comparable to the results reported in other studies.[9,10] The significant differences with regard to the Bleeding Index can be explained by differences in assessment. In group 1 (the TMI group), bleeding was scored after gentle probing of the sulcus, while in groups 2 and 3 it was scored after assessing the pocket probing depth, a parameter not assessed in group 1. The PTVs found in groups 2 and 3 are in accordance with other studies.[40,41] The higher PTVs recorded in group 1 may be explained partly by the differences in geometric design and material properties of the implants, which again would be consistent with other studies.[42] The improvement of the PTVs observed in group 2 during the evaluation period can be explained by the remodeling process that took place in the augmented mandible, which resulted in a denser bone structure and caused stronger bone-implant contact.[43]

Bone height at the mesial and distal aspects of the implants assessed with the lateral oblique technique appeared to be stable during the 2-year evaluation period for most locations in the 3 treatment groups. A significant loss of bone (up to 1.0 mm) could be noted at 5 locations (2 in group 1, 3 in group 2). Significant differences between the 3 treatment groups could be detected at only 1 location; the decrease of bone height in group 2 was significantly greater than the decrease found in the other 2 groups. These results are comparable with other longitudinal studies in which the reduction of the marginal bone level was assessed radiographically.[44–46] Most of these studies reported a loss of 0.5 to 1.5 mm during the first year following placement of the implants; thereafter, resorption was reduced to a minimal level (< 0.2 mm/y).[47,48]

Compared with a preclinical setting the SDDs found in this study had increased.[32] Superimposition of soft tissues can cause unclear delineation of bony structures, thereby influencing the accuracy of this technique. The smallest SDD provides the clinician with knowledge regarding the statistical relevance of observations. For the oblique lateral technique and the measurement procedure described, an overall SDD of 0.6 mm, the maximum value of the 95% CI of the mean SDD, can be used. From a clinical point of view, the loss of marginal bone around the neck of an implant becomes relevant in case of progressive bone loss, ie, bone loss exceeding the "expected" loss of bone during the first year following placement of the implants (up to 1.5 mm). In this study, baseline data were recorded at the beginning of prosthetic loading, approximately 6 months after placement of the implants. The initial bone (re)modeling processes taking place at the bone-implant interface during the first 6 months after placement were not recorded in this study. Therefore, to detect progressive bone loss between subsequent radiographs during prosthetic loading, a threshold of 1.0 mm is justified. Regarding the SDD found in this study (0.6 mm) the oblique radiographic technique and the described measurement procedure appeared to be suitable for detection of progressive bone loss. Being an extraoral technique with limited resolution, this level of detection is probably inferior to intraoral techniques.

Despite the unfavorable ratio between the limited implant length and the distance to the occlusal plane, there was stable bone height at the mesial and distal aspects of the implants in group 3. Thus, implants in combination with an implant-retained overdenture in patients with an extremely resorbed mandible appear to be able to withstand occlusal loading and maintain a stable marginal bone level. This is in accordance with other studies.[13,14]

Since the studies of Tallgren and Atwood, clinicians have been familiar with a continuing process of the loss of alveolar and even basal bone following the extraction of teeth.[49,50] The effect of dental implants on the (re)modeling processes of the mandibular bone is yet not thoroughly understood. In this study the bone height distal to the lateral implants did not decrease in groups 1 and 3 during the 2-year evaluation period. In contrast, there was a significant increase in bone height at 3 locations (2 in group 1, 1 in group 3), and at the other 4 locations distal to the lateral implants there was a tendency for bone height to increase. An explanation for this phenomenon could be the changing pattern of forces applied to the (muco)periosteum of the mandible after placement of the implants and fabrication of an implant-retained overdenture. Loading of a conventional mandibular denture causes compressive forces on the mucoperiosteum, enhancing resorption of mandibular bone.[49] After treatment the distribution of occlusal forces is changed; forces applied to the implants create bending forces in the mandibular area distal to the lateral implants, which might be the mechanical stimulus for bone (re)modeling processes and could be described as a functional adaptation.[51]

This is not the first time that an increase in bone height of the edentulous mandible has been reported; this phenomenon has been reported in several case studies.[52–55] According to various reports, placement of a TMI can lead to an increase in bone height distal to the lateral implants up to 9 mm if a specified protocol is used.[22,56,57] However, the evaluation instrument used in these studies, the panoramic radiograph, is questionable. The recording technique was not standardized, making comparison of subsequent radiographs relative to distortion and magnification errors hazardous.[58] Moreover, the data were not analyzed statistically, so interpretation of the results is subject to considerable bias. Although the same treatment protocol was used in this study, the results are not as spectacular and are more comparable to results reported by Kwakman and colleagues, implying stabilization rather than increased bone height.[59] There are indications (eg, increased radiographic bone density) that placement of dental implants in the edentulous mandible leads to consolidation of alveolar bone. Functional adaptation of mandibular bone height as observed in this study also seems possible.[43,60]

A significant decrease of mandibular bone height was observed in the grafted area distal to the lateral implants in group 2 during the 2-year evaluation period. This decrease was limited, up to 10%, and diminished in time. The amount of resorption during the first 3 months of bone healing and the subsequent 3-month implant integration period was not recorded. This explains why limited mandibular bone height reduction was found in the present study as compared to other studies.[61,62] In this study, mandibular bone height was evaluated during prosthetic loading of the implants, a period during which bone height in the grafted area could be maintained for the most part. The minimal loss of height is comparable to the results of a recent study by Bell and coworkers.[63]

A drawback of these kinds of radiographic evaluation studies is that 3-dimensional (re)modeling processes are projected on a 2-dimensional radiograph, thus limiting interpretation of these processes. Other techniques, such as high-frequency resonance imaging,[64] should be developed to assess qualitative and quantitative aspects of the bone-implant interface more exactly. The prosthetic complications that occurred are minor in terms of quantity and quality, resulting in minor adjustments. Compared to other studies it is remarkable that the superstructures and retention clips only caused minor problems in 1 patient.[65,66] The use of robust Dolder bars (groups 2 and 3) and U bars (group 1) with corresponding retention clips could be the reason for these observations.

CONCLUSION

From this study it can be concluded that all 3 evaluated methods resulted in satisfactory clinical and radiographic performance during a 2-year evaluation period. Because of the relatively low morbidity, high survival rate, and the favorable periodontal parameters, the use of implants alone can be an attractive treatment option for patients with an extremely resorbed mandible presenting functional problems with mandibular dentures. Moreover, the surgical treatment procedure can be performed in an outpatient clinic setting, an interesting option in those situations where cost-effectiveness plays a role in making decisions about the treatment of choice.

REFERENCES

1. Van Waas MA. The influence of clinical variables on patients' satisfaction with complete dentures. J Prosthet Dent 1990;63:307–310.
2. Meijer HJ, Raghoebar GM, van 't Hof MA, Geertman ME, van Oort RP. Implant-retained mandibular overdentures compared with complete dentures; a 5-years' follow-up study of clinical aspects and patient satisfaction. Clin Oral Implants Res 1999;10:238–244.
3. Brånemark P-I, Hansson BO, Adell R, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg Suppl 1977;11(suppl 16):1–132.
4. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.
5. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;10:387–416.
6. Batenburg RHK, Meijer HJA, Raghoebar GM, Vissink A, van Oort RP, Boering G. Review of the literature on mandibular overdentures supported by endosseous implants. Int J Oral Maxillofac Implants 1998;13:539–545.
7. Cune MS, de Putter C, Hoogstraten J. Characteristics of 5410 edentulous implant candidates and the treatment they receive. Community Dent Oral Epidemiol 1995;23:110–113.
8. Cune MS, de Putter C, Hoogstraten J. A nationwide evaluative study on implant-retained overdentures. J Dent 1997;25 (suppl 1):S13–S19.
9. Batenburg RHK, Meijer HJA, Raghoebar GM, van Oort RP, Boering G. Mandibular overdentures supported by two Brånemark, IMZ or ITI implants. A prospective comparative preliminary study: One-year results. Clin Oral Implants Res 1998;9:374–383.
10. Roynesdal AK, Ambjornsen E, Stovne S, Haanaes HR. A comparative clinical study of three different endosseous implants in edentulous mandibles. Int J Oral Maxillofac Implants 1998;13:500–505.
11. Raghoebar GM, Meijer HJA, Stegenga B, van 't Hof M, van Oort RP, Vissink A. Effectiveness of three treatment modalities for the edentulous mandible. A five-year randomized clinical trial. Clin Oral Implants Res 2000;11:195–201.

12. Geertman ME, Boerrigter EM, Van Waas MAJ, van Oort RP. Clinical aspects of a multicenter clinical trial of implant-retained mandibular overdentures in patients with severely resorbed mandibles. J Prosthet Dent 1996;75:194–204.
13. Stellingsma C, Meijer HJ, Raghoebar GM. Use of short endosseous implants and an overdenture in the extremely resorbed mandible: A five-year retrospective study. J Oral Maxillofac Surg 2000;58:382–387.
14. Friberg B, Grondahl K, Lekholm U, Brånemark P-I. Long-term follow-up of severely atrophic edentulous mandibles reconstructed with short Brånemark implants. Clin Implant Dent Relat Res 2000;2:184–189.
15. Stellingsma C, Raghoebar GM, Meijer HJ, Batenburg RH. Reconstruction of the extremely resorbed mandible with interposed bone grafts and placement of endosseous implants. A preliminary report on outcome of treatment and patients' satisfaction. Br J Oral Maxillofac Surg 1998;36:290–295.
16. Satow S, Slagter AP, Stoelinga PJ, Habets LL. Interposed bone grafts to accommodate endosteal implants for retaining mandibular overdentures. A 1–7 year follow-up study. Int J Oral Maxillofac Surg 1997;26:358–364.
17. Verhoeven JW, Cune MS, Terlou M, Zoon MA, de Putter C. The combined use of endosteal implants and iliac crest onlay grafts in the severely atrophic mandible: A longitudinal study. Int J Oral Maxillofac Surg 1997;26:351–357.
18. Bosker H, Jordan RD, Sindet-Petersen S, Koole R. The transmandibular implant: A 13-year survey of its use. J Oral Maxillofac Surg 1991;49:482–492.
19. Verhoeven JW, Cune MS, Van Kampen FM, Koole R. The use of the transmandibular implant system in extreme atrophy of the mandible; A retrospective study of the results in two different hospital situations. J Oral Rehabil 2001;28: 497–506.
20. Zielhuis GA, Straatman H, van 't Hof-Grootenboer AE, van Lier HJJ, Rach GH, van den Broek. The choice of a balanced allocation method for a clinical trial in otitis media with effusion. Stat Med 1990;9:237–246.
21. Bosker H, Powers MP. The transmandibular reconstruction system. In: Fonseca R, Davis WH (eds). Reconstructive Preprosthetic Oral and Maxillofacial Surgery. Philadelphia: Saunders, 1995:565–668.
22. Powers MP, Bosker H, van Pelt H, Dunbar N. The transmandibular implant: From progressive bone loss to controlled bone growth. J Oral Maxillofac Surg 1994;52:904–910.
23. Powers MP, Bosker H. Functional and cosmetic reconstruction of the facial lower third associated with placement of the transmandibular implant system. J Oral Maxillofac Surg 1996;54:934–942.
24. Bosker H, Wardle LM. Muscular reconstruction to improve the deterioration of facial appearance and speech caused by mandibular atrophy: Technique and case reports. Br J Oral Maxillofac Surg 1999;37:277–284.
25. Khamis MM, Zaki HS, Rudy TE. A comparison of the effect of different occlusal forms in mandibular implant overdentures. J Prosthet Dent 1998;79:422–429.
26. Mombelli A, van Oosten MAC, Schürch E, Lang NP. The microbiota associated with succesful or failing osseointegrated titanium implants. Oral Microbiol Immunol 1987;2: 145–151.
27. Löe H, Silness J. Periodontal disease in pregnancy. I. Prevalence and severity. Acta Odontol Scand 1963;21:533–551.
28. Teerlinck J, Quirynen M, Darius P, van Steenberghe D. Periotest: An objective clinical diagnosis of bone apposition toward implants. Int J Oral Maxillofac Implants 1991;6: 55–61.
29. Jonkman RE, van Waas MA, Plooij J, Kalk W. Measuring mandibular ridge reduction on oblique cephalometric radiographs. J Craniomaxillofac Surg 1991;19:27–30.
30. Verhoeven JW, Ruijter J, Cune MS, Terlou M. Oblique lateral cephalometric radiographs of the mandible in implantology: Usefulness and reproducibility of the technique in quantitative densitometric measurements of the mandible in vivo. Clin Oral Implants Res 2000;11:476–486.
31. Steen WH. Errors in oblique cephalometric radiographic projections of the edentulous mandible. Part I: Geometric errors. J Prosthet Dent 1984;51:411–418.
32. Stellingsma K, Batenburg RH, Meijer HJ, Raghoebar GM, Kropmans TJ. The oblique radiographic technique for bone height measurements on edentulous mandibles: A preclinical study and an introduction to the clinical use. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:522–529.
33. Kropmans TJ, Dijkstra PU, Stegenga B, Stewart R, de Bont LG. Smallest detectable difference in outcome variables related to painful restriction of the temporomandibular joint. J Dent Res 1999;78:784–789.
34. Kalk WI, Raghoebar GM, Jansma J, Boering G. Morbidity from iliac crest bone harvesting. J Oral Maxillofac Surg 1996;54:1424–1429.
35. Wismeijer D, Van Waas MA, Vermeeren JI, Kalk W. Patients' perception of sensory disturbances of the mental nerve before and after implant surgery: A prospective study of 110 patients. Br J Oral Maxillofac Surg 1997;35:254–259.
36. Ellies LG, Hawker PB. The prevalence of altered sensation associated with implant surgery. Int J Oral Maxillofac Implants 1993;8:674–679.
37. Wallace RH. The relationship between cigarette smoking and dental implant failure. Eur J Prosthodont Restorative Dent 2000;8:103–106.
38. Keller EE, Desjardins RP, Tolman DE, Laney WR, Van Roekel NB. Reconstruction of the severely resorbed mandibular ridge using the tissue-integrated prosthesis. Int J Oral Maxillofac Implants 1986;1:101–109.
39. Payne AG, Walton TR, Walton JN, Solomons YF. The outcome of implant overdentures from a prosthodontic perspective: Proposal for a classification protocol. Int J Prosthodont 2001;14:27–32.
40. Salonen MA, Raustia AM, Kainulainen V, Oikarinen KS. Factors related to Periotest values in endosseal implants: A 9-year follow-up. J Clin Periodontol 1997;24:272–277.
41. Haas R, Saba M, Mensdorff-Pouilly N, Mailath G. Examination of the damping behavior of IMZ implants. Int J Oral Maxillofac Implants 1995;10:410–414.
42. Versteegh PA, van Beek GJ, Slagter AP, Ottervanger JP. Clinical evaluation of mandibular overdentures supported by multiple-bar fabrication: A follow-up study of two implant systems. Int J Oral Maxillofac Implants 1995;10:595–603.
43. Verhoeven JW, Ruijter J, Cune MS, Terlou M, Zoon M. Onlay grafts in combination with endosseous implants in severe mandibular atrophy: One-year results of a prospective, quantitative radiological study. Clin Oral Implants Res 2000;11:583–594.
44. Adell R, Eriksson B, Lekholm U, Brånemark P-I, Jemt T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. Int J Oral Maxillofac Implants 1990;5:347–359.
45. Batenburg RHK, Meijer HJA, Geraets WGM, van der Stelt PF. Radiographic assessment of changes in marginal bone around endosseous implants supporting mandibular overdentures. Dentomaxillofac Radiol 1998;27:221–224.

46. Heydenrijk K, Raghoebar GM, Meijer HJ, van der Reijden WA, van Winkelhoff AJ, Stegenga B. Two-stage IMZ implants and ITI implants inserted in a single-stage procedure. A prospective comparative study. Clin Oral Implants Res 2002;13:371–380.
47. Lindquist LW, Rockler B, Carlsson GE. Bone resorption in edentulous patients treated with mandibular fixed tissue integrated prostheses. J Prosthet Dent 1988;59:59–63.
48. Carlsson GE, Lindquist LW, Jemt T. Long-term marginal periimplant bone loss in edentulous patients. Int J Prosthodont 2000;13:295–302.
49. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: A mixed-longitudinal study covering 25 years. J Prosthet Dent 1972;27:120–132.
50. Atwood DA. Reduction of residual ridges: A major oral disease entity. J Prosthet Dent 1971;26:266–279.
51. Reddy MS, Geurs NC, Wang IC, et al. Mandibular growth following implant restoration: Does Wolff's law apply to residual ridge resorption? Int J Periodontics Restorative Dent 2002;22:315–321.
52. Taylor TD. Osteogenesis of the mandible associated with implant reconstruction: A patient report. Int J Oral Maxillofac Implants 1989;4:227–231.
53. Oikarinen VJ, Siirila HS. Reparative bone growth in an extremely atrophied edentulous mandible stimulated by an osseointegrated implant-supported fixed prosthesis: a case report. Int J Oral Maxillofac Implants 1992;7:541–544.
54. Keller EE. Reconstruction of the severely atrophic edentulous mandible with endosseous implants: A 10-year longitudinal study. J Oral Maxillofac Surg 1995;53:305–320.
55. Wright PS, Glantz PO, Randow K, Watson RM. The effects of fixed and removable implant-stabilised prostheses on posterior mandibular residual ridge resorption. Clin Oral Implants Res 2002;13:169–174.
56. Bosker H, Jordan RD, Powers MP, Van Pelt AWJ. Bone induction and bone loss by use of the TMI. Oral Surg Oral Diagn 1991;2:18–26.
57. Betts NJ, Barber HD, Powers MP, Wu L, Hennig T, Fonseca RJ. Osseous changes following placement of the transmandibular implant system in edentulous mandibles. Implant Dent 1993;2:11–17.
58. Batenburg RH, Stellingsma K, Raghoebar GM, Vissink A. Bone height measurements on panoramic radiographs: The effect of shape and position of edentulous mandibles. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;84:430–435.
59. Kwakman JM, Van Waas MAJ, Hagens M, Voorsmit RA. Bone level changes in patients with transmandibular implants. J Oral Maxillofac Surg 1997;55:15–18.
60. von Wowern N, Gotfredsen K. Implant-supported overdentures, a prevention of bone loss in edentulous mandibles? A 5-year follow-up study. Clin Oral Implants Res 2001;12:19–25.
61. Vermeeren JI, Wismeijer D, van Waas MA. One-step reconstruction of the severely resorbed mandible with onlay bone grafts and endosteal implants. Int J Oral Maxillofac Surg 1996;25:112–115.
62. Satow S, Slagter AP, Stoelinga PJ, Habets LL. Interposed bone grafts to accommodate endosteal implants for retaining mandibular overdentures. A 1–7 year follow-up study. Int J Oral Maxillofac Surg 1997;26:358–364.
63. Bell RB, Blakey GH, White RP, Hillebrand DG, Molina A. Staged reconstruction of the severely atrophic mandible with autogenous bone graft and endosteal implants. J Oral Maxillofac Surg 2002;60:1135–1141.
64. Meredith N, Shagaldi F, Alleyne D, Sennerby L, Cawley P. The application of resonance frequency measurements to study the stability of titanium implants during healing in the rabbit tibia. Clin Oral Implants Res 1997;8:234–243.
65. Payne AG, Solomons YF. Mandibular implant-supported overdentures: A prospective evaluation of the burden of prosthodontic maintenance with 3 different attachment systems. Int J Prosthodont 2000;13:246–253.
66. Visser A, Geertman ME, Meijer HJ, et al. Five years of aftercare of implant-retained mandibular overdentures and conventional dentures. J Oral Rehabil 2002;29:113–120.