Alveolar Distraction Osteogenesis for the Correction of Vertically Deficient Edentulous Ridges: A Multicenter Prospective Study on Humans

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Purpose: *The purposes of this prospective multicenter study were to evaluate the use of vertical distraction osteogenesis in the correction of vertically deficient alveolar ridges and to evaluate whether the vertical bone gained by distraction osteogenesis was maintained over time when dental implants were placed in the distracted areas.* ***Materials and Methods:*** *Thirty-seven patients presenting vertically deficient edentulous ridges were treated in 4 different centers by means of distraction osteogenesis with an intraoral alveolar distractor. Two to 3 months after consolidation of the distracted segments, 138 dental implants were placed in the distracted areas. Four to 6 months later, abutments were connected and prosthetic loading of the implants began.* ***Results:*** *The mean follow-up after initial prosthetic loading was 34 months (range 15 to 55 months). The mean bone gain obtained by distraction was 9.9 mm (range 4 to 15 mm). The cumulative success rate of the implants 4 years after the onset of prosthetic loading was 94.2%, while the implants' cumulative survival rate was 100%. No statistically significant differences were found between the different centers as far as survival and success rates of implants were concerned.* ***Discussion and Conclusion:*** *The results of this study appear to demonstrate that distraction osteogenesis is a reliable technique for the correction of vertically deficient edentulous ridges. The regenerated bone appeared to withstand the functional demands of implant loading. The survival and success rates of the implants placed in the distracted areas were consistent with those reported in the literature regarding implants placed in native bone in this patient population.* INT J ORAL MAXILLOFAC IMPLANTS 2004;19:399–407

Key words: *alveolar ridge, bone regeneration, dental implants, distraction osteogenesis, edentulism*

Dental rehabilitation of partially or totally edentulous patients with dental implants has become common practice in the last few decades, with reliable long-term results.[1–9] However, the local conditions of edentulous alveolar ridges may be unfavorable for implant placement. In particular, a vertically deficient alveolar ridge may have insufficient bone volume to harbor implants of adequate dimensions, making implant placement difficult or impossible. To correct this situation, a variety of surgical procedures have been proposed, including onlay bone grafts, vertical guided bone regeneration (GBR), and alveolar distraction osteogenesis (DO).

Reconstruction of vertically atrophied ridges with onlay bone grafts, the first procedure to be used, has been well documented in terms of number of cases treated and the follow-up of implants placed in the reconstructed areas.[10–19] However, the results reported appear dissimilar. They are difficult to compare because different donor sites (eg, intraoral sites; sites in the calvaria, tibia, and iliac crest) have been used as sources of autogenous bone and different systems have been used for the evaluation of implant survival and success rates.[20] The need to harvest bone from a separate site may increase morbidity, operating times, and the duration of the patient's hospitalization. Moreover, onlay bone grafts may be prone to infection and unpredictable

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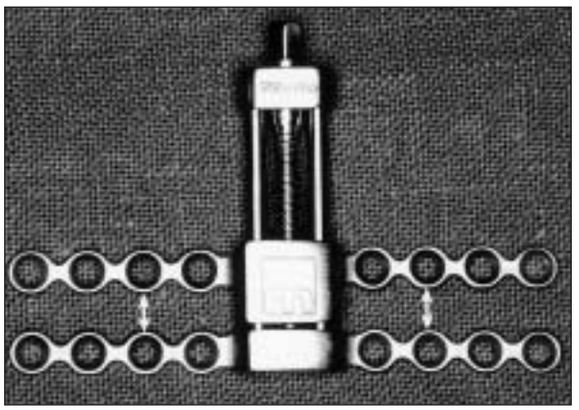

Fig 1 Landmarks for the measurement of vertical gain after distraction are represented by the arrows at the upper margin of the distractor's lower plate and inferior margin of the upper plate.

bone resorption, before or after implant placement. A study by Vermeeren and colleagues[21] demonstrated bone resorption up to 50% of the original volume when autogenous onlay bone grafts were used for the correction of severely vertically atrophied edentulous mandibles, despite the use of dental implants in the reconstructed areas.

Information on the clinical use of vertical GBR is limited compared to that concerning onlay bone grafting, but promising results have been presented.[22–26] However, the usefulness of this technique may be limited. Treatment may be confined to limited edentulous areas (1- to 3-tooth edentulous spaces on average). Vertical bone gain may be limited (2 to 7 mm on average). The risk of membrane exposure and infection, the technique-related success, and the necessity of bone harvesting (which may increase morbidity) must be considered.[26] Moreover, a study by Rasmusson and associates[27] demonstrated that extensive bone resorption may occur after the removal of membranes used for the GBR procedures.

Alveolar DO is another method used to correct vertically atrophied alveolar ridges. Originally applied in the orthopedic field,[28,29] this method has been extended more recently to correct maxillofacial deformities such as those caused by Franceschetti's syndrome or hemifacial microsomia.[30–32] Since 1996, it has been suggested for the correction of vertical defects of the alveolar ridges.[33–46] Preliminary results seem promising, but the reported data have been mainly retrospective and focused on the outcome of DO rather than on well-defined criteria for the evaluation of survival and success rates of implants placed in the distracted areas.

The aim of this multicenter study was to evaluate prospectively the use of vertical DO in the correction of vertically deficient alveolar ridges and to evaluate whether the vertical bone gained was maintained over time when dental implants were placed in the distracted areas. This bone was assessed according to the criteria of Albrektsson and colleagues.[1]

MATERIALS AND METHODS

Over a 4-year period (from 1998 to 2001) 37 systemically healthy individuals, 21 men and 16 women between 18 and 78 years of age (mean 39.2 years), who presented with vertical alveolar ridge deficiency consequent to atrophy, trauma, congenital malformations, and sequelae of oncologic surgery were selected for surgical correction by means of DO. The treatment goal was to improve implant support, the crown-to-implant ratio, and the potential esthetics of the implant-supported prostheses fabricated for edentulous areas. Four centers participated in the study: the Unit of Oral Surgery, Department of Surgery, Medicine and Dentistry, San Paolo Hospital, University of Milan, Italy; the Department of Dentistry and Oral and Maxillofacial Surgery, University of Modena and Reggio Emilia, Italy; the Department of Maxillofacial Surgery, S. Anna Hospital, Como, Italy; and the Unit of Maxillofacial Surgery, S. Orsola Hospital, University of Bologna, Italy.

Patient exclusion criteria were

1. Vertical defects of the edentulous ridge associated with a severely knife-edged ridge
2. Insufficient bone between the alveolar ridge crest and maxillary sinus, floor of the nose, and inferior alveolar canal (less than 5 mm)
3. Excessive tobacco use (more than 15 cigarettes per day)
4. Severe renal and liver disease
5. History of radiotherapy in the head and neck region
6. Chemotherapy for treatment of malignant tumors at the time of the surgical procedure
7. Uncontrolled diabetes
8. Active periodontal disease involving the residual dentition
9. Mucosal disease, such as lichen planus, in the areas to be treated
10. Poor oral hygiene
11. Noncompliance

Routine radiographic documentation of the treated patients was obtained with panoramic and intraoral radiographs taken preoperatively, immediately after the application of the distraction device, at the end of the distraction procedure, at the time of implant placement, at the time of prosthetic rehabilitation, and annually thereafter. In all centers, the

Table 1 Anagraphic Data and Clinical Features of Patients Treated with DIstraction Osteogenesis

Center/ patient no.	Age	Sex	Defect etiology	Implant			Edentulous area*	BG (mm)	Complications
				No.	Brand	Length (mm)			
1									
1	27	F	Atrophy	2	Brånemark	10, 11.5	29 (45), 30 (46)	8.0	None
2	27	M	Tumor resection	4	Brånemark	18	23 (32)–31 (47)	15.0	None
3	20	F	Congenital malformation	5	Brånemark	15	EM	7.0	None
4	37	M	Trauma	4	ITI	12	19 (36)–22 (33)	7.0	None
5	42	M	Tumor resection	3	ITI	14	18 (37)–21 (34)	10.0	Mandibular fracture
6	33	F	Trauma	4	Brånemark	13	3 (16)–6 (13)	7.0	None
7	42	M	Atrophy	2	ITI	12	29 (45)–30 (46)	4.0	None
8	18	F	Tumor resection	5	ITI	12	27 (43)–31 (47)	6.0	None
9	19	M	Trauma	2	Brånemark	15	23 (32)–25 (41)	6.0	Lingual inclination
10	55	M	Tumor resection	4	ITI	14	21 (34)–28 (44)	9.0	None
11	46	F	Atrophy	3	ITI	8	18 (37)–20 (35)	6.0	Incomplete distraction
12	39	M	Atrophy	3	ITI	12	28 (44)–30 (46)	5.0	Lingual inclination
2									
13	62	F	Atrophy	4	Frialit	13	8 (11)–11 (23)	6.0	None
14	64	F	Atrophy	4	Frialit	13	8 (11)–11 (23)	7.0	None
15	24	M	Trauma	3	Frialit	15	7 (12)–10 (22)	12.0	None
16	37	M	Trauma	3	ITI	12	27 (43)–30 (46)	6.5	None
17	20	M	Trauma	2	Frialit	15	6 (13), 7 (12)	10.0	None
18	23	M	Trauma	2	Frialit	13	10 (22)–12 (24)	7.0	None
19	31	M	Trauma	2	Frialit	13–15	21 (34)–23 (32)	8.0	Palatal inclination
3									
20	19	F	Tumor resection	3	3i	13	21 (34), 22 (33)	9.0	None
21	29	F	Trauma	2	3i	13	21 (34), 22 (33)	8.0	None
22	78	M	Atrophy	3	3i	13–15	EM	8.5	None
23	34	M	Trauma	3	3i	13	21 (34)–24 (31)	14.0	None
24	67	M	Atrophy	7	3i	10–15	EM	11.0	None
25	43	F	Atrophy	6	3i	13–15	EM	12.0	Lingual inclination
26	65	F	Atrophy	5	3i	15–18	EM	14.0	None
27	48	F	Atrophy	4	3i	10–13	28 (44)–31 (47)	6.5	None
28	47	F	Atrophy	2	3i	10	18 (37)–21 (34))	7.0	None
4									
29	36	F	Trauma	2	Frialit	15	7 (12)–10 (22)	9.5	None
30	27	F	Trauma	4	Frialit	11–13	7 (12)–11 (23)	9.0	Palatal inclination
31	43	M	Trauma	3	Frialit	13	7 (12)–11 (23) 24 (31)–28 (44)	10.0	Secondary bone grafting
32	55	M	Tumor resection	5	Brånemark	15	18 (37)–22 (33)	15.0	None
33	61	M	Atrophy	6	Brånemark	11.5–13	22 (33)–29 (45)	15.0	None
34	55	M	Tumor resection	6	Brånemark	13	EM	11.0	None
35	22	M	Tumor resection	5	ITI	11–13	19 (36)–23 (32)	15.0	None
36	32	F	Trauma	7	ITI	12–14	EM	15.0	None
37	23	M	Trauma	3	Brånemark	13–15	21 (34)–23 (32)	8.0	None

BG = bone gain at the end of distraction; EM = edentulous mandible.
*Sites 1 (18) through 16 (28) are in the maxilla; sites 17 (38) to 32 (48) are in the mandible).

patients were treated by means of the DO principle with an intraoral extraosseous distraction device (Track 1 or Track 1.5; Gebrüder Martin, Tuttlingen, Germany) (Fig 1). Anagraphic data and the clinical features of the patients are reported in Table 1.

Surgical Procedure

The DO procedure was performed under local anesthesia in 6 patients, under local anesthesia with intravenous sedation (diazepam 0.2 mg/kg) in 12 patients, and under general anesthesia with nasotracheal intubation in the remaining 19 patients. The type of anesthesia was chosen according to the amount of extension needed, the accessibility of the site, the predetermined duration of the procedure, and patient compliance.

An intraoral incision was made in the buccal vestibule without lateral releasing incisions. Careful

subperiosteal dissection was performed to obtain adequate visibility of the underlying bone, but no mucoperiosteal dissection was performed toward the alveolar crest or on the lingual/palatal side so as to preserve adequate blood supply to the bone segment to be osteotomized. With an oscillating saw and/or a fissure bur, the bone segment to be vertically distracted was completely separated from the basal bone. Once the osteotomy was completed, the intraoral distractor was affixed to both the basal bone and the osteotomized segment with 1.5-mm-wide titanium microscrews (Gebrüder Martin). The osteotomized segment to be distracted was immediately moved by activating the distractor to check the direction of distraction and freedom of movement. Finally, the osteotomized segment was repositioned at its initial position, and the surgical access was sutured with 4-0 sutures.

All patients received 3 g of ampicillin per day, starting approximately 1 hour before surgery and continuing for 6 days after surgery, and nonsteroidal analgesics postoperatively. Postoperative instructions included a soft diet for 2 weeks and appropriate oral hygiene, including 0.2% chlorhexidine mouth rinse. In cases of intravenous sedation or general anesthesia, antibiotics were administered intravenously at the time of induction and then continued orally for 6 days.

After a waiting period of 7 days for closure of the surgical wound, the sutures were removed and the distraction device was activated. A distraction of 1 mm per day (subdivided in 2 activations of 0.5 mm every 12 hours) was performed until the desired amount of distraction (4 to 15 mm) was obtained. The distractor was then maintained in position for 2 to 3 months while the neocallus formed between the basal bone and the distracted segment matured. After this waiting period, the distractor was removed and endosseous implants were placed following the indications of prefabricated surgical templates. A total of 138 titanium screw-type endosseous implants were placed in the distracted segments. Three to 6 months later, abutments were connected to the implants and prosthetic treatment was initiated. Thirty-five patients were rehabilitated with implant-supported fixed prostheses; the remaining 2 patients (patients 24 and 25) were rehabilitated with implant-supported overdentures.

Four surgeons performed all of the reconstructive and implant placement procedures. The number and types of implants are reported in Table 1. The following parameters were evaluated by calibrated examiners: *(a)* vertical bone gain obtained after distraction; *(b)* radiographic assessment of bone resorption between the end of DO and the time of implant placement; *(c)* radiographic assessment of peri-implant bone resorption before and after implant loading; and *(d)* implant survival and success rates.

Vertical Bone Gain Obtained by Distraction

Vertical bone gain was evaluated clinically by summing the number of rotations performed with the activating device (every complete rotation was equal to 0.5 mm). Also, the distance in millimeters between the upper and lower miniplates of the distractor was measured with a transparent ruler on panoramic radiographs taken at the end of the distraction procedure (Fig 1). Measurements were made at the beginning and at the end of distraction. Dimensional distortion between the different panoramic radiographs was corrected using the actual dimensions of the distractor. Periapical radiographs were not routinely used for this evaluation because the basal part of the distractor could be placed deeply, where it would not be clearly visible on a periapical radiograph.

Radiographic Assessment of Bone Resorption Between the End of the DO Procedure and Implant Placement

This parameter was evaluated by comparing the distance between the upper margin of the osteotomized segment and the upper margin of the distractor plate on periapical radiographs taken at the end of distraction and at the time of implant placement. The measurements were made to the nearest 0.5 mm.

Radiographic Assessment of Peri-implant Bone Resorption After Implant Placement

Peri-implant bone resorption was recorded by comparing periapical radiographs made perpendicular to the long axis of the implants, where the platform and threads were clearly visible, using conventional film holders. Radiographs were taken immediately after implant placement, at the time of prosthetic loading, and annually thereafter. Bone level change was evaluated mesial and distal to each implant by means of a transparent ruler, measuring the distance in millimeters between the top of implant head and the most coronal point of direct bone-to-implant contact. The bone level measured on periapical radiographs taken immediately after implant placement was considered the baseline for further measurements. The measurements were recorded to the nearest 0.5 mm.

Implant Success and Survival Rates

Successful implants met the following criteria: *(1)* absence of persistent pain or dysesthesia; *(2)* absence of peri-implant infection with suppuration;

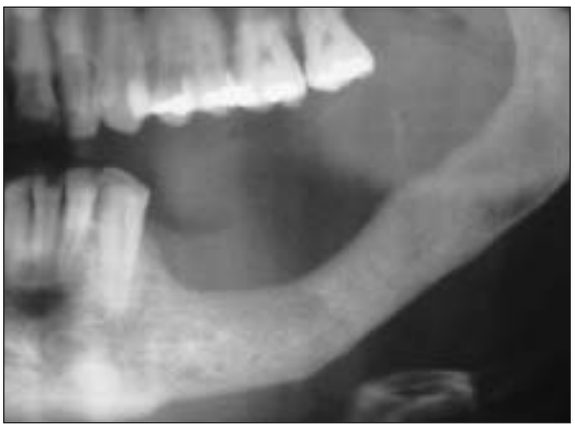

Fig 2a Panoramic radiograph showing the sequelae of odontogenic tumor resection of the left mandible with reconstruction with an iliac bone graft. A relevant vertical deficit is visible distal to the mandibular left canine.

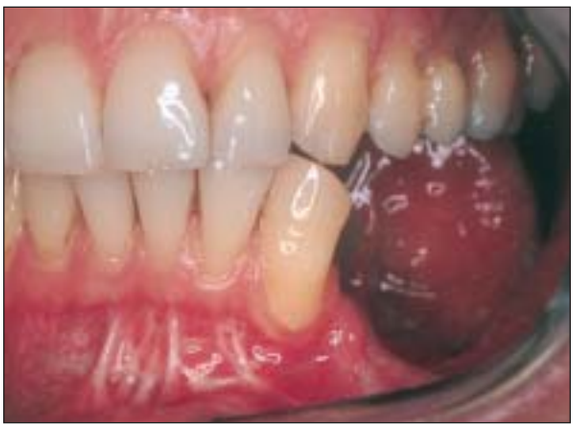

Fig 2b Preoperative clinical situation showing the vertical deficit of the left mandible with increased interarch distance.

(3) absence of mobility; *(4)* absence of continuous peri-implant radiolucency; and *(5)* less than 1.5 mm peri-implant bone resorption in the first year of function and less than 0.2 mm in subsequent years.[1]

Criteria for implant survival included success 1 through 4, but peri-implant bone resorption greater than the values proposed by Albrektsson and colleagues[1] was permitted. The criteria used in the present study differed from those of Albrektsson and colleagues only in the lack of results 5 years after prosthetic loading and neural disturbances. This latter parameter could not be evaluated in 6 patients because of inferior alveolar nerve severance before distraction, in 5 patients because of mandibular resection in the lateral segments related to tumor diagnosis, and in 1 patient because of a recurring keratocyst.

RESULTS

Recovery of the surgical sites after the distraction procedure was uneventful in all cases. The mean bone gain was 9.9 mm (range 4 to 15 mm). In 3 patients (patients 9, 12, and 24), a progressive lingual inclination of the distracted segment occurred during distraction. This was probably the result of traction on the osteotomized segment by muscle forces on the floor of the mouth. In 2 patients a progressive palatal inclination of the distracted segment occurred, probably because of traction by the palatal fibromucosa. To avoid consolidation of the distracted segment in an unfavorable position, orthodontic traction was applied to the distracted segments. The orthodontic appliance was maintained until consolidation of the neocallus in the desired position was reached. At the end of orthodontic treatment it was possible to place implants in the correct, prosthetically determined position.

Patient 30 presented with adequate vertical gain at the time of implant placement, but a reduced width at the level of the neogenerated distracted tissue. Implant placement according to surgical template indications resulted a partial exposure of implant threads (fenestration in the middle part of the implants), which was corrected with grafting of autogenous bone chips harvested from the mandibular ramus at the time of implant placement.

The case of patient 5 is presented in Figs 2 to 4. He presented with a mandibular fracture 4 weeks after the completion of distraction (Fig 3b). The fracture was treated by means of rigid maxillomandibular fixation. Consolidation of the fracture occurred after 4 weeks. Three months after the completion of distraction it was possible to place implants in the correct, prosthetically determined positions.

Patient 11 presented with incomplete distraction (3 mm instead of the planned 6 mm), probably the result of incorrect vertical osteotomies, which interfered with vertical distraction. This was the only complication that partially compromised the final outcome. Three months after the completion of distraction, it was possible to place 2 implants 8 mm in length rather 10 mm. Longer crowns had to be fabricated to compensate for the incomplete correction of the preoperative vertical deficit (see Table 1 for further details).

In the remaining patients (36 of 37) it was possible to place the planned number of implants with primary implant stability in both native and neogenerated bone at the level of the distracted area. The mean follow-up from the start of prosthetic loading was 34 months (range 15 to 55 months), and none of the patients dropped out of the study during the

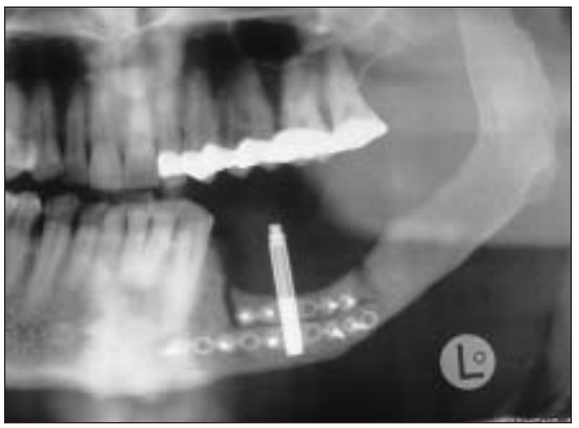

Fig 3a Radiograph obtained immediately after the application of distraction device.

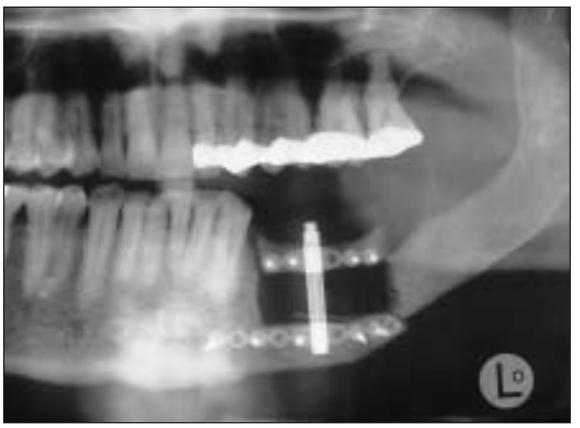

Fig 3b Radiograph taken at the end of distraction demonstrating the vertical gain obtained.

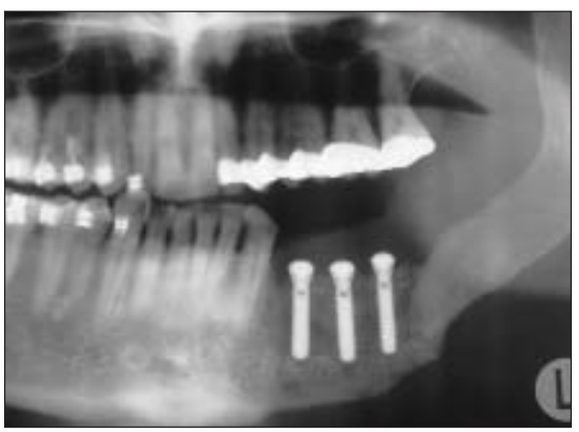

Fig 4 Radiograph obtained after the placement of 3 implants 3 months after the end of distraction.

follow-up period. No implants were lost during the follow-up period. All patients demonstrated acceptable function of the implant-supported prostheses.

The mean bone resorption between the end of DO and the time of implant placement (cumulative results of the 4 centers) was 0.3 mm (standard deviation [SD] 0.4). Medians and quartile ranges are reported in Table 2.

Mean peri-implant bone resorption between implant placement and abutment connection was 0.2 mm (SD 0.3). Mean peri-implant bone resorption was 0.8 mm (SD 0.4) 1 year after prosthetic loading, 1.1 mm (SD 0.5) after 2 years, 1.2 mm (SD 0.4) after 3 years, and 1.4 (SD 0.4) after 4 years. Medians and quartile ranges are reported in Table 2.

Eight implants presented peri-implant bone resorption values higher than those proposed by Albrektsson and associates' criteria. Thus, cumulative survival and success rates of implants placed at the end of the follow-up period were 100% and 94.2%, respectively.

Combined cumulative survival and success rates of implants for the 4 centers are reported in Table 3.

DISCUSSION

Results from this multicenter prospective study seem to demonstrate that DO can be an effective and reliable surgical alternative to correct vertical deficits of edentulous ridges resulting from atrophy, trauma, congenital malformation, and the resection of benign or malignant tumors. These results have been confirmed by other studies.[36–38,42–45]

Compared to onlay bone grafts, the following advantages can be anticipated with this technique. DO provides an opportunity to obtain a natural formation of bone between the distracted segment and the basal bone in a relatively short time span. DO eliminates the need to harvest bone and requires less operating time. Soft tissues can follow the elongation of the underlying bone (neohistogenesis) and there is a lower risk of infection of the surgical site (0% in this case series). The procedure can be performed more frequently under local anesthesia, and postoperative recovery generally is favorable. The more crestal part of the distracted segment appears to present a significantly lower risk of resorption. Regenerated bone seems to withstand the biomechanical demands of implant loading well. It is worth noting that a progressive increase in bone density was consistently found in this patient series, as shown by the comparison between periapical radiographs taken at the time of implant placement and at the end of the observation period, 3 to 4 years after prosthetic loading. These encouraging results have been confirmed by other studies[45,46] from the histologic and histomorphometric perspectives. Biopsies of the tissue regenerated by

Table 2 Bone Resorption (in mm) at the Time of Abutment Connection, and 1, 2, 3, and 4 Years After Abutment Connection (Cumulative Data of the 4 Centers)

	BG	BRIP	BRAC	BR-1	BR-2	BR-3	BR-4
Mean	9.9	0.3	0.2	0.8	1.1	1.2	1.4
SD	3.4	0.4	0.3	0.4	0.5	0.4	0.4
Median	9.0	0.5	0.5	1.0	1.0	1.0	1.5
First quartile	7.0	0.0	0.0	1.0	1.0	1.0	1.0
Third quartile	13.0	0.5	0.5	1.5	1.5	1.5	1.5
Minimum	4.0	0.0	0.0	0.0	0.0	0.5	0.5
Maximum	15.0	2.0	1.0	2.0	2.0	2.0	2.0
No. of implants with excessive bone resorption*				2	8	8	8

BG = bone gain at the end of the distraction procedure; BRIP = bone resorption between the end of distraction and the time of implant placement; BRAC = peri-implant bone resorption between the time of implant placement and the time of abutment connection; BR-1 = peri-implant bone resorption 1 year after abutment connection; BR-2 = peri-implant bone resorption 2 years after abutment connection; BR-3 = peri-implant bone resorption 3 years after abutment connection; BR-4 = peri-implant bone resorption 4 years after abutment connection.
*≥ 2.0 mm in the first year of function; ≥ 0.2 mm in subsequent years.

Table 3 Life Table Analysis—Cumulative Survival and Success Rates of Implants for the 4 Centers

Interval	Implants at start of interval	Withdrawn implants	Failures	Implants at risk at the end of interval	Cumulative survival rate (%)	Cumulative success rate (%)
Placement to loading	138	0	0	138	100	100
Loading to 1y	138	0	2	136	100	98.6
1 to 2 y	138	37	8	101	100	94.2
2 to 3 y	101	61	8	40	100	94.2
3 to 4 y	40	18	8	22	100	94.2

Failures = implants with bone resorption > 1.5 mm after the first year of loading and > 0.2 mm in subsequent years but fulfilling the other criteria of Albrekesson and coworkers.[1]

means of DO demonstrated intramembranous ossification of newly formed bony trabeculae oriented parallel to the distraction vector.

Peri-implant bone resorption and the survival and success rates of implants placed in the distracted areas were within the limits proposed by Albrektsson and colleagues[1] and were consistent with values reported in the literature as regards implants placed in native bone.[2–9]

The absence of significant differences in peri-implant bone resorption as well as in survival and success rates between the 4 different centers appears to demonstrate that the technique is reliable and probably not connected to surgeon-related capabilities.

Compared to vertical GBR, DO apparently results in greater vertical bone gain (up to 15 mm), thus permitting the correction of very relevant defects. Moreover, it has also been successfully applied to extended defects such as total or partial edentulism. It can be used for the vertical elongation of free fibular flaps used for the reconstruction of defects following tumor ablation.[37,40]

Despite very promising results, some limits related to DO were found in this study. First, inclination of the distracted bone segment, probably the result of traction of the palatal mucosa or of the muscles of the floor of the mouth, occurred before implant placement in 13.5% of the patients (5 of 37). It was successfully corrected by means of orthodontic appliances, thus permitting the placement of implants in the planned, prosthetically determined positions at the time of distractor removal. No permanent adverse effects were determined by this temporary complication. Second, it is possible to find insufficient width of the neocallus in the distracted area at the time of implant placement, which may result in partial exposure of the implant threads in the distracted neogenerated tissue because of insufficient bone volume. This event occurred in 1 patient (2.7% of this patient series) and it was therefore necessary to graft the area with autogenous bone to cover the exposed implant threads. Nevertheless, primary implant stability was already present at the time of implant placement and prosthetic restoration was not compromised.

Third, the distraction device used in this study cannot simultaneously correct a concomitant horizontal deficit. This may limit the application of the technique to composite vertical and horizontal defects. Two different situations can be found. Where relevant reduction in width is evident, this technique is contraindicated and other surgical alternatives such as GBR or grafting procedures are preferential. In the case of width reduction only in the more crestal part of the edentulous ridge, the problem can be overcome by an overcorrection of the vertical deficit by means of DO. At the time of implant placement, the atrophic margin of the distracted segment can be removed with a bur until adequate bone width is found in the inferior part of the distracted segment.

Fourth, it is of the utmost importance that adequate vertical osteotomies be made to prevent interferences in the movement of the osteotomized segment, which may jeopardize the final result. In this patient series, only 1 patient presented with this problem, which resulted in the positioning of an implant in a more apical position than was considered optimal.

Finally, minimal residual bone height of the atrophic area is needed to avoid the risk of alveolar damage, violation of the floor of the nose or the maxillary sinus, or mandibular fracture. The authors arbitrarily chose a minimum bone height of approximately 5 mm to obtain a bone segment with enough volume to be stabilized by the distraction plate and microscrews with no risk of violation of the floor of the nose, the maxillary sinus mucosa, or the alveolar nerve. Moreover, vertically atrophied mandibles with less than 5 mm of bone height present a relevant risk of fracture during or after the performance of the osteotomy. In this study 1 fracture occurred in the region of distraction. However, it was successfully corrected without negative effects on the final outcome of the prosthetic rehabilitation.

Therefore, it can be summarized that, despite adverse events in 21.6% (8 of 37) of the patients (5 cases of inclination of the distracted segment, 1 case with insufficient callus formation, 1 case of mandibular fracture, and 1 case of insufficient distraction), only in the patient with insufficient distraction was the final outcome partially compromised (2.7%). It was in fact necessary to use shorter implants than had been originally planned; these implants had to be restored with longer suprastructures, resulting in a less-than-ideal esthetic outcome. These implants are still in service and may be considered successful according to the criteria of Albrektsson and coworkers.

CONCLUSION

Despite the limited number of patients and implants studied, the following conclusions can be drawn:

1. Alveolar vertical DO has proven to be a reliable and predictable technique, as demonstrated by this study and others.
2. Vertical bone gain may reach more than 15 mm using DO without the use of bone transplantation; thus, morbidity is reduced with this technique.
3. The bone gain reached at the end of distraction appears to be lasting.
4. The risk of infection of the surgical site was extremely limited.
5. The survival rate of 100% and success rate of 94.2% seem to confirm that implants placed in the tissue generated by DO can successfully withstand the biomechanic demands of implant loading. The results obtained with implants placed in distraction-generated tissue were comparable to the results obtained in cases of implant placement in native, residual alveolar bone.

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