Anterior Maxillary Alveolar Distraction Osteogenesis: A Prospective 5-Year Clinical Study

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Purpose: *Anterior maxillary alveolar vertical distractions were followed for a 5-year period of time.* ***Materials and Methods:*** *A total of 30 vertical distractions were done in 28 patients. Two patients had both anterior maxilla and anterior mandibular distractions for a total of 30 distractions. Two distraction techniques were used: an implant device (3i) and an orthodontic screw device (Osteomed) for orthodontic attachment. Both devices enabled some horizontal as well as vertical movement. The average net vertical distraction was 6.5 mm, but the average anterior horizontal movement was less than 2 mm.* ***Results:*** *Eighty-four implants were placed, but 8 implants failed to integrate.* ***Discussion:*** *All failed implants had been placed in poor quality bone that needed bone grafting. The most common restoration was a fixed prosthesis supported by implants; the longest follow-up post loading was 4.4 years.* ***Conclusion:*** *This clinical study gives additional evidence in favor of the stability and utility of vertical distraction procedures in the maxillary esthetic alveolar zone.* (INT J ORAL MAXILLOFAC IMPLANTS 2002;17:52–68)

Key words: *alveolar distraction osteogenesis, alveolar orthognathic form, alveolar orthognathic position, alveolar projection, avascular necrosis, crestal bone, distraction screws, horizontal distraction, implant esthetics, LeFort I osteotomy, osseointegration, overdistraction, regenerate, segmented osteotomies, temporary distraction implant, Utah paradigm, vertical alveolar distraction*

The principle of distraction osteogenesis (DO), although well established in endochondral bones of the exoskeleton[1–21] and more recently applied to the craniofacial skeleton,[22–36] has not been studied extensively for the human dental alveolar process.[37–46] Most clinical reports have been in the form of case reports. However, a recent series was reported by Gaggl and associates, who used an intra-alveolar device that served as the restorative implant following distraction.[40] In their study, 35 patients were treated with 62 distraction implants with an average distraction vertical gain of about 5 mm. However, the follow-up of this series was only 9 months after prosthetic loading with a total of 18 distractions done in the maxilla.[42]

Though the alveolar distraction procedure can be employed in any alveolar area of the jaws, the anterior maxilla is where alveolar distraction is most likely to be required as a definitive treatment modality because of the failure of other techniques to consistently establish both sufficient volume of vertical bone for implants *and* satisfy esthetic demands.[47–53] Whereas grafting procedures to gain height in the posterior maxilla and mandible are mostly concerned with volume and not esthetics, various strategies employed to gain sufficient vertical height can be applied without critical regard to final alveolar form.[54–64]

The alveolar location then, where distraction osteogenesis may possibly serve as a preferred tool for practitioners and is likely to gain favor for long term clinical use, is in the exposed alveolar zones of the anterior maxilla and on occasion in the anterior mandible. For this reason, a prospective clinical study was carried out over a 5-year period in order to verify the efficacy of alveolar distraction osteogenesis as it relates to implant placement in the anterior maxilla, and to critically evaluate post-distraction alveolar form and dental restorative esthetics.

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Specific questions to be addressed by the study were: Can satisfactory implant-supported dental restorations be established using distraction osteogenesis? What is the best approach when there is a bone width deficiency as well as a vertical deficiency present? What is the preferred timing for implant placement after distraction? Can esthetically favorable restorations be consistently fabricated following alveolar distraction? These questions have been essentially unanswered by available clinical reports or animal studies.[65–71]

The overarching question posed was whether or not alveolar distraction osteogenesis can do any better as a bone augmentation technique than available established bone grafting protocols.[72–78]

MATERIALS AND METHODS

A prospective clinical study was designed for a set of 25 patients who presented with anterior maxillary defects that had at least 4 mm of vertical bone loss. The patients were selected consecutively over 16 months starting in February 1996 and followed annually for a 5-year period.

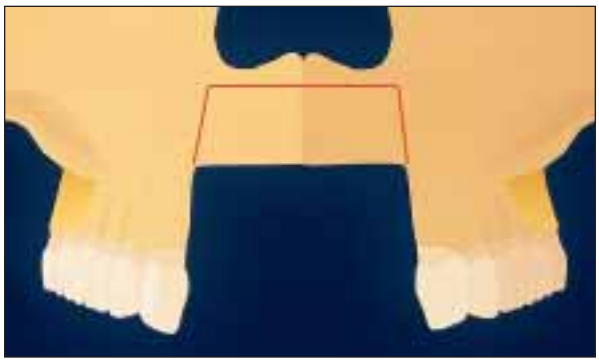
For all cases, dental casts were obtained and measurements were correlated clinically based on an idealized diagnostic wax-up keyed to normal adjacent dento-alveolar anatomy. A clear acrylic resin diagnostic template made for use during surgery demonstrated the amount of vertical and horizontal defects present in desired implant locations. Using guide holes, the exact measure in millimeters of both horizontal and vertical bone loss was made. The surgical guides were used to place distraction devices and later implants into the augmented alveolus.

Each treatment plan was designed individually, but all had similar surgical approaches to test the stability and functional result of the alveolar distraction. Following avulsion injury or extraction of diseased teeth, a 6-week period of time was allowed for mucoperiosteal healing. Then, a full-thickness circumvestibular incision was made high in the vestibule which extended laterally about 5 mm beyond the defect margins. While avoiding stripping of the periosteum from the crestal alveolar process inferiorly, the flap was advanced superiorly until the nasal apertures were identified.

The anterior nasal spine was exposed and served as a landmark for a horizontal osteotomy cut about 3 to 5 mm below the floor of the nose, which extended through the alveolus on the palatal side without disturbing the palatal mucosa. An oscillating saw rather than a drill was used for this procedure. Slightly tapered vertical osteotomy cuts were made a few millimeters medial to the teeth roots bordering the defect. These cuts connected the horizontal cut in such a way that a trapezoid shape and not a square shape or undercut line angle was created, so that when the segment was freed it advanced and would "draw" both vertically and anteriorly (Fig 1a). At this point, 1.2-mm diameter titanium bone marker screws were placed on each side of the horizontal osteotomy cut for which interscrew measurements were made radiographically as the distraction progressed (Fig 1b). The distraction device was then placed.

If a bidirectional orthodontic approach was needed, then 1 or 2 4.0-mm diameter transcortical distraction screws that had holes through their necks (Osteomed Quick-fix System, Osteomed, Dallas, TX) were placed horizontally through the alveolus with the screw head placed anteriorly to connect to an orthodontic utility wire (Fig 2). The screws extended out through the soft tissue about 3 to 5 mm. The distraction screws perforated inferior to the circumvestibular incision through the mucoperiosteal flap overlying the anterior aspect of the alveolar process (Figs 3a to 3d). The fixation screws were placed as far superiorly in the segment as possible to be certain they were well engaged in the broad basal section of the osteotomy segment, but also to allow for vertical transport of the segment without screw interference with the orthodontic utility or arch wires as the segment was moved to a more inferior-anterior position in the mouth. (Placement of the distraction screws too far crestally limits the amount of movement the segment can undergo before the distraction screws engage the arch wires.)

In most cases, the distraction screws were positioned at least 10 mm superior to the arch wire. This was sufficient to allow for a 5- to 10-mm vertical movement and up to 5-mm horizontal distraction of the segment. Generally, where there were 2 to 4 missing teeth, 2 distraction screws were sufficient. After the bone markers and the distraction screws were in place and measurements made both clinically and radiographically, an osteotome was used to complete the osteotomy cuts to free the segment, taking care to avoid injury to the palatal mucosa or papillae adjacent to the bordering teeth. The freed osteotomy segment was then tested with traction to see if it would draw both vertically and horizontally. At this point, most segments move about 4 mm vertically. The segment was then closed back down to a small gap of about 1 to 2 mm and then connected to the orthodontic utility wire by the eyelet holes in the distraction screws. In this passive position, the wound was closed in 2 layers and left to heal for 7 days (Fig 3d).



Figs 1a and 1b The design of the study included a segmental osteotomy with bone marker screws placed on each side of the horizontal distraction osteotomy to measure the amount of distraction radiographically.

Fig 2 A special screw was designed for the study to allow for orthodontic traction. The screw had an eyelet hole placed in the neck of the 2.4-mm-diameter screw for an orthodontic wire.

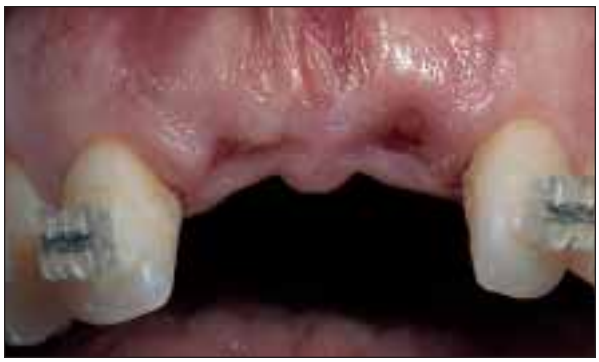


Fig 3a Six weeks following avulsive loss of Nos. 8 and 9, alveolar facial plate, and interseptal bone.

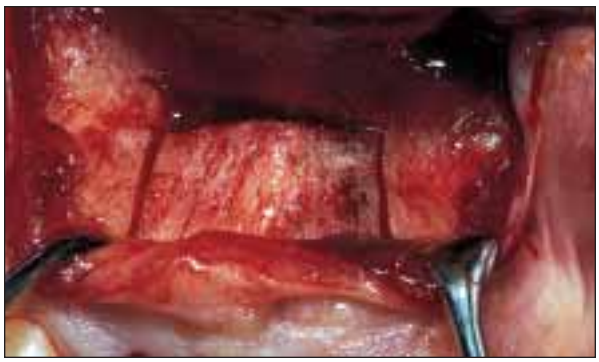


Fig 3b A "drawable" distraction osteotomy was done.

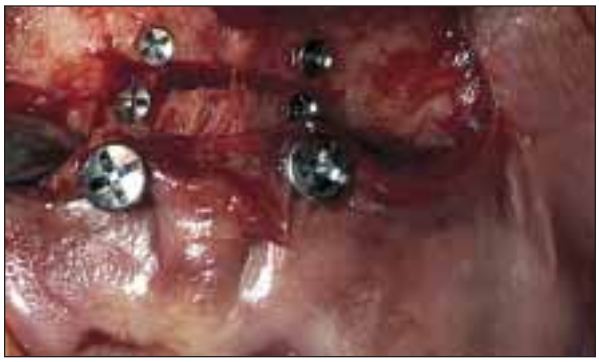


Fig 3c Bone markers were placed.

Fig 3d Distraction screws were placed horizontally in the mobilized segment.

The protocol included antibiotic prophylaxis with amoxicillin, which was continued for a 1-week period.

At the 1-week postoperative appointment, the wound was inspected for primary closure. The segment was then moved vertically 1 mm, 3 times per week for about 2 weeks using a cinch wire technique (Figs 4a and 4b). The segment tended to bind unless moved uniformly with this approach, which was followed visually as well as radiographically using the bone markers (Fig 4c). Horizontal movement was more difficult to judge and was sometimes facilitated by the placement of 1 or 2 1.5-mm-diameter utility screws of at least 10 mm in length, into the palate vertically within the segment. These were then ligated to the arch wire and used to activate (cinch) the segment anteriorly (usually 3 to 5 mm) to complete the final positioning of the transported alveolus to an *alveolar orthognathic position.* The segment was overcorrected somewhat so as to establish sufficient gingival height in an attempt to create papillae interdentally when the implants were placed. After the final position was established, the still mobile segment was fixed and held in place orthodontically for 2 months. Implants were then placed and minor grafting or soft tissue procedures followed in accordance with previously described principles of osseointegration. A 1-stage implant technique was preferred. Final dental restoration commenced 6 months after implant placement (Figs 4c to 4e).

When an orthodontic approach was not taken, a distraction implant (3i Implant-distractor, Implant Innovations, West Palm Beach, FL) was used (Fig 5). The implant is 3.5 mm in diameter and 5 or 7 mm in length with a prominent hole for standard abutment screws, which are available with various lengths from 10 to 22 mm. With this distraction device, the osteotomy procedure was still performed with the above incision and osseous surgical approach, but the distraction implants were placed directly through the crestal mucosa using a template, without making a flap, using standard implant drilling technique directly through the mucosa. This relatively blind procedure was generally easily accomplished, provided there was sufficient width at the crest of the alveolus. The distraction implant was placed and the abutment screw, usually 15 mm in length, was screwed through the distraction implant and through the segment until it engaged basal bone (Figs 6a to 6d).

The screw was positioned into the marrow space or a notch was created in the basal bone so that a secure pivot point was established. A foot plate was not required. The distraction was then "tested" by tightening the abutment screw until about a 4-mm distraction was observed. The distraction site was then closed down and the wound was closed in 2 layers. The patient was seen 1 week later for activation following a thrice-weekly protocol as above. In a few cases, orthodontic wires were also in place so that it was possible to anteriorize the segment with this device, which pivoted and allowed a few millimeter anteriorization of the segment. This was done by either attaching to an extended abutment screw off the distraction implant, or by placing a 1.5 $\times$ 10 mm utility screw vertically through the segment as an aid for anterior orthodontic traction (Figs 7a and 7b). Following distraction, the segment was left in place for 2 months and then the distraction implant was removed with reverse torque, which was easily done. In the same receptor site (though not always as the segment sometimes moved the implant site slightly off of an ideal axial location), a conventional, 4-mm-wide 1-stage implant (3i Osteotite, Implant Innovations, West Palm Beach, FL) was placed and left to integrate for a 6-month period prior to restoration.

Following finalization of the prostheses, especially when implant crowns were involved, an effort was made to make an esthetic appraisal of the final restoration. A restorative index was created scaled from 1 to 10, with 1 being an extremely poor result and 10 being a superlative esthetic result. The index was based on combined objective and subjective criteria as shown in Fig 8. For a "good result" to occur, the restored implant had to be of the same shape and size as the contra-lateral tooth, it had to blend into the arch, it had to have papillae on either side of the tooth, and the gingival form and coloration had to be within acceptable limits (Figs 9a and 9b).

Follow-up methods used computer-based radiography, which traced the relation of bone levels to thread levels on these implants. Initially, X-rays were taken monthly for 6 months; they were subsequently taken at 12-month intervals. Following restoration, gingival levels on the date of the final restoration were compared annually at the papillae and marginal gingival areas by measuring changes in tooth exposure from the incisal edge.

RESULTS

Over an 18-month period from February 1996 to July 1997, 28 consecutive patients with anterior maxillary vertical defects were treated with distraction osteogenesis for 30 alveolar segments. (Two patients had mandibular anterior alveolar distractions done concurrently with the maxillary procedure.)

Fig 4a The eyelet distraction screw is used to distract the segment down and forward using a utility arch wire.

Fig 4b Some forward movement of the segment can be obtained without the use of a head gear because of the mobility of the segment. In this case, a 12-mm vertical and 4-mm horizontal distraction was done.

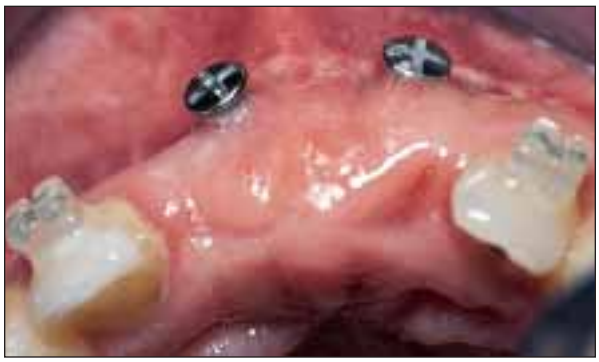


Fig 4c The presentation of distraction screws following removal of orthodontic wires.

Fig 4d *(Right)* Two months after the cessation of distraction, exposure of the area reveals the distraction site at the time of implant placement.

Fig 4e Restorative result 3.5 years after final restoration.

Fig 5 *(Right)* A 5- or 7-mm length 3.5-mm diameter titanium implant was modified with an open apical portion to allow for extended abutment screws.

Fig 6a The implant distraction screw was placed using a non-flap approach through the alveolus. A long abutment screw passes through the end of the implant and distracts the segment. A foot plate was not needed as it was placed into the basal bone by direct vision and screwed into the bone until a firm "footing" was obtained.

Fig 6b The segment was then distracted.

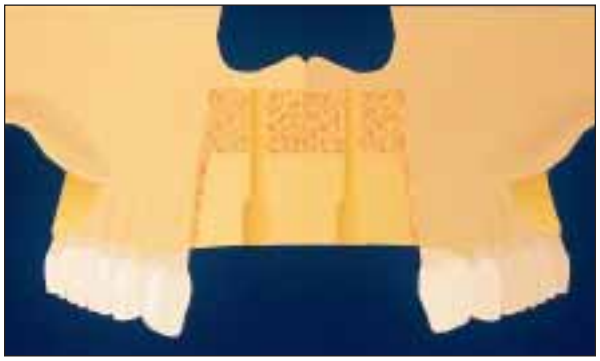


Fig 6c The segment was maintained post-distraction to allow for consolidation of the regenerate.

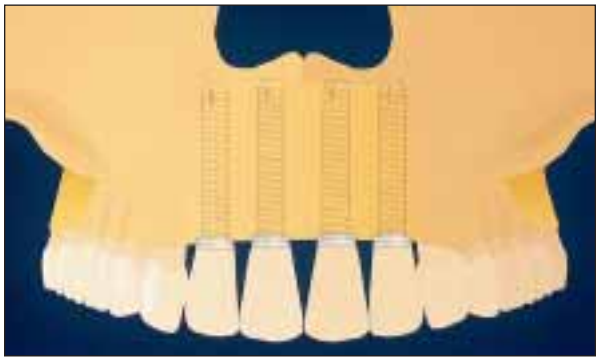
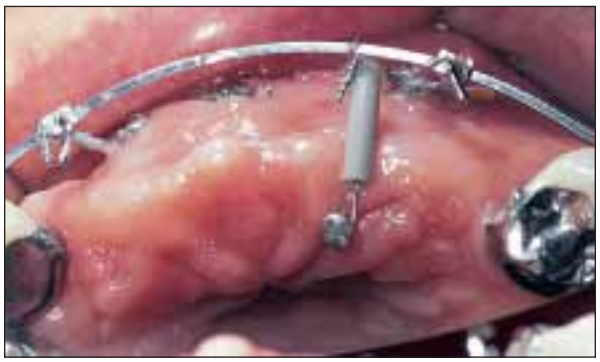


Fig 6d Implants were placed following the consolidation of the regenerate.



Figs 7a and 7b Use of the implant distraction allows only for a vertical move, which is often a net vertical palatal move. A 1-mm-diameter screw is placed and is vertically used to pull the segment anteriorly after it has been distracted vertically and has some mobility. The vertical utility screw can be secured with a small gauge wire to the teeth, prosthesis, or an arch wire to allow for a 3- or 4-mm horizontal move of the segment.

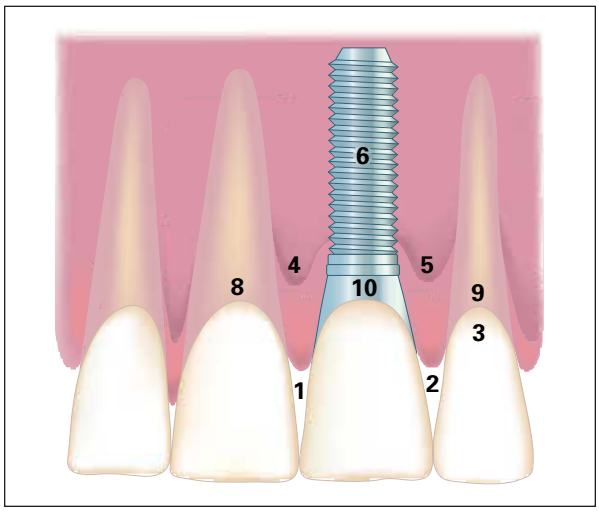
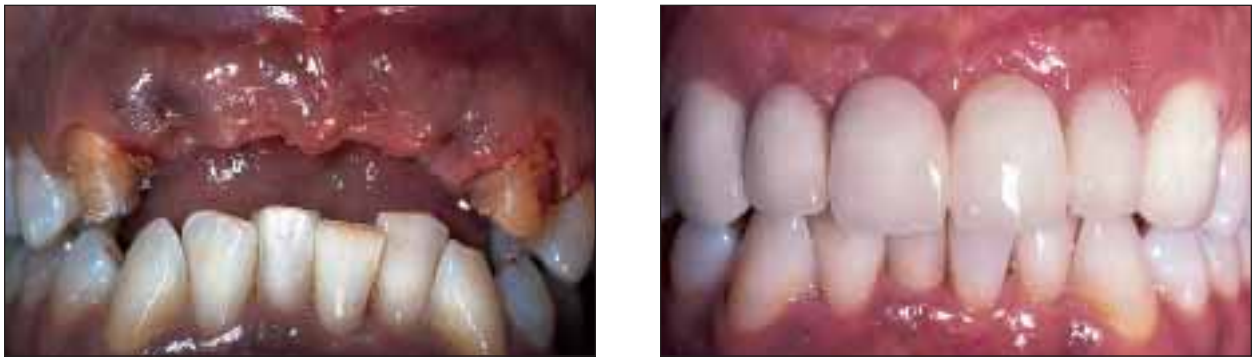


Fig 8 Esthetic restoration of a single incisor tooth requires optimization of the above 10 factors as follows: The mesial papillae (1) is perhaps the most important feature to maintain in an implant case, followed closely by the distal papillae (2). The marginal gingiva (3) should be close to the adjacent marginal gingiva (8,9) and is next in importance. To maintain the papillae, intercrestal bone needs to be maintained (4,5). The implant integration, depth, and angle (6) help establish the emergence angle (10). Whenever any one of these items is compromised, the esthetics will also be compromised.



Figs 9a and 9b A patient with severe periodontitis who, 6 weeks following extraction of the teeth, (a) presents with a 7-mm vertical alveolar defect, which was distracted and a fixed prosthesis was fabricated (b) which facilitated anatomic papillae and an esthetic result.

Table 1 lists patients by classification of bone loss found at the time of initial examination. Fourteen of the 28 patients had traumatic injury, 4 patients had severe bone loss related to periodontitis, 2 had failed implants, 9 patients had failed bone graft attempts, 7 patients presented with severe vertical atrophy, and 7 patients had had multiple surgical procedures in the defect area. Soft tissue cicatrix was present in 18 patients, which usually involved significant loss of attached gingiva and total mucosal volume.

Vertical defects ranged from 4 to 15 mm. The horizontal defects were also measured and ranged from 0 to 10 mm. The average vertical defect was 6.5 mm and the average horizontal defect was about 2 mm. Tooth numbers corresponding to the defect sites are listed in Table 1.

Table 2 lists preoperative bone and soft tissue grafting experience.

Table 3 shows the vertical and horizontal distraction accomplished on each patient. Three to 15 mm of vertical distraction was accomplished with a mean distraction of 6.5 mm (SD ± 1.4 mm). A total of 11 patients had anteriorization of the distracted segment. The farthest horizontal distraction was 10 mm, the least, 4 mm. Eleven segments moved palatally during the distraction and ended up in a horizontally negative position (–1 to –4 mm). Five segments were in a neutral position after the completion of distraction, having neither loss nor gain in horizontal position.

Relapse of the segment occurred in 14 segments, with 1 segment completely regressing a distance of

Table 1 Correlation Between Tooth Numbers and Defect Sites

Patient	Trauma	Vertical defect (mm)	Horizontal defect (mm)	Teeth involved
JA	Avulsion	5	0	8,9
SB	Baseball	7	4	8–10
GW	Steering wheel	8	0	7–10
JC	Avulsion	4	0	8,9
TS	Atrophy	5, 3	0	18–20, 9, 10
NM	Steering wheel	8	0	7–9
JJ	Atrophy	4	0	8, 9
WH	Industrial accident	4	0	4–8
ID	Traumatic extractions	8	0	8, 9
JD	MVA	5	0	7–9
TG	Atrophy	3	3	7–10
MS	Atrophy	7	4	6–8
SB	Football	8	3	9, 10
JS	MVA	6	0	7–10
TC	MVA	5	0	8, 9
DN	Atrophy	7	2	9–11
RE	Industrial accident	7, 15	0	7–10, 23–26
PP	Periodontal	12	0	7–9
FA	MVA	8	0	7–9
AS	Periodontal	7	0	7–10
SS	Avulsion	7	0	7–10
BG	Introgenic implants	8	0	8, 9
GW	Atrophy	5	10	5–12
TE	Atrophy	12	5	7–10
WH	MVA	4	0	
GL	Periodontal	4	0	7–10
JT	Atrophy	6	1	7–10
JM	Introgenic implants	3	2	8, 9

Of the 28 patients who had 30 distractions, the initial lesions were mostly traumatic, with most vertical defects between 5 and 10 mm. The majority of the segments were anterior maxillary 2 to 4 tooth segments, and 2 patients had concomitant mandibular segments.

10 mm during the early postdistraction phase because of distraction device failure. However, most regressions were minimal, usually 1 mm or less (mean 1.6 ± 1.5 mm).

Secondary bone grafting was required in 18 patients. Gingival augmentation procedures were done in 12 cases. (These procedures were all done after implant placement as shown in Table 4.)

Table 5 lists bone quality, the devices used, and device failures.

Restorative procedures done in the distraction zone included the placement of implants, crowns, fixed prostheses, overdentures, and conventional (nonimplant) dental treatments (Table 6). Eighty-four implants were placed. Eight implants failed to integrate (9.6%), all of which were lost prior to restoration. Six of the failed implants were replaced and restored in the course of the study so that a total of 84 implants were followed for at least 3 years postrestoration. During this period, the implants maintained stable bone levels (1 mm or less bone loss, SD ± 1.3 mm) and remained well integrated with stable gingival esthetics (1 mm or less gingival recession, SD ± 1.2 mm) during the course of the study.

According to evaluations made over the course of the study, there were no superlative results. Sixteen distraction restorations were graded as either 8 or 9. These categories required papillae and esthetic crown forms to be present, but had some relatively minor deficiency present. Eight cases were scored as either 6 or 7, indicating less than optimal

Table 2 Preoperative Bone and Soft Tissue Grafting Experience

Patient	Failed grafts	Cicatrix
JA	No	Yes
SB	No	Yes
GW	No	No
JC	No	No
TS	No	No
NM	No	Yes
JJ	No	No
WH	No	Yes
ID	No	No
JD	No	Yes
TG	Yes	Yes
MS	No	No
SB	Yes	Yes
JS	No	Yes
TC	No	No
DN	No	No
RE	No	Yes
PP	Yes (3)	Yes
FA	No	Yes
AS	No	No
SS	No	No
BG	Yes (3)	Yes
GW	Yes (3)	Yes
TE	Yes	Yes
WH	Yes	Yes
GL	Yes	Yes
JT	No	Yes
JM	Yes	Yes

Many of the patients presented with a history of failed grafts or implants prior to distraction. Severe cicatrix was present in 18 out of 28 patients.

Table 3 Vertical and Horizontal Distraction Accomplished on Each Patient

Patient	Distraction period		Stability regression
	Vertical (mm)	Horizontal (mm)	
JA	5	0	0
SB	7	4	2
GW	8	0	4
JC	4	0	0
TS	5, 3	0	0, 3
NM	8	0	4
JJ	4	0	0
WH	4	0	0
ID	8	0	3
JD	5	0	0
TG	3	3	3
MS	7	4	0
SB	8	3	2
JS	6	0	0
TC	5	0	0
DN	7	2	0
RE	7, 10	0	3, 4
PP	10	0	10
FA	8	0	4
AS	7	0	0
SS	10	5	0
BG	8	0	0
GW	15	10	4
TE	10	5	0
WH	4	0	0
GL	10	4	—
JT	12	6	1
JM	9	3	2

The distractions averaged about 6.5 mm vertical, but less than 2 mm horizontal. There was generally good stability, but 14 out of 28 maxillary cases had at least 1 mm regression and 1 case totally relapsed.

esthetics usually because of the crown or alveolar form still being deficient following the restoration. These cases usually had abbreviated or absence of papillae or the final crown length was still long relative to adjacent teeth. One case failed and had no improvement from the preoperative finding, and the distraction segment eventually completely resorbed.

DISCUSSION

Despite the 5-year span for the study, the follow-up is still relatively short and very limited in its focus of 2 to 5 tooth segments for the anterior maxilla. Thus, it is difficult to make firm conclusions that will pertain to the entire alveolus in both the maxilla and the mandible. A question arises as to the validity of the operation as follows: Is there sufficient biologic basis for this procedure to be recommended, and if so, what are the end-point parameters where the procedure should not be attempted because of the risk of vascular embarrassment?

It is well understood in orthognathic surgery that segmental procedures, especially in the maxilla, are very well vascularized but there are several reports of loss of entire segments of bone from Lefort I or maxillary segmental osteotomies.[79–81]

Table 4 Secondary Bone Grafting and Gingival Augmentation Procedures

Patient	Bone grafting	Soft tissue grafting	Device type	Bone quality
JA	No	Yes	Osteomed	Adequate bone
SB	Yes	Yes	Osteomed	Poor bone
GW	Yes	Yes	Osteomed	Poor bone
JC	No	No	Osteomed	Adequate bone
TS	No, Yes	No	Osteomed	Adequate bone
NM	Yes	Yes	3i	Poor bone
JJ	No	No	Osteomed	Adequate bone
WH	No	No	Osteomed	Poor bone
ID	Yes	Yes	3i	Adequate bone
JD	Yes	No	3i	Adequate bone
TG	Yes	No	Osteomed	Adequate bone
MS	No	No	Osteomed	Adequate bone
SB	Yes	Yes	Osteomed	Adequate bone
JS	Yes	Yes	Osteomed	Adequate bone
TC	No	No	Osteomed	Adequate bone
DN	No	No	3i	Adequate bone
RE	Yes, Yes	No	3i, 3i	Adequate bone
PP	Yes	Yes	Osteomed	Poor bone
FA	Yes	Yes	Osteomed	Poor bone
AS	No	No	3i	Adequate bone
SS	No	No	3i	Adequate bone
BG	No	Yes	3i	Adequate bone
GW	Yes (combined)	Yes	Osteomed	Adequate bone
TE	Yes	No	3i	Poor bone
WH	Yes	No	Osteomed	Poor bone
GL	Yes	No	Osteomed	Poor bone
JT	Yes (combined)	No	Osteomed	Poor bone
JM	Yes	Yes	Osteomed	Poor bone

Secondary bone grafting or soft tissue grafting was required in half of the cases treated. Poor bone quality was evident in 11 cases and contributed to device failure. Ten distractions used 3i distraction screws and 20 distractions used the modified eyelet screw with orthodontics.

Table 5 Bone Quality and Device Failures

Patient	Intraoperative device No.	Device failure
JA	1	No
SB	2	No
GW	2	No
JC	1	No
TS	4	No
NM	2	Yes
JJ	1	No
WH	1	—
ID	1	Yes
JD	1	No
TG	1	Yes
MS	2	No
SB	2	No
JS	1	No
TC	1	No
DN	2	No
RE	1, 1	Yes, Yes
PP	1	Yes
FA	1	Yes
AS	2	No
SS	2	No
BG	2	No
GW	2	No
TE	2	No
WH	2	No
GL	3	No
JT	2	No
JM	2	No

Number and type of bone screw distraction devices used on each case. In severe cases, there was at least some relapse because of device slippage; mostly the result of poor fixation in poor quality bone.

With the vestibular incision approach rendered here there is still a broad band of attached tissue on the facial and *crestal* bone, and the entire palatal mucosa remains undisturbed, as long as there is not incidental tearing or cutting of the flap during manipulation of the segment. The rationale here is that there will be less bone stability because of vascular disturbance at the crest if crestal soft tissue reflection is done.[82] In the avulsion or trauma patient, there may be a marked decrease in vascularization present in any case and cautious exposure of the segment is probably warranted.[83,84]

Marrow vasculature is interrupted by the trauma of osteotomy surgery, but healthy marrow will start to revascularize within 24 hours and start to become well established within 5 to 7 days.[85,86] Allowing for this latency period helps secure an *endosteal* revascularization potential for the mobilized segment that then participates in supporting matrix proliferation as distraction osteogenesis progresses. In long bones, transport blood supply is mostly from intact periosteum. Indeed, for 3 months following distraction surgery, the blood flow is 7 times normal.[87] Investing tissues, including alveolar facial plate periosteum (where the incision was made in this study), undergo primary healing but may have a limited role in early distraction bone formation as disrupted periosteum will not be fully functional up to 6 weeks after

Table 6 Restorative Procedures

Patient	Implant placement		Implant restoration	Conventional fixed partial prosthesis	Overdenture
	Implants	Implant failure			
JA	3	0	3	No	No
SB	3	2	3	No	No
GW	2	2	2	No	No
JC	2	0	2	No	No
TS	5	0	5	No	No
NM	2	2	2	No	No
JJ	2	0	2	No	No
WH	8	1	8	Yes	No
ID	2	0	2	No	No
JD	3	0	3	No	No
TG	0	0	0	Yes	No
MS	3	0	0	No	No
SB	3	0	0	No	No
JS	2	0	0	No	No
TC	2	0	0	No	No
DN	4	0	4	No	No
RE	2	0	0	No	No
PP	0	0	0	No	No
FA	0	0	0	No	No
AS	0	0	0	Yes	No
SS	2	0	2	No	No
BG	2	0	2	No	No
GW	8	0	8	No	Yes
TE	5	1	4	No	No
WH	5	0	5	No	No
GL	0	0	0	Yes	No
JT	10	0	10	No	Yes
JM	4	0	4	No	No

Eighty-four implants were placed but 8 implants failed, 6 of which were replaced and later integrated. Implant restorations were mostly conventional cemented crowns and fixed partial dentures.

reflection because of disruption of the cambian layer and depolymerization of collagen in the fibrous layer of the periosteum.[88,89] Oda and coworkers found there was increased bone formation in the distraction site on the lingual (nonreflected periosteum) side.[71] So it would appear that endosteal proliferation within the osteotomy defect combined with palatal periosteal expansion partake in formation of the early distraction callus. In any case, the less periosteal reflection, ie, the less surgical trauma, the more highly responsive the distraction site healing is likely to be.

As the distraction progresses, the rate of 0.5 to 1 mm per day is used as a guide and appears to be confirmed in animal studies for both long bones and maxillofacial bones.[90,91] However, successful distraction frequency has been demonstrated in regular, sporadic or continuous modes. The type of bone being distracted may require a certain daily frequency to obtain optimal results. Aronson found in a long bone experimental study that the best distraction rate in diaphyseal bone was 0.5 mm per day, while in metaphyseal bone the optimal distraction rate was up to 2 mm per day, which suggests

that the marrow-vascular component plays a significant role in distraction healing.[91] Gaggl and associates also recommended 0.5 mm per day movement using the alveolar distraction implant, but only to not compromise integration of the device.[40] In any case, the absolute optimal daily rate may not be as important as the force per unit of time for which it is done. In 1 in vivo study, the magnitude of the mechanical stimulus was found to play a much greater role in osteogenesis than the frequency of the applied force.[89,90]

Implied by this is a favorable force limit, for which bone fails to form and soft tissue forms instead. Optimal microstrain forces are as yet not well defined for distraction osteogenesis, nor are there clinical measuring devices available for use. A judicious force of distraction, such as a fractionated (¼ mm) 4 times per day routine, may be less disruptive to extension by Type I collagen formation. However, this can only be inferred at this point. Another study by Aronson looked at failed distractions in long bones and the causative factors for them and found that there were 4 categories of failed distraction osteogenesis: *(1)* ischemic fibrogenesis caused by arterial disruption, *(2)* cystic degeneration related to obstructed venous return, *(3)* nonunion, which was categorized as device fixation failure, and *(4)* late buckling or fracture usually caused by premature removal of fixation.[21] It would seem that all of these could also occur in the maxillofacial skeleton, despite its increased vascularity and greater capacity to withstand a more extensive periosteal reflection.[91]

Though union of the segment may still occur in rapid distractions of 2 mm or more per day, the mechanism of union may become one of healing of a critical gap or fracture healing repair and not distraction osteogenesis.[92] Bending or shear forces have been shown to induce fractures of microcolumns with local hemorrhage and subsequent retarded bone development when fixation is inadequate which suggests that (not only) stability of the fragments is important but that the magnitude of the force plays an important role as well.[93] This concept is supported by the theory of the Utah paradigm, which states that bone forms proportionate to favorable mechanical forces in an intrinsic "nephron equivalent" physiology.[94–103] That is to say, osseous healing does not occur because the right bone forming cells are there, but rather because these cells have been activated by favorable mechanical strain and not just humoral stimulation. And furthermore, the activation and continued operation of these bone forming cells relates to *specific* magnitudes of defined mechanical strain, which though still not delineated, suggest both an upper and lower operational threshold.[104]

In this study, the magnitude of force was not measured and in many cases the displacement distraction was not strictly quantifiable because of the flexion of orthodontic appliances or the nature of the devices used. Also, the approach was to use a sporadic, 1 mm every other day activation frequency because of clinical practicality. It seems (at present) unlikely that for vertical alveolar movements the clinician can expect that patients will always be able to adjust appliances on a daily basis. In any case, there may be no measurable difference in the final result when compared to a daily adjustment protocol, as the frequency of segment activation is not as important as the magnitude of the force.[90–91] It was found in 1 dog study that distraction can still occur with a latency of up to 21 days before osseous union and distraction is not possible.[90] Lability within the maxillary regenerate was observed for at least 3 weeks after the osteotomy procedure, suggesting that there is considerable leeway in a frequency protocol.

In this study, the latency period of 1 week was chosen so as to ensure primary soft tissue healing. Immediate distraction starting at day 1 of surgery, though successful in the dog model, should be avoided clinically lest inadvertent wound dehiscence develops and the osseous regenerate becomes exposed to the oral environment. Thus, a guideline for starting distraction 4 to 7 days after the osteotomy surgery seems justified.[105–107]

Facial exposure of the distraction site 2 months after the cessation of distraction in most cases showed areas of poor ossification, or scar tissue, indicating the presence of small osseous defects despite bony union and segmental stability. This most often was observed in cases where both a vertical and horizontal movement was done, which may indicate that the bidirectional force disturbed the fragile isotropism of the regenerate. Also, it was observed that in some cases there was a thinning of the alveolus (a reduced bone volume) in the facial regenerate zone, which was indented and sometimes inconsistent in its mineralization. This occurred in distractions of greater than 5 mm, which still showed patches of radiolucency 1 year after the osteotomy was done. However, these findings did not appear to influence the overall augmentation result significantly. One case in this study with a 12-mm vertical and 4-mm horizontal distraction showed a central radiolucent defect 5 years after the distraction procedure, which was of no clinical consequence.

The rather high implant failure rate of almost 10% in a region of the mouth where generally only a

small percentage of implants fail, suggests that the osteotomy procedure did not fully provide adequate bone for osseointegration. However, it was difficult to get adequate primary stability of many of the implants which eventually failed. The loss of implants could also have been the result of the traumatic nature of the cases, as all the implants lost were in trauma cases. The bone quality in these cases were generally Type III, rarely Type IV. But these same cases had some compromise observed within the distraction zone where presumably mineralization was incomplete and could have contributed to implant loss. The implants that were lost all required bone grafting of dehiscences in the regenerate zone or near the crest of the alveolus. This could have also been a factor in the loss of implants. The need for grafting in distraction osteogenesis when implants are planned will frequently be an issue. In long bones, Aronson reported that in 100 consecutive long bone distractions, including adults and children, 11 cases subsequently needed to be treated with bone grafts.[91] The consideration of whether to bone graft or distract or both and the timing for each procedure is now left to the judgment of the practitioner until there is further refinement and development of the procedure.

Implants were placed about 10 weeks after surgery, or about 8 weeks after the distraction had been completed. A dog study indicated that early placement of implants led to osseointegration in the regenerate as early as 5 weeks after distraction osteotomy in the mandible.[108] Whether it might be better to wait longer than the 8-week timeframe used in this study, at least until consolidation occurs, is uncertain. But it appears that osseointegration within the regenerate occurs just as well as in native bone.

Implants in this study extended through the regenerate into the basal bone. However, another animal study by Block and associates showed that implants that extended only into the regenerate and then were loaded for a 1-year period maintained stability and were well integrated at sacrifice.[108]

A comment should be made on the use of the *temporary* distraction-implant used in this study that was removed rather than restored. The rationale for use of a temporary distraction implant is threefold:

1. A *prosthetic* distraction-implant device, though laudable in its ingenuity, carries additional risk for infection. This happens either through its internal mechanism by bacterial tracking, or at the bone-implant interface that is being mechanically activated at a critical time during osseointegration healing, so that final osseointegration content may be reduced.
2. The placement of the prosthetic implant device may compound variables if there is a dehiscence. A greater reflection of tissue is required to place it and, therefore, it is more likely to have less stable crestal bone. In some cases, there may be a millimeter or more of bone resorption following distraction, resulting in a relatively high profile implant. The use of additional countersinking to anticipate this may undermine a small transport segment. It becomes, in a sense, compromise and guesswork.
3. The prosthetic distraction-implant orientation may not end up in an ideal axial location, especially if a higher magnitude distraction such as greater than 5 or 6 mm in vertical height is needed. It may be prosthetically desirable to place the distraction implant very close to the vertical osseous cuts, which can compromise the fixation of the device.

Also, the esthetic accuracy of conventional implant placement in the anterior maxilla is difficult to match predictably with a prosthetic distraction-implant method, which may be better suited for posterior locations. In short, the implant design in this study sought to avoid these potential disadvantages in favor of removal as an interim device so as to achieve both well located and well defined osseointegration, as well as optimal dentoalveolar esthetics. There is a weakness to this design in that in those cases where the devices slipped, it was due to inadequate fixation of the implant portion of the devices.

As a practical matter, more that half of vertical defect cases actually have both vertical and horizontal deficits. How and when the horizontal defect should be addressed is probably the first clinical decision to be made. It is sometimes possible to "overdistract" *past* the horizontal defect, so that grafting for width can be avoided. In this study no bone grafting was done prior to the distraction procedures by the authors. In retrospect, and as is current practice, it is preferable to bone graft for width first, and following consolidation of the graft at 4 months, distract to the final alveolar form and then place implants in a third surgical procedure.[77] This 3-surgery approach may be needed in even moderately ablated cases to obtain the desired result. For now, the use of combined bone grafting (for width) and distraction procedures (for height) still needs more investigation. The cost of 2 augmentation procedures, 1 for width and 2 for height, may be prohibitive in many cases. However, in many cases soft or hard tissue grafting can be done at the time of implant surgery.

The osseous volume of the transported segment must be sufficient for appliance fixation, but should also be of sufficient bone volume to minimize the risk for resorption of the segment. The transport segments in this study were generally about 8 to 10 mm in vertical measure. But also, the segments were at minimum 2 teeth in alveolar span. Single tooth osteotomies have had the highest complication rate in orthognathic surgery because of devascularization, so it would seem wise to be wary of single-tooth distraction procedures because of a probable increased incidence of complication.[81] There are now incidences of complete resorption of the transport segment following attempted distraction procedures being reported, which are most likely due to vascular embarrassment.[108] The smaller the segment, the more likely there will be difficulty with device fixation as there will be less places for screw fixation. In this study, there were several instances of device slippage because of this issue. Early on a 5-mm length distraction implant was thought to be adequate, but this was changed to 7 mm in length to improve the fixation capacity. Screw fixation loosened during the holding phase on occasion, with most of these occurring in compromised bone. Selection of the device type and the size of the segment to be osteotomized are critical decisions that are best made at the time of surgery under direct vision, since one can be deceived by radiography or dental casts. When there is insufficient quantity or quality of bone to distract, the surgeon should be prepared to bone graft to gain width for a future distraction procedure. This is something that could have been done in several of the cases reported here that ended up with less than an ideal esthetic result.

The location in the dental arch where distraction osteogenesis will be most valuable is in the anterior alveolar areas. In the posterior mandible, the use of such procedures as the combined iliac and implant fasted graft, or the use of high profile implants and membrane to support bone grafts, have been employed with some success.[57,72] However, most grafting procedures have advanced the idea of gaining needed width in the area of the mandible being grafted and have found this useful enough in the majority of atrophic cases.[61] The use of orthognathic procedures in the resorbed posterior mandible, where nerve injury may occur because of technical difficulty and where loss of the transport segment may be more likely to occur because of a relatively poor blood supply, must be balanced by the perceived need to decrease crown root ratio.[109] The risk-benefit ratio of orthognathic procedures can be relatively high when compared to alternative procedures such as the use of short implants and/or cantilever prosthetics.[83,109] The least performed segmental osteotomies done by orthognathic surgeons are mandibular segmental osteotomies; within that group, rarer still are anterior subapical procedures. It would appear that the surgeon must have at least 7 or 8 mm of bone above the inferior alveolar nerve in order to make osteotomy cuts and have a large enough segment to fixate to and transport with a given device. This is hard to rationalize with the many short rough surface implants available, some as short as 6 mm in height, with more holding power than standard diameter 10-mm length smooth surface implants.[110–113]

In the posterior maxilla, the sinus graft, will in most cases, obviate the need for an alveolar distraction.[66]

In severe resorption cases, such as Cawood Class IV-VI, iliac or cranial graft reconstruction is required because there is insufficient bone mass in any case to consider distraction osteogenesis as a primary procedure.[114,115] At present, there is only 1 report of the staged use of alveolar distraction after vertical bone graft enhancement in the maxilla.[116]

CONCLUSIONS

A consecutive series of 30 anterior alveolar segmental distraction procedures were done prior to implant placement and prosthetic restoration. Using bone markers in a prospective study design, the average vertical distraction was 6.5 mm. Horizontal distraction was also accomplished using an orthodontic technique attaching the transport segment by special fixation screws. Implants were placed and followed for a 5-year period. Eighty-four implants were placed, but 8 implants failed to integrate for a 90.4% survival rate. Most of the completed restorative cases were judged to have satisfactory esthetic results. However, there were no ideal restorations when judged by critical criteria. One single tooth alveolar distraction segment failed and eventually completely resorbed.

The use of distraction osteogenesis in the alveolar process appears, based on this study, to have a rational basis from both a physiologic and prosthetic standpoint. These results bring the clinician closer to the conclusion that alveolar distraction procedures can now be considered a predictable adjunct in dento-alveolar restoration.

In the majority of cases satisfactory dental restorations were achievable. Bone width deficiency was improved with vertical distraction, but more than half the time, secondary bone grafting was required. It would appear that implant placement 2

months after distraction is a reasonable approach; however, it is uncertain when waiting longer may improve overall implant success rates.

The overriding question of whether or not alveolar distraction osteogenesis can provide better results than conventional augmentation techniques was judged affirmatively, though the risk of the surgical procedure may possibly be somewhat greater than conventional grafting procedures.

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