Alveolar distraction osteogenesis: a systematic literature review

Lili Yang[1], Eduardo Yugo Suzuki[2], Boonsiva Suzuki[3]

[1] D.D.S, Student of Doctor of Philosophy Program in Dentistry, Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University.

[2] D.D.S, Ph.D, Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University.

[3] D.D.S, Ph.D, Associate Professor, Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University.

Abstract

Objective: Alveolar distraction osteogenesis is a viable clinical alternative for vertical, horizontal and interdental alveolar ridge augmentation, and mostly used to regenerate bone for the placement of dental implants, closure of the defect and creation of new bone. This review was performed to analyze the most commonly followed protocols for, and clinical outcomes of, alveolar distraction osteogenesis.

Materials and methods: A PUBMED search was carried out to list articles published on alveolar distraction osteogenesis between January 1996 and May 2010. Although 180 articles were identified, only101 human clinical case reports were included. Out of 101 only 59 fulfilled the criteria for the study. These studies covered 209 cases and were analyzed for indication, distraction protocol and amount of regenerated bone.

Results: Alveolar distraction was generally indicated in cases of vertical bone deficiency and interdental distraction was mainly applied to patients with clefts. The mean latency period applied was 6.26 days, rate of distraction per day was 0.81 mm, and the consolidation period was 79 days. The mean amount of regenerated bone was 11.34 mm (range, 2 to 26 mm).

Conclusions: Alveolar distraction osteogenesis is effective in increasing alveolar bone volume with simultaneous lengthening of the surrounding soft tissues for implant placement. The application of different treatment modalities were beneficial to the patient in enhancing the quality of distracted bone, shortening the overall treatment period and improving the performance of dental implants placed in the distracted alveolar ridges.

Key words: Alveolar distraction osteogenesis, interdental distraction, alveolar cleft, distraction protocol, distraction distractor, regenerated bone

How to cite: Yang K, Yugo Suzuki E, Suzuki B. Alveolar distraction osteogenesis: a systematic literature review. M Dent J 2014; 34: 289-300.

Correspondence author:
Lili Yang
Student of Doctor of Philosophy Program in Dentistry, Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University.
Email: yanglili_lily@hotmail.com
Received: 25 March 2014
Accepted: 1 August 2014

Introduction

Distraction osteogenesis is the bone formation of new bone formation between the surfaces of bone segments that are gradually separated by incremental traction.[1] This process is initiated when a traction force is applied to the bone segments and it continues as long as the callus tissues are stretched. This traction force, in turn, generates tension within the tissue that connects the bone segments, which stimulates new bone formation parallel to the vector of distraction.[2-4]

In 1905, Codivilla first performed lengthening of a femur using external skeletal traction after an oblique osteotomy.[5] Later, several surgeons modernized Codivilla's "continuous extension" procedure by modifying the osteotomy technique, distraction protocol, and the device for bone fixation. Significant contributions in the development of distraction osteogenesis were made by a Russian orthopedic surgeon named Gavril Ilizarov.[2,3,6-9] In 1951, Ilizarov developed an external device and bone lengthening method. Based on his clinical experience, in 1989, Ilizarov discovered two biologic principles of distraction osteogenesis known as the "Ilizarov effects"- (a) the tension-stress effect on the genesis and growth of tissues, and (b) the influence of blood supply and loading on the shape of bones and joints.[2,3] Following the basic principles of Ilizarov, in 1992, McCarthy and colleagues were the first to clinically apply distraction osteogenesis in the craniofacial skeleton.[10] McCarthy and colleagues used extra-oral distraction osteogenesis on four children with congenital craniofacial anomalies.[11]

Since the clinical application of the craniofacial distraction osteogenesis, a number of experimental and clinical investigations have demonstrated that gradual mechanical traction of bone segments at an osteotomy site created in the craniofacial region also generated new bone parallel to the direction of traction and allowed adaptation of the surrounding soft tissue to the new dimensions, with complete preservation of function and without relapse. This phenomenon opened up new possibilities in the correction of severe craniofacial deformities. The application of distraction osteogenesis offers novel solutions for surgical-orthodontic management of developmental anomalies of the craniofacial skeleton. Distraction osteogenesis provides a means whereby bone may be molded into different shapes to more adequately address the nature of skeletal deformities and asymmetries. Similar to distraction osteogenesis in the long bones, craniofacial distraction osteogenesis evolved from skeletal traction, osteotomy techniques, and external fixation methods.

The clinical evolution of extra-oral distraction began with the use of miniaturized orthopedic devices for small bone lengthening.[10,11] One of the first clinical applications of midface distraction was reported in 1995 by Polley and Figueroa, who used an externally fixed cranial halo to distract the midface.[12] The advantages of a rigid external distraction device (RED) are that it is fairly simple to apply intraoperatively, it is easy to activate for patients, and can be removed without the need for a second operative procedure at the completion of consolidation.

In several reports, Polley and Figueroa's group demonstrated that full correction of the midface deficiency, including both skeletal and soft tissue deficiencies, was possible with their technique.[13,14] In 1995, Molina and Ortiz-Monasterio simplified the methods established by McCarthy.[15] They were the first to use bidirectional distraction osteogenesis in the mandible. In 1998, Molina and Ortiz-Monasterio used distraction osteogenesis as an alternative technique in patients with cleft lip and palate with associated maxillary hypoplasia and mixed dentition.[16] In an attempt to simplify distraction in patients needing simultaneous maxillomandibular correction, the same authors introduced a technique for simultaneous mandibular and maxillary distraction using only a mandibular device. The technique involved an incomplete Le Fort I osteotomy and a mandibular corticotomy. As the mandible was elongated, the maxilla moved with it.[17]

Although bone transport has been less commonly employed in the craniofacial region relative to the previously mentioned techniques, nowadays its use has increased for the correction of large mandibular defects, reconstruction of neocondyles, cleft lip and palate, and alveolar defects for dental implants . Bone transport consists of resection of a pathologic bone followed by gradual transport of an osteotomized healthy bone segment (transport disk) via a distraction device across the area of the defect. As the transported bone segment is advanced, new bone tissue is generated, gradually filling the defect. After the transport disk reaches the opposite host bone segment, the intervening fibrous tissue is removed followed by application of compression between the transport and host bone segments at the docking site.[8,18]

The first report of the clinical application of bone transport was presented in 1995 by Costantino and colleagues, who successfully applied transport distraction to restore the continuity of a mandibular defect formed as a result of cancer resection following radiation therapy.[19] A year later, Block presented the results of four cases with bone transport using a Synthes lengthening device.[20] After these reports, bone transport has been sporadically used to treat bone defects caused by trauma or bone resection. Importantly, mandibular distraction recreates the alveolar ridge with its attached mucosa.

An intriguing application of the bone transport technique is the augmentation of the maxillary and mandibular alveolar ridges. Alveolar deformities and defects may result from a variety of pathologic processes including (a) developmental anomalies, such as cleft palate and congenital tooth absence, (b) maxillofacial trauma, which often involves damage to the teeth and associated jaw structures, and (c) periodontal disease leading to bone and tooth loss from the alveolar process. These deformities may be managed by a variety of surgical techniques, such as autogenous onlay bone grafting, alloplastic augmentation, connective tissue grafting, or guided tissue regeneration.

However, each of these modalities has its limitations.[21,22] These grafts do not provide an increase in osseous volume. Guided tissue regeneration is restricted in the volume of generated bone, often resulting in unpredictable results. Alternatively, distraction osteogenesis of the alveolar process may provide superior reconstruction of these types of defects. In 1996, Chin and Toth reported the first clinical application of vertical mandibular alveolar distraction osteogenesis.[21] Since the clinical introduction of alveolar ridge distraction by Chin, the use of the technique, as well as the number of available devices, has increased tremendously. Alveolar distraction devices and techniques have recently been established as a viable treatment modality for correction of severe alveolar bone defects and maxillary/mandibular alveolar ridge augmentation.[21] In recent years it has become quite accepted in oral and maxillofacial surgery and has been used for narrowing of large alveolar clefts before grafting.[23] This method is based on distracting a dento-osseous segment created posterior to the cleft site and narrowing the large alveolar defect with mesial movement of the segment.[23,24] New alveolar bone and soft tissue can be generated by this technique. Thus, the alveolar cleft can be more easily repaired with a bone graft, which makes an ideal soft tissue closure possible using newly generated attached gingiva.[24]

In 2000, Liou and colleagues first reported a new technique "Interdental distraction osteogenesis" (IDO). They used distraction osteogenesis as the basis of a new method for lengthening of the dental arch, minimizing the alveolar cleft/fistula and, thus, reducing the need for large surgical reconstructions of the maxillary dento-alveolar defects. IDO and rapid orthodontic tooth movement were used on patients with wide alveolar clefts or bony defects.[25] The technique displayed many advantages, including minimizing the need for extensive alveolar bone grafting, eliminating tooth extraction in cases of dental crowing, and maintaining velopharyngeal function.

In 2001, Yen reported a case of closure of a large alveolar cleft by bony transport of a posterior segment using orthodontic arch wires attached to bone.[26] This technique is effective in reducing the palatal fistula and closing the alveolar cleft. An increasing number of reports note that bony transport of a premaxillary segment provides space for dental implants,[27] and the anterior transport of a posterior segment was developed as a strategy for closing clefts with autogenous bone grafts.[26] In 2003, Dolanmaz et al[24] reported management of alveolar cleft using dento-osseous transport distraction osteogenesis. They developed an efficient device to repair small or large alveolar clefts without bone grafts. In 2006, Suzuki and Suzuki[28] developed a new alveolar distraction device that allowed three-directional movement of the osteotomized segment. The device allowed simultaneous maxillary advancement, wide cleft closure and creation of edentulous alveolar bone.

This technique corrected severe craniofacial deformities with fewer surgical interventions and, consequently, resulted in less total treatment time than with current techniques.[28] With the development of distraction devices and techniques, distraction osteogenesis is widely employed for vertical augmentation of alveolar ridge following failed grafting procedures[29,30] and for segmental bone grafting,[31] prior to orthognathic surgery,[32] and for anterior advancement of maxillary segments for closure of alveolar clefts.[26,33]

However, there is a lack of evidence regarding appropriate distraction osteogenesis protocols, maximum possible augmentation distance and application of various devices. This review analyzed studies published on the application of distraction osteogenesis for alveolar ridges and assessed the current state of knowledge.

Materials and methods

The review of the literature on alveolar distraction was based on a PUBMED search, covering the period from January 1996 to May 2010. The key words searched were alveolar distraction osteogenesis, interdental distraction osteogenesis and alveolar cleft. Although the search listed 179 articles, 101 human clinical case reports were included in this review. Individual case reports (43 articles) and animal studies (36 articles) were excluded from the data analysis. The 101 human articles included 60 articles (554 cases, 72%) on vertical alveolar distraction, 23 articles (184 cases, 21%) on horizontal alveolar distraction and 18 articles (56 cases, 7%) on interdental distraction (Table 1). The data from all publications were analyzed, despite the possibility of some results being reported in more than one publication, which was not possible to verify in all cases.

The identified studies were searched for defined inclusion criteria. These included indications for alveolar distraction osteogenesis, total number of alveolar distractions per patient, protocol parameters and type of distractor used. The specific protocol parameters recorded were: duration of the latency period before the active phase of distraction, the rate and rhythm of activation, the mean and maximum distraction distance achieved, the duration of the consolidation phase and the quality of regenerated bone.

The statistical analysis was performed using SPSS for Windows (Release 13.0, standard version; SPSS, Chicago, IL, USA). Data analysis methods included the X text and the independent Student's t-test for evaluation of statistical significance. A p-value less than 0.05 was considered as significant.

Results

Although many studies on alveolar distraction osteogenesis have reported data on the study outcome, only a limited body of literature was available to validate the methodology. In several studies the exact protocol parameters or the amount of new bone created were not reported for a standard time interval, but as a range. These data were not acceptable for the present analysis. A total of 59 articles (219 cases) that met the criteria were reviewed, including interdental distraction osteogenesis (10 articles) [23-25,28,33-38], horizontal alveolar distraction (13 articles) [39-51] and vertical alveolar distraction (36 articles),[52-87] covering a total of 219 distractions in 209 patients.

Alveolar distraction osteogenesis was generally indicated in cases of alveolar bone deficiency with an unfavorable implant-to-crown relation, collapsed dental arches and aesthetically compromised rehabilitation.[30,81,88] The most frequent diagnosis was bone atrophy (Table 2).[81,82,89] Interdental distraction was performed for lengthening the dental arch while minimizing the alveolar cleft/fistula or reconstructing maxillary/mandibular dento-alveolar defects (Table 3).[24-26] IDO was commonly used for patients with clefts.

Table 1 Literature review of alveolar distraction osteogenesis

Alveolar distraction osteogenesis	No. of article	%	No. of cases	%
1.Vertical alveolar distraction	60	59	554	70
2.Horizontal alveolar distraction				
Bucco-lingual	7	7	26	3
Mesiodistally	16	16	158	20
3.Interdental distraction osteogenesis	18	18	56	7
Total	101	100	794	100

Table 2 Indications for alveolar distraction osteogenesis

Indication	No. of case	%
1. Alveolar cleft	15	7
2. Trauma	19	9
3. Bone atrophy	137	62
4. Tumor resection	22	10
5. Crowding	26	12
Total	219	100

Table 3 Indications for IDO

Indication	No. of case	%
1. Cleft	15	68
2. Trauma	3	14
3. Bone atrophy	1	4.5
4. Tumor resection	1	4.5
5. Crowding	2	9
Total	22	100

Distraction osteogenesis protocol

The mean latency period applied was 6.26 days (range, three to 14 days). A latency period of seven days was used in 15 cases to permit healing of mucoperiosteum and to reduce the risk of wound dehiscence.

The mean rate of distraction per day was 0.81 mm (range, 0.3 to 1.5 mm/day). A total of 25 cases (76%) were distracted up to 1 mm/day, while two cases (6%) were distracted over 1 mm/day. In the other 6 cases (18%) continuous force was applied. The rhythm of distraction ranged from one (17 cases, 52%) to three (one case, 3%) times daily. In 9 cases (27%) distraction was used twice daily. In the other 6 cases (18%) continuous force was applied.

The mean consolidation period was 79 days (range, 30 to 161 days). In 6 cases (18%) the consolidation period was not reported. (Table. 4)

The mean amount of distraction achieved was 21.15 mm (range, 4 to 65 mm).

Distraction device

Similar to the intra-oral distraction devices, the alveolar ridge distraction devices can be classified as tooth-borne, bone-borne, and hybrid, based on their fixation points. In this study, the application of various devices in alveolar distraction osteogenesis was also analyzed. All of the vertical alveolar distraction devices were bone-borne. Most of the

Table 4 Protocol of IDO

Protocol	Data	No. of cases	%
Latency	Up to 7 days	66	96
	Over 7 days	2	3
	Not specified	1	1
Rate	0.3mm/day -0.5mm/day	36	52
	0.5mm/day -1mm/day	28	41
	1mm/day -1.5 mm/day	2	3
	Not specified	3	4
Rhythm	1 time/day	40	58
	2 times/day	26	38
	Not specified	3	4
Consolidation	Up to 3 months	61	89
	Over 3 months	3	4

horizontal alveolar distractions used bone-borne devices, whereas 78% of interdental distractions employed tooth-borne devices (Table. 5)

Discussion

Distraction osteogenesis is effective in endochondral and craniofacial bone lengthening and augmentation.[6,90] It was originally used in the treatment of mandibular deficiency[10] and, subsequently, used to treat hypoplastic maxilla,[91] zygoma, and midface.[21,92] In the dento-alveolar region, the application of distraction osteogenesis includes vertical height augmentation of the alveolus,[21] creation of an edentulous alveolar ridge for rapid orthodontic tooth movement through the regenerated bone [93] and dental distraction for rapid orthodontic tooth movement into freshly extracted sockets.[94] Segments of new alveolus and attached gingiva are created during dento-alveolar distraction osteogenesis, without grafting of alveolar bone or free gingiva.

The closure of a wide alveolar cleft and fistula in patients with clefts and the reconstruction of a maxillary dento-alveolar defect in patients with trauma are challenging for both orthodontists and surgeons, because of the difficulty in achieving complete closure by using local attached gingiva and the greater volume of bone required for the graft. IDO for the treatment of a wide alveolar cleft and oronasal fistula or a maxillary defect has proven to be an effective treatment modality. This technique creates new alveolar bone and attached gingiva at a site distant to the fistula or defect, and the fistula or defect is approximated by native local alveolar bone and attached gingiva. The principle of this technique is a modification of bifocal distraction osteogenesis, that has been used successfully in long bones[95] and, recently, also in the correction of mandibular defects.[20]

The rate and rhythm of distraction are two major parameters of critical importance, which influence the treatment results. The results of Ilizarov's experimental studies demonstrated that the latency period should be at least five days.[3] The benefit of seven days of latency was demonstrated in a long-bone distraction in a rabbit model, but the results from other studies in long bones and in the craniofacial region have questioned the need for a latency period.[96] A latency period of seven days reduces the risk of bone exposure to the oral environment and, thus, is probably the optimal choice in the majority of cases of IDO. A slower rate could result in premature union, while non-union can occur if the rate is too rapid. As with the distraction rate, it seems that the rhythm of distraction in IDO tends to be chosen empirically, perhaps reflecting a lack of experimental findings on distraction.

Compared with conventional orthodontic and orthognathic surgical treatment, distraction osteogenesis has the advantage of producing new bone in the palate and the alveolar ridge for dental implants and tooth movement. Displaced teeth can then be moved into the

Table 5 Application of distraction device

	Tooth-borne	Bone-borne	Hybrid
1.Vertical alveolar distraction		491	
2.Horizontal alveolar distraction			
Bucco-lingual		10	
Mesiodistally	10	77	1
3.Interdental distraction osteogenesis (IDO)	36	12	
Total	46	590	1

newly created bone rather than having to be extracted. In comparison with conventional alveolar bone grafting, there is no need for alveolar bone grafting and further gingivoperiosteoplasty with IDO. One of the potential advantages of IDO is that the soft palate is not distracted forward; it is left at the same sagittal position, before, during, and after distraction. This has the benefit of avoiding possible disturbance to the velopharyngeal function of those patients with clefts who need distraction of the entire maxilla.[25]

However, IDO also has some disadvantages that influence the outcome of treatment, including (a) technique sensitive surgery, (b) equipment-sensitive surgery, (c) possible need of a second surgery to remove distraction devices, (d) patient compliance, and (e) experience with the technique is limited.

In conclusion, alveolar distraction osteogenesis is effective in increasing alveolar bone volume with simultaneous lengthening of the surrounding soft tissues for implant placement. IDO is a variation of alveolar distraction osteogenesis and can successfully be applied to patients with clefts.

The application of different treatment modalities are beneficial to the patient in enhancing the quality of distracted bone, shortening the overall treatment period and improving the performance of dental implants placed in the distracted alveolar ridges.

However, there is a need for further evaluation of appropriate distraction osteogenesis protocols, effective distractors and augmented distance.

Acknowledgments

The authors acknowledge the assistance of Dr. M. K. Kevin O. Carroll, professor emeritus of the University of Mississippi School of Dentistry, and faculty consultant of the Chiang Mai University Faculty of Dentistry, Thailand, in the preparation of the manuscript.

Funding: This study was supported by grant from the Faculty of Dentistry, Chiang Mai University and grant number RSA 5480029 from the Thailand Research Funding.

Conflict Interest: None declared

Ethic approval: None (Systematic review)

References

1. ML S, AM C, JB C. Distraction osteogenesis: history and biologic basis of new bone formation. ***Quintessence Int*** 1998.
2. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. ***Clin Orthop Relat Res*** 1989; (239): 263-85.
3. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. ***Clin Orthop Relat Res*** 1989; (238): 249-81.
4. Ilizarov GA. Clinical application of the tension-stress effect for limb lengthening. ***Clin Orthop Relat Res*** 1990; Jan(250): 8-26.
5. Codivilla A. On the means of lengthening, in the lower limbs, the muscles and tissues which are shortened through deformity. 1904. ***Clin Orthop Relat Res*** 1994; Apr(301): 4-9.
6. Ilizarov GA, Lediaev VI, Shitin VP. The course of compact bone reparative regeneration in distraction osteosynthesis under different conditions of bone fragment fixation (experimental study). ***Eksp Khir Anesteziol*** 1969; 14: 3-12.
7. Ilizarov GA, LM S. Some clinical and experimental data concerning lengthening of lower extremities. ***Exp Khir Arrestar***. 1969; 14: 27.
8. Ilizarov GA. The principles of the Ilizarov method. ***Bull Hosp Jt Dis Orthop Inst*** 1988; 48: 1.
9. Ilizarov GA. Some possibilities with our method for treating damage to and disorders of locomotor apparatus. ***J Craniofac Surg*** 1995; 6: 352.
10. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. ***Plast Reconstr Surg*** 1992; 89: 1-8; discussion 9-10.
11. McCarthy JG. The role of distraction osteogenesis in the reconstruction of the mandible in unilateral craniofacial microsomia. ***Clin Plast Surg*** 1994; 21: 625-31.

12. Polley JW, Figueroa AA, Charbel FT, Berkowitz R, Reisberg D, Cohen M. Monobloc craniomaxillofacial distraction osteogenesis in a newborn with severe craniofacial synostosis: a preliminary report. *J Craniofac Surg* 1995; 6: 421-3.
13. Polley JW, Figueroa AA. Rigid external distraction: its application in cleft maxillary deformities. *Plast Reconstr Surg* 1998; 102: 1360-72; discussion 73-4.
14. Figueroa AA, Polley JW, Ko EW. Maxillary distraction for the management of cleft maxillary hypoplasia with a rigid external distraction system. *Semin Orthod* 1999; 5: 46-51.
15. Molina F, Ortiz Monasterio F. Mandibular elongation and remodeling by distraction: a farewell to major osteotomies. *Plast Reconstr Surg* 1995; 96: 825-40; discussion 41-2.
16. Molina F, Ortiz Monasterio F, de la Paz Aguilar M, Barrera J. Maxillary distraction: aesthetic and functional benefits in cleft lip-palate and prognathic patients during mixed dentition. *Plast Reconstr Surg* 1998; 101: 951-63.
17. Molina F. Combined maxillary and mandibular distraction osteogenesis. *Semin Orthod* 1999; 5: 41-5.
18. Ilizarov GA. Basic principles of transosseous compression and distraction osteosynthesis. *Ortop Travmatol Protez* 1971; 32: 7-15.
19. Costantino PD, Shybut G, Friedman CD, Pelzer HJ, Masini M, Shindo ML, et al. Segmental mandibular regeneration by distraction osteogenesis. An experimental study. *Arch Otolaryngol Head Neck Surg* 1990; 116: 535-45.
20. Block MS, Otten J, McLaurin D, Zoldos J. Bifocal distraction osteogenesis for mandibular defect healing: case reports. *J Oral Maxillofac Surg* 1996; 54: 1365-70.
21. Chin M, Toth BA. Distraction osteogenesis in maxillofacial surgery using internal devices: review of five cases. *J Oral Maxillofac Surg* 1996; 54: 45-53; discussion 4.
22. Chin M. The role of distraction osteogenesis in oral and maxillofacial surgery. *J Oral Maxillofac Surg* 1998; 56: 805-6.
23. Binger T, Katsaros C, Rucker M, Spitzer WJ. Segment distraction to reduce a wide alveolar cleft before alveolar bone grafting. *Cleft Palate Craniofac J* 2003; 40: 561-5.
24. Dolanmaz D, Karaman AI, Durmus E, Malkoc S. Management of alveolar clefts using dento-osseous transport distraction osteogenesis. *Angle Orthod* 2003; 73: 723-9.
25. Liou EJ, Chen PK, Huang CS, Chen YR. Interdental distraction osteogenesis and rapid orthodontic tooth movement: a novel approach to approximate a wide alveolar cleft or bony defect. *Plast Reconstr Surg* 2000; 105: 1262-72.
26. Yen SL, Gross J, Wang P, Yamashita DD. Closure of a large alveolar cleft by bony transport of a posterior segment using orthodontic archwires attached to bone: report of a case. *J Oral Maxillofac Surg* 2001; 59: 688-91.
27. Guerrero CA, Bell WH, Contasti GI, Rodriguez AM. Intraoral mandibular distraction osteogenesis. *Semin Orthod* 1999; 5: 35-40.
28. Suzuki EY, Watanabe M, Buranastidporn B, Baba Y, Ohyama K, Ishii M. Simultaneous maxillary distraction osteogenesis using a twin-track distraction device combined with alveolar bone grafting in cleft patients: preliminary report of a technique. *Angle Orthod* 2006; 76: 164-72.
29. Aragon CE, Bohay RN. The application of alveolar distraction osteogenesis following nonresorbable hydroxyapatite grafting in the anterior maxilla: a clinical report. *J Prosthet Dent* 2005; 93: 518-21.
30. Jensen OT, Cockrell R, Kuhike L, Reed C. Anterior maxillary alveolar distraction osteogenesis: a prospective 5-year clinical study. *Int J Oral Maxillofac Implants* 2002; 17: 52-68.
31. Chiapasco M, Brusati R, Galioto S. Distraction osteogenesis of a fibular revascularized flap for improvement of oral implant positioning in a tumor patient: a case report. *J Oral Maxillofac Surg* 2000; 58: 1434-40.
32. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001; 59: 26-34; discussion -5.
33. Mitsugi M, Ito O, Alcalde RE. Maxillary bone transportation in alveolar cleft-transport distraction osteogenesis for treatment of alveolar cleft repair. *Br J Plast Surg* 2005; 58: 619-25.
34. Turk T, Cakmak F, Sumer M. Advancement of mandibular symphysis with distraction osteogenesis. *Am J Orthod Dentofacial Orthop* 2009; 135: 232-40.
35. Baek SH, Kim NY, Paeng JY, Kim MJ. Trifocal distraction-compression osteosynthesis in conjunction with passive self-ligating brackets for

the reconstruction of a large bony defect and multiple missing teeth. *Am J Orthod Dentofacial Orthop* 2008; 133: 601-11.
36. Basa S, Varol A, Yilmaz S. Transport distraction osteogenesis of a dentoalveolar segment in the posterior mandible: a technical note. *J Oral Maxillofac Surg* 2007; 65: 1862-4.
37. Kondoh T, Hamada Y, Kamei K, Seto K. Transport distraction osteogenesis following marginal resection of the mandible. *Int J Oral Maxillofac Surg* 2002; 31: 675-6.
38. Suzuki EY, Buranstidporn B, Ishii M. Simple and inexpensive approach for the management of cleft patients with the twin-track distraction: case report. *J Oral Maxillofac Surg* 2006; 64: 722-6.
39. Karacay S, Akin E, Okcu KM, Bengi AO, Altug HA. Mandibular distraction with MD-DOS device. *Angle Orthod* 2005; 75: 685-93.
40. Muraki Y, Tominaga K, Yoshioka I, Fujita M, Khanal A, Matsushita S, et al. Mandibular reconstruction with bone transport in a patient with osteogenesis imperfecta. *Int J Oral Maxillofac Surg* 2008; 37: 870-3.
41. Takenobu T, Nagano M, Taniike N, Furutani M, Tanaka Y. Mandibular reconstruction using intraoral trifocal bone transport: report of a case. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007; 103: 630-5.
42. Gonzalez-Garcia R, Naval-Gias L, Rubio-Bueno P, Rodriguez-Campo FJ, Usandizaga JL. Double-step transport osteogenesis in the reconstruction of mandibular segmental defects: a new surgical technique. *Plast Reconstr Surg* 2006; 118: 1608-12.
43. Hibi H, Ueda M. New internal transport distraction device for reconstructing segmental defects of the mandible. *Br J Oral Maxillofac Surg* 2006; 44: 382-5.
44. Whitesides LM, Wunderle RC, Guerrero C. Mandible reconstruction using a 2-phase transport disc distraction osteogenesis: a case report. *J Oral Maxillofac Surg* 2005; 63: 261-6.
45. Yonehara Y, Takato T, Harii K, Hirabayashi S, Susami T, Komori T, et al. Secondary lengthening of the reconstructed mandible using a gradual distraction technique--two case reports. *Br J Plast Surg* 1998; 51: 356-8.
46. Aikawa T, Iida S, Senoo H, Hori K, Namikawa M, Okura M, et al. Widening a narrow posterior mandibular alveolus following extirpation of a large cyst: a case treated with a titanium mesh-plate type distractor. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 106: e1-7.
47. Watzak G, Zechner W, Tepper G, Vasak C, Busenlechner D, Bernhart T. Clinical study of horizontal alveolar distraction with modified micro bone screws and subsequent implant placement. *Clin Oral Implants Res* 2006; 17: 723-9.
48. Oda T, Suzuki H, Yokota M, Ueda M. Horizontal alveolar distraction of the narrow maxillary ridge for implant placement. *J Oral Maxillofac Surg* 2004; 62: 1530-4.
49. Takahashi T, Funaki K, Shintani H, Haruoka T. Use of horizontal alveolar distraction osteogenesis for implant placement in a narrow alveolar ridge: a case report. *Int J Oral Maxillofac Implants* 2004; 19: 291-4.
50. Laster Z, Rachmiel A, Jensen OT. Alveolar width distraction osteogenesis for early implant placement. *J Oral Maxillofac Surg* 2005; 63: 1724-30.
51. Uckan S, Guler N, Arman A, Mutlu N. Mandibular midline distraction using a simple device. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; 101: 711-7.
52. Adolphs N, Sproll C, Raguse JD, Nelson K, Heberer S, Scheifele C, et al. Stable vertical distraction osteogenesis of highly atrophic mandibles after ablative tumour surgery of the oral cavity--a salvage pathway for mandibular reconstruction prior to oral rehabilitation with dental implants. *J Craniomaxillofac Surg* 2009; 37: 320-6.
53. Oh HK, Park HJ, Cho JY, Park YJ, Kook MS. Vector control of malpositioned segment during alveolar distraction osteogenesis by using rubber traction. *J Oral Maxillofac Surg* 2009; 67: 608-12.
54. Robiony M, Zorzan E, Polini F, Sembronio S, Toro C, Politi M. Osteogenesis distraction and platelet-rich plasma: combined use in restoration of severe atrophic mandible. Long-term results. *Clin Oral Implants Res* 2008; 19: 1202-10.
55. Mendonca G, Mendonca DB, Fernandes Neto AJ, Neves FD. Use of distraction osteogenesis for repositioning of an osseointegrated implant: a case report. *Int J Oral Maxillofac Implants* 2008; 23: 551-5.
56. Hirota M, Matsui Y, Mizuki N, Saito T, Watanuki K, Iwai T, et al. Management considerations in reconstruction of postablative defects of the

mandible: vertical distraction of a scapular bone flap and removable lip support: a case report. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 106: e6-9.
57. Hirota M, Chikumaru H, Matsui Y, Adachi M, Aoki S, Watanuki K, et al. Osteosynthesis and simultaneous irregular trifocal distraction osteogenesis for segmental mandibular defect after tumor ablative surgery: a case report. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 106: 651-5.
58. Gunbay T, Koyuncu BO, Akay MC, Sipahi A, Tekin U. Results and complications of alveolar distraction osteogenesis to enhance vertical bone height. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 105: e7-13.
59. Hirota M, Mizuki N, Iwai T, Watanuki K, Ozawa T, Maegawa J, et al. Vertical distraction of a free vascularized osteocutaneous scapular flap in the reconstructed mandible for implant therapy. *Int J Oral Maxillofac Surg* 2008; 37: 481-3.
60. Kurkcu M, Benlidayi ME, Kurtoglu C, Kesiktas E. Placement of implants in the mandible reconstructed with free vascularized fibula flap: comparison of 2 cases. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 105: e36-40.
61. Lee HJ, Ahn MR, Sohn DS. Piezoelectric distraction osteogenesis in the atrophic maxillary anterior area: a case report. *Implant Dent* 2007; 16: 227-34.
62. Ozkan Y, Akoglu B, Varol A, Ucankale M, Ozkan YK. Surgical and prosthodontic treatment using alveolar distraction osteogenesis and implant placement for a patient with mandibular prognathism: a clinical report. *Int J Prosthodont* 2007; 20: 256-8.
63. Chiapasco M, Zaniboni M, Rimondini L. Autogenous onlay bone grafts vs. alveolar distraction osteogenesis for the correction of vertically deficient edentulous ridges: a 2-4-year prospective study on humans. *Clin Oral Implants Res* 2007; 18: 432-40.
64. Turker N, Basa S, Vural G. Evaluation of osseous regeneration in alveolar distraction osteogenesis with histological and radiological aspects. *J Oral Maxillofac Surg* 2007; 65: 608-14.
65. Emtiaz S, Noroozi S, Carames J, Fonseca L. Alveolar vertical distraction osteogenesis: historical and biologic review and case presentation. *Int J Periodontics Restorative Dent* 2006; 26: 529-41.
66. Saulacic N, Somosa Martin M, de Los Angeles Leon Camacho M, Garcia Garcia A. Complications in alveolar distraction osteogenesis: A clinical investigation. *J Oral Maxillofac Surg* 2007; 65: 267-74.
67. Ortakoglu K, Suer BT, Ozyigit A, Ozen T, Sencimen M. Vertical distraction osteogenesis of fibula transplant for mandibular reconstruction: a case report. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; 102: e8-11.
68. Susami T, Matsuzaki M, Ogihara Y, Sakiyama M, Takato T, Sugawara Y, et al. Segmental alveolar distraction for the correction of unilateral open-bite caused by multiple ankylosed teeth: a case report. *J Orthod* 2006; 33: 153-9.
69. Chiapasco M, Lang NP, Bosshardt DD. Quality and quantity of bone following alveolar distraction osteogenesis in the human mandible. *Clin Oral Implants Res* 2006; 17: 394-402.
70. Iida S, Nakano T, Amano K, Kogo M. Repeated distraction osteogenesis for excessive vertical alveolar augmentation: a case report. *Int J Oral Maxillofac Implants* 2006; 21: 471-5.
71. Erkut S, Uckan S. Alveolar distraction osteogenesis and implant placement in a severely resorbed maxilla: a clinical report. *J Prosthet Dent* 2006; 95: 340-3.
72. Riccardi O, Pieri F, Marchetti C. A new method for vector control during alveolar distraction osteogenesis: a case report. *Int J Periodontics Restorative Dent* 2006; 26: 53-7.
73. Kim SG, Mitsugi M, Kim BO. Simultaneous sinus lifting and alveolar distraction of the atrophic maxillary alveolus for implant placement: a preliminary report. *Implant Dent* 2005; 14: 344-6.
74. Iizuka T, Hallermann W, Seto I, Smolka W, Smolka K, Bosshardt DD. Bi-directional distraction osteogenesis of the alveolar bone using an extraosseous device. *Clin Oral Implants Res* 2005; 16: 700-7.
75. Alkan A, Bas B, Inal S. Alveolar distraction osteogenesis of bone graft reconstructed mandible. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005; 100: e39-42.
76. Walker DA. Mandibular distraction osteogenesis for endosseous dental implants. *J Can Dent Assoc* 2005; 71: 171-5.
77. Gellrich NC, Suarez-Cunqueiro MM, Schon R, Hoffmann M, Schramm A. Distraction osteogenesis in an anterior mandibular bone defect utilizing

lingual periosteal release: a case report. ***Int J Oral Maxillofac Implants*** 2004; 19: 753-7.
78. Garcia AG, Martin MS, Vila PG, Saulacic N, Rey JM. Palatal approach for maxillary alveolar distraction. ***J Oral Maxillofac Surg*** 2004; 62: 795-8.
79. Nocini PF, Albanese M, Buttura da Prato E, D' Agostino A. Vertical distraction osteogenesis of the mandible applied to an iliac crest graft: report of a case. ***Clin Oral Implants Res*** 2004; 15: 366-70.
80. Nocini PF, De Santis D, Ferrari F, Bertele GP. A customized distraction device for alveolar ridge augmentation and alignment of ankylosed teeth. ***Int J Oral Maxillofac Implants*** 2004; 19: 133-44.
81. Garcia-Garcia A, Somoza-Martin M, Gandara-Vila P, Saulacic N, Gandara-Rey JM. Alveolar distraction before insertion of dental implants in the posterior mandible. ***Br J Oral Maxillofac Surg*** 2003; 41: 376-9.
82. Raghoebar GM, Liem RS, Vissink A. Vertical distraction of the severely resorbed edentulous mandible: a clinical, histological and electron microscopic study of 10 treated cases. ***Clin Oral Implants Res*** 2002; 13: 558-65.
83. Hurzeler MB, Zuhr O, Schenk G, Schoberer U, Wachtel H, Bolz W. Distraction osteogenesis: a treatment tool to improve baseline conditions for esthetic restorations on immediately placed dental implants--a case report. ***Int J Periodontics Restorative Dent*** 2002; 22: 451-61.
84. Uckan S, Dolanmaz D, Kalayci A, Cilasun U. Distraction osteogenesis of basal mandibular bone for reconstruction of the alveolar ridge. ***Br J Oral Maxillofac Surg*** 2002; 40: 393-6.
85. Rachmiel A, Srouji S, Peled M. Alveolar ridge augmentation by distraction osteogenesis. ***Int J Oral Maxillofac Surg*** 2001; 30: 510-7.
86. Klug CN, Millesi-Schobel GA, Millesi W, Watzinger F, Ewers R. Preprosthetic vertical distraction osteogenesis of the mandible using an L-shaped osteotomy and titanium membranes for guided bone regeneration. ***J Oral Maxillofac Surg*** 2001; 59: 1302-8; discussion 9-10.
87. Garcia Garcia A, Somoza Martin M, Gandara Vila P, Lopez Maceiras J. Alveolar ridge osteogenesis using 2 intraosseous distractors: uniform and nonuniform distraction. ***J Oral Maxillofac Surg*** 2002; 60: 1510-2.
88. Chiapasco M, Romeo E, Casentini P, Rimondini L. Alveolar distraction osteogenesis vs. vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans. ***Clin Oral Implants Res*** 2004; 15: 82-95.
89. Gaggl A, Schultes G, Karcher H. Vertical alveolar ridge distraction with prosthetic treatable distractors: a clinical investigation. ***Int J Oral Maxillofac Implants*** 2000; 15: 701-10.
90. Aronson J. Experimental Assessment of Bone Regenerate Quality during Distraction Osteogenesis. In C. T. Brighton, G. E. Friedlaender, and J. M. Lane (Eds.), ***Bone Formation and Repair*** Rosemont, Ill. American Academy of Orthopaedic Surgeons. 1994: 405-19.
91. Polley JW, Figueroa AA. Management of severe maxillary deficiency in childhood and adolescence through distraction osteogenesis with an external, adjustable, rigid distraction device. ***J Craniofac Surg*** 1997; 8: 181-5; discussion 6.
92. Cohen SR, Boydston W, Burstein FD, Hudgins R. Monobloc distraction osteogenesis during infancy: report of a case and presentation of a new device. ***Plast Reconstr Surg*** 1998; 101: 1919-24.
93. Liou EJ, Polley JW, Figueroa AA. Distraction osteogenesis: the effects of orthodontic tooth movement on distracted mandibular bone. ***J Craniofac Surg*** 1998; 9: 564-71.
94. Liou EJ, Huang CS. Rapid canine retraction through distraction of the periodontal ligament. ***Am J Orthod Dentofacial Orthop*** 1998; 114: 372-82.
95. Tucker HL, Kendra JC, Kinnebrew TE. Tibial defects. Reconstruction using the method of Ilizarov as an alternative. ***Orthop Clin North Am*** 1990; 21: 629-37.
96. White SH, Kenwright J. The timing of distraction of an osteotomy. ***J Bone Joint Surg Br*** 1990; 72: 356-61.