ORIGINAL ARTICLE

Long-term skeletal and dental effects of mandibular symphyseal distraction osteogenesis

Marinho Del Santo, Jr, DDS, MS, MSD, PhD,[a] Cesar A. Guerrero, DDS,[b] Peter H. Buschang, MA, PhD,[c] Jeryl D. English, DDS, MS,[c] Mikhail L. Samchukov, MD,[d] and William H. Bell, DDS[e]
Dallas, Tex, and Caracas, Venezuela

The purpose of this study was to evaluate the effects of mandibular symphyseal distraction osteogenesis using a tooth-borne expansion device. The sample included 20 Hispanic nonsyndromic patients (11 males and 9 females) between 13.5 years and 37.3 years of age. Predistraction (1.5 months before surgery), postdistraction (1 month after surgery), and long-term follow-up (1.3 year after surgery) records included posteroanterior, lateral, and panoramic radiographs and models. Postdistraction radiographic evaluation showed that symphyseal distraction osteogenesis produced insignificant increases in the bicondylar, bigonion, and biantegonion widths; intermolar and, especially, intercanine widths increased significantly and a distraction gap was observed in the symphyseal region. Follow-up model analysis showed the largest width increases between the first molars and second premolars and the smallest width increases between canines and first premolars. The difference between the postdistraction and long-term follow-up width changes was explained by the postdistraction orthodontic effect, which modified the shape of the dental arch. A disproportionate pattern of distraction, characterized by significantly greater dental than skeletal widening, was observed in the second molar and antegonion region. Distraction osteogenesis without presurgical orthodontic treatment produced significant proclination of the mandibular incisors; no proclination was observed in cases with predistraction orthodontic treatment. Dental crowding was resolved by the movement of teeth into the distraction regenerate and concomitant orthodontic treatment. Follow-up radiographs showed transverse skeletal stability of the distraction procedure. We conclude that mandibular symphyseal distraction osteogenesis increased mandibular arch width and partially corrected dental crowding, with a potential for disproportionate distraction patterns and proclination of the mandibular incisors. (Am J Orthod Dentofacial Orthop 2000;118:485-93)

Transverse skeletal deficiency is a common clinical problem associated with narrow basal and dentoalveolar bone. In comparison with maxillary deficiencies,[1-3] diagnosis and treatment of mandibular transverse discrepancies have received little attention. Posterior buccal crossbites and crowding are commonly used clinical indicators of transverse mandibular deficiency. The majority (78%) of the US population presents with some crowding, and 15% have severe or very severe crowding.[4] Posterior crossbites are present in slightly less than 10% of the US population[4] and approximately 1% to 1.6% have buccal posterior crossbites.[5]

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[a]Orthodontist in private practice in São Paulo, Brazil; former resident, Department of Orthodontics, Baylor College of Dentistry, TAMUS.
[b]Oral surgeon in private practice in Caracas, Venezuela.
[c]Professor, Department of Orthodontics, Baylor College of Dentistry, TAMUS.
[d]Professor, Texas Scottish Rite Hospital for Children.
[e]Professor, Department of Oral and Maxillofacial Surgery and Pharmacology, Baylor College of Dentistry, TAMUS.
Reprint requests to: Dr Peter H. Buschang, Department of Orthodontics, Baylor College of Dentistry, The Texas A & M University System, 3302 Gaston Ave, Dallas, TX 75256; e-mail, phbuschang@tambcd.edu.
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Transverse mandibular deficiencies in growing patients are commonly corrected with orthodontic expansion, using lip bumpers,[6-8] Schwarz devices,[9] or functional devices.[10,11] These therapies show relatively stable results for younger patients,[10-12] particularly patients who presented with lingually tipped teeth that need to be "decompensated."[13] However, expansion in older patients or expansion in the anterior area is unstable and tends to relapse toward the original dimension.[14,15]

In adult patients, symphyseal osteotomy has been proposed as a solution for correction of transverse mandibular deficiencies.[16] Symphyseal mandibular osteotomies, however, have not been well accepted, perhaps because of the risk of periodontal problems that might occur when the bone segments are rapidly and excessively separated. The lack of adequate rigid fixation and the need to use grafts increase the risk of relapse.[17] Theoretically, greater stability could be expected if the expansion is performed slowly, allowing better adaptation of the soft tissues, and allowing bone to grow in the osteotomy site.

Distraction osteogenesis (DO) is the biologic process of new bone formation between bone segments that are gradually separated by incremental traction.[18] It was introduced in the beginning of the 20th century

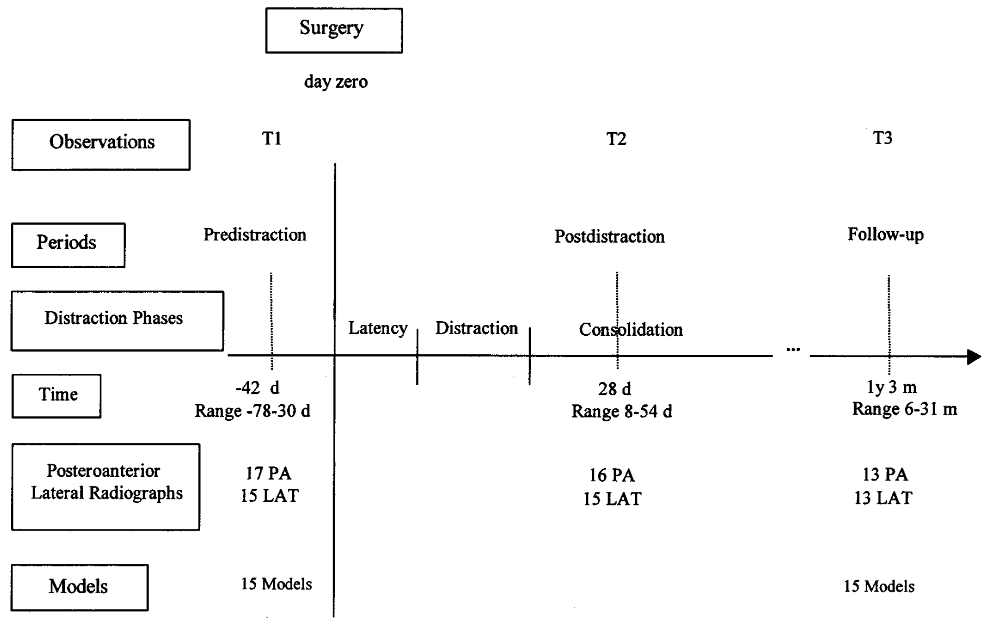

Fig 1. Time frame (*d,* day; *m,* month; *y*, year) of observations and records.

and popularized by Ilizarov in the 1960s.[18,19] DO involves a surgical cut that allows gradual separation of bone segments, with deposition of newly formed bone in the distraction gap. Significant amounts of bone formation have been reported for DO of long bones, making the technique especially suited for limb lengthening and filling of bone defects.[20-22] In the early 1970s, DO procedures were proposed as an alternative therapy for patients requiring major craniofacial reconstruction,[23-25] including mandibular lengthening in hemifacial microsomia and micrognathia.[26]

DO holds great potential for correcting transverse mandibular deficiencies. Guerrero[27] pioneered the use of rapid surgical mandibular expansion to correct mandibular transverse discrepancies. Guerrero et al[28] later showed that mandibular symphyseal DO, using both tooth-borne and bone-borne expansion devices, provides an efficient surgical alternative to orthognathic surgery for the treatment of transverse deficiencies. Bell et al,[29] however, performed mandibular symphyseal DO in monkeys and showed disproportional movement between the bone segments and dental tipping when using tooth-borne DO devices. Hollis et al[30] confirmed adverse dental effects with tooth-bone devices in 4 dogs; the teeth moved approximately twice as much as the bone segments.

Although mandibular symphyseal DO is a treatment approach that holds great promise for the correction of transverse discrepancies, there are no human studies available that objectively evaluate the treatment outcomes and the stability of the procedures. In order to properly plan treatment, it is important to understand the short-term and long-term positional changes of the dento-osseous segments produced by expansion devices. The purpose of this study was to assess the effects of DO using a tooth-borne expansion device in the mandibular symphyseal area of nonsyndromic patients. The specific goals were: (1) to evaluate the positional changes of dentoalveolar segments after symphyseal DO, (2) to study the dental effects of mandibular symphyseal DO, and (3) to evaluate the stability of the mandibular symphyseal DO.

MATERIAL AND METHODS

Sample

The sample comprised 20 Hispanic patients, 11 males (55%) and 9 females (45%), who had undergone mandibular symphyseal DO (Fig 1). The mean age of the sample at the time of the surgery was 17 years 4 months (range, 13 years 6 months to 37 years 4 months). Predistraction (T1) records were taken 42 days (range, 30-78 days) before surgery; postdistraction (T2) records were taken 28 days (range, 8-54 days) after surgery and long-term follow-up records were taken 1 year 3 months (range, 6-31 months) postsurgery. All patients required mandibular symphyseal DO according to the clinical judgment of 1 of 4 referring orthodontists and the oral and maxillofacial surgeon, based primarily on mandibular dental crowding.

The patients were selected based on the following criteria:

1. Treated with mandibular symphyseal DO using a tooth-borne expansion device.
2. Presented with complete permanent dentition (except third molars).

Patients were rejected based on the following criteria:

1. Any other surgical intervention in the craniofacial area, except maxillary advancement, maxillary surgically assisted expansion, or genioplasty.
2. Records (radiographs and models) of poor quality.
3. Craniofacial syndromes.
4. Mandibular dental expansion before the surgical procedure.

Due to the retrospective nature of this study, all records for all subjects were not available at all the periods. Changes between periods were evaluated based on the maximum number of records available.

Maxillary predistraction orthodontic devices were placed in all the patients 6 months before distraction. Leveled and aligned maxillary arches were used as a reference to plan the mandibular widening.[16] Mandibular predistraction orthodontic devices were placed in 41% of the patients. A Hyrax device was placed in all patients using conventional bands on the mandibular first premolars and first molars. The expansion screw was positioned as far anteriorly as possible to avoid tongue interference and to facilitate its activation with a key.

All the mandibular symphyseal DO procedures were performed by the same surgeon (C.G.) with the patient under local anesthesia and intravenous sedation in an ambulatory clinic. Nine patients received maxillary surgery (advancement or surgically assisted expansion) under general anesthesia in addition to the symphyseal mandibular DO. The surgery consisted of an intraoral symphyseal osteotomy, as described by Guerrero et al.[28] In order to access the osteotomy site, a horizontal incision was made 4 to 6 mm above the deepest area of the mandibular vestibule. The orbicularis oris muscle was dissected obliquely, through the mandibular symphysis, and reflected inferiorly and superiorly. Soft tissues were detached from the planned osteotomy site at the crest of the alveolar ridge; after the flaps were raised and reflected, the incisor roots were visualized and a groove in the labial cortical plate was made with a 701 bur. The inferior portion of the mental symphysis, 2 to 3 mm below the level of the incisors, was sectioned vertically with a reciprocating saw. A spatula osteotome with light tapping pressure was used to complete the surgical cut into the partially sectioned interdental osteotomy site. In 13 (76%) patients, the surgical cut was performed between the central incisors, in 1 (5%) patient the surgical cut was performed between the central and lateral incisors, and in 2 (10%) patients, the surgical cut was performed between the lateral incisors and the canines. After the surgical cut was completed, the mentalis muscle and the mucosa margins were sutured. Immediately after the osteotomy, the expansion device was activated to achieve 2 mm expansion. After an average latency period of 8 days (range, 4-17), the distraction device was activated 1 mm per day by the surgeon. Based on the number of turns recorded in the charts, the device was expanded 8.1 ± 2.5 mm, which included the immediate postsurgical expansion. After the expansion was complete, acrylic was applied over the Hyrax screw for stabilization and the device was maintained in place for approximately 60 to 90 days. Orthodontic tooth movement was started after radiographic evidence of bone healing was seen. An acrylic pontic was placed in the area of the surgical cut for esthetics and to prevent tipping of the teeth into the osteotomy site. The pontic was regularly reduced in size mesiodistally during orthodontic leveling and alignment until the space was closed. All the patients received postdistraction orthodontic treatment until adequate dental leveling and alignment had been achieved. Approximately 53% of the patients still had orthodontic appliances at long-term follow-up.

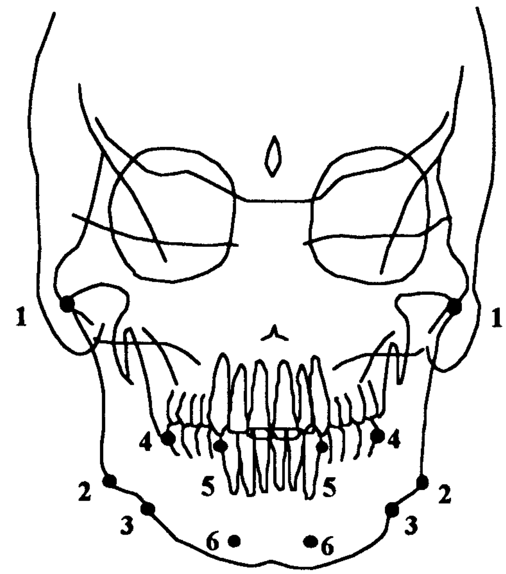

Fig 2. Bilateral posteroanterior radiograph landmarks: *1,* lateral condylar; *2,* gonion; *3,* antegonion; *4,* second molars; *5,* canines; *6,* bone markers.

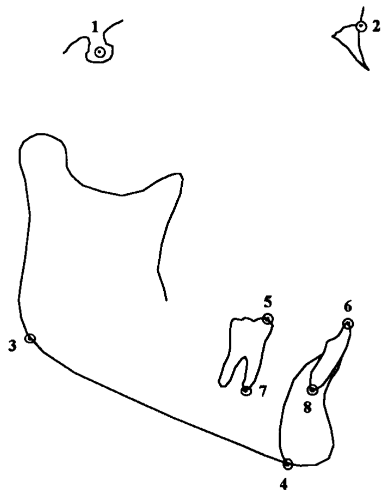

Fig 3. Lateral radiograph landmarks: *1,* sella turcica; *2,* nasion; *3,* gonion; *4,* menton; *5,* molar tip; *6,* incisor tip; *7,* molar apex; *8,* incisor apex.

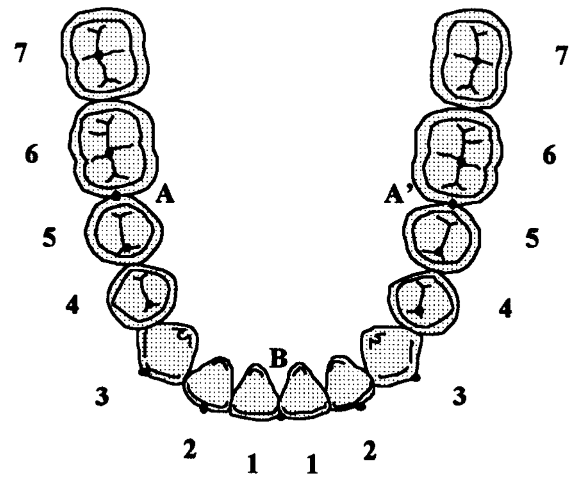

Fig 4. Model landmarks: *7,* central fossa of the second molar; *6,* central fossa of the first molar; *5,* mesial fossa of the second premolar; *4,* mesial fossa of the first premolar; *3,* canine tip; *A and A',* mesial marginal ridge of the first molar, and *B* contact point between the central incisors.

DATA COLLECTION

Posteroanterior Radiographs

The posteroanterior (PA) radiographs were traced and 12 landmarks were identified (Fig 2). The following measurements were calculated using the DFPlus software:

- Bicondylar width: distance between the most lateral point of the right and left condyles.
- Bigonion width: distance between the right and left gonion landmarks. Gonion point was found by bisecting the angle formed by the mandibular plane and a plane along the mandibular ramus.
- Biantegonion width: distance between the right and left antegonion landmarks. Antegonion is the deepest point of the gonial notch.
- Intersecond molar width: distance between the most distal and facial point of the right and left second molars.
- Intercanine width: distance between the most distal and facial point of the right and left mandibular canines.
- Symphyseal bone marker width: distance between the bilateral wires, located on either side of the distraction gap and used for rigid fixation of the chin (genioplasty).

A subsample of 15 randomly selected radiographs was retraced and digitized to calculate the systematic and random errors. Systematic error was not significant and random method error, defined according to Dahlberg[31] ($\sqrt{\Sigma d^2/2n}$), ranged from 0.41 (intersecond molar width) to 0.96 (bicondylar width).

Lateral Radiographs

On the lateral radiographs, 8 landmarks were identified (Fig 3), digitized using the DFPlus software, and used to compute the following measurements:

- L1MP: angle between the long axis of the incisor (incisor tip and apex) and the mandibular plane.
- L6MP: angle between the long axis of the first molar (molar tip and apex) and the mandibular plane.
- L1L6: distance between the tip of the first molar and the tip of the incisor.

A subsample of 15 randomly selected radiographs was retraced and digitized to calculate the systematic and random errors. Systematic error was not significant and random method error ranged from 0.29 (L1L6) to 1.17 (L6MP).

Models

On the models, 17 landmarks were identified (Fig 4), marked, and measured with electronic calipers (Fowler). The following distances were measured:

- Intersecond molar width: distance between the central fossae of the second molars.
- Interfirst molar width: distance between the central fossae of first molars.
- Intersecond premolar width: distance between the mesial fossae of second premolars.

Table I. Skeletal and dental effects of mandibular symphyseal DO, analyzed in posteroanterior radiographs

	Predistraction (T1)		Postdistraction (T2)		Change (T1-T2)	
Width	Mean	SD	Mean	SD	Mean	SD
Bicondylar	121.3	6.8	122.0	6.8	0.7	1.8
Bigonion	96.8	8.8	97.5	9.2	0.7	4.4
Biantegonion	86.9	7.9	88.0	7.4	1.2	4.4
Intermolar	63.7	5.2	65.9	4.4	2.2*	4.2
Intercanine	30.5	2.8	33.6	5.2	3.2*	3.3

*$P < .05$.

Table II. Dental effects of mandibular symphyseal DO, analyzed in lateral radiographs

	Predistraction (T1)		Postdistraction (T2)		Change (T1-T2)	
Variables	Mean	SD	Mean	SD	Mean	SD
L1MP	89.9	9.0	95.7	7.1	5.8*	6.9
L6MP	75.9	6.9	77.7	7.1	1.8	4.7
L1L6	26.4	3.5	28.6	3.6	2.2*	2.1

*$P < .05$.

Table III. Interdental effects of mandibular symphyseal DO analyzed in models

	Predistraction (T1)		Follow-up (T3)		Change (T1-T3)	
Interdental space	Mean	SD	Mean	SD	Mean	SD
Second molar	45.3	4.8	49.4	3.7	4.1*	3.7
First molar	38.5	3.5	43.5	4.0	5.0**	3.2
Second premolar	31.8	2.9	36.7	4.1	4.9**	3.9
First premolar	26.8	2.1	30.3	2.6	3.5**	2.4
Canine	24.8	3.0	27.2	2.9	2.4**	1.9

*$P < .05$; **$P < .01$.

- Interfirst premolar width: distance between the mesial fossae of first premolars.
- Intercanine width: distance between the cusp tips of the canines.

The following distances were computed:

- Arch length: sum of right AB and left BA'.
- Irregularity index: summed displacement of the anatomic contact points of the mandibular anterior teeth.[32]

A subsample of 15 randomly selected models was re-marked and digitized to calculate the systematic and random errors. Systematic error was not significant, and random method error ranged from 0.45 (interfirst premolar and intersecond molar widths) to 1.29 (intercanine width).

Table IV. Dental effects of mandibular symphyseal DO analyzed in models

	Predistraction (T1)		Follow-up (T3)		Change (T1-T3)	
Variables	Mean	SD	Mean	SD	Mean	SD
Arch length	43.7	3.7	47.32	4.1	3.6**	3.4
Irregularity	7.8	4.0	3.3	2.6	–4.6**	4.4

**$P < .01$.

Table V. Skeletal and dental long-term effects of mandibular midsagittal DO analyzed in posteroanterior cephalograms

	Postdistraction (T2)		Follow-up (T3)		Change (T2-T3)	
Widths	Mean	SD	Mean	SD	Mean	SD
Bicondylar	119.0	5.7	118.8	5.0	–0.2	3.1
Bigonion	94.3	6.6	95.0	6.0	0.7	4.7
Biantegonion	85.0	5.6	86.1	5.2	1.2	4.1
Intermolar	64.9	4.0	64.4	3.0	–0.4	3.0
Intercanine	33.5	3.7	33.8	2.8	0.5	3.3
Bone marker	16.6	1.3	16.9	2.3	0.5	1.4

Table VI. Long-term follow-up of mandibular symphyseal DO analyzed in lateral radiographs

	Postdistraction (T2)		Follow-up (T3)		Change (T2-T3)	
Variables	Mean	SD	Mean	SD	Mean	SD
L1MP	95.7	7.6	96.4	7.5	0.6	4.9
L6PM	78.6	5.9	78.2	5.1	–0.5	4.3
L1L6	28.1	3.8	26.9	4.7	1.3	2.6

Statistical Methods

All the data were transferred to the software SPSS (release 9.0) for analysis. Normal distributions were verified for each variable. Paired *t* tests were performed to evaluate the surgical (T1-T2) and the follow-up changes (T2-T3). A significance level of $P < .05$ was used.

RESULTS

Distraction Effects (T1-T2)

When mandibular widening was analyzed in the PA radiographs, there were small increases in the bicondylar, bigonion, and biantegonion widths, none of which were statistically significant. There were significant dental effects; intercanine width increased 3.2 (±3.3)

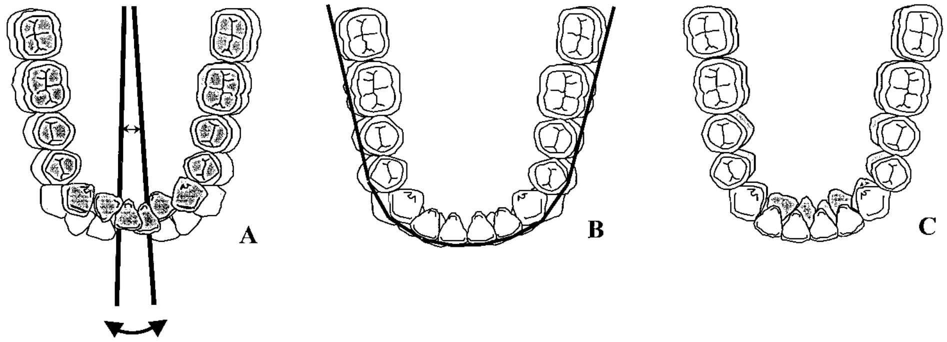

Fig 5. A, Predicted distraction (predistraction); **B**, orthodontic effect (postdistraction); **C**, net changes (predistraction and postdistraction effect).

mm; intermolar width increased 2.2 (±4.2) mm (Table I); the incisors also flared significantly (Table II). Proclination was significantly greater ($P < .05$) for the patients who did not have predistraction orthodontic treatment (mean, 8.5° ± 4.6°) than for those who did (mean, –1.5° ± 3.6°). Arch length increased but the molar inclination did not change significantly (Table II).

Model Analysis (T1-T3)

The dental models showed significant width increases for all 5 measurements (Table III). Widths increased steadily from 2.4 (±1.9) mm at the canines to 5.0 (±3.2) mm at the first molars. Intersecond molar width increased 4.1 (±3.7) mm. Arch length increased 3.6 (± 3.4) mm and irregularity decreased 4.6 (±4.4) mm (Table IV).

Long-term Follow-up (T2-T3)

Long-term follow-up of PA radiographs did not show any significant transverse change, neither skeletally (bicondylar, bigonion, and biantegonion widths) nor dentally (intermolar and intercanine). Neither was there significant change between the fixation wires in the symphyseal region, suggesting stability of the distraction procedure (Table V). The lateral radiographs showed no significant postdistraction changes for incisor or molar angulation, or arch length (Table VI). The bone formed in the distraction gap as seen on the PA and panoramic radiographs presented the same radiodensity as the adjacent bone. Clinically, the gingival tissues were normal in appearance.

DISCUSSION

Theoretically, mandibular symphyseal DO should produce greater width increases in the anterior part of the mandible than in the posterior (Fig 5*A*). Our radiographic results confirmed that intercanine width increased more than intermolar width. Follow-up model analysis, however, showed greater widening in the second premolar and first molar region than in the canine region. The difference in expansion between the models and the PA radiographs may be explained by orthodontic treatment after the distraction procedure. Orthodontic treatment will align the arch and close spaces by moving the incisors and canines lingually and the other teeth mesially along the preformed wire shape (Fig 5*B*). Our results showed that postdistraction orthodontic treatment largely resolved the crowding by moving teeth into the newly formed bone in the distraction gap, emphasizing that the timing of the records is important in distinguishing between orthodontic and distraction osteogenesis effects. The mandibular arch was expanded by distraction, with most of the space being used for correction of crowding (Fig 5*C*).

The location and orientation of the distraction force are of fundamental importance because they might influence the shape of the distraction gap. Theoretically, if the force is applied near the center of resistance of the mandible, the distraction will produce pure translation of the segments and the distraction gap will have parallel margins. However, if the force is applied above the center of resistance, rotation of the two segments might be expected, resulting in a disproportionally larger gap in the dentoalveolar area than in the basal area (Fig 6*A*). Our results confirmed that symphyseal distraction, using a tooth-borne device, was disproportional because width increases between the second molars were greater than biantegonion width increases; both are located in approximately the same coronal plane (Fig 6*B*). Disproportional patterns have also been demonstrated with tooth-borne appliances in animal models.[29,30] In addition to the location of the force application, the disproportional widening observed might be related to the wires to fixate the genioplasty. These wires could

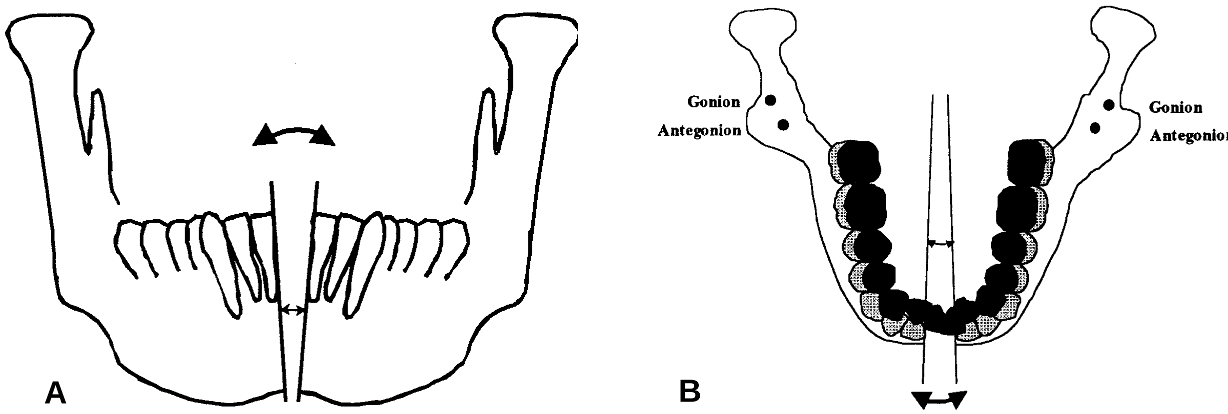

Fig 6. Distraction effect on mandible: **A**, coronal view; **B**, transverse view.

restrict lateral displacement of the symphysis. Ideally, the fixation wires are placed so as not to impede the movements of the hemimandibles. Regardless of its cause, a disproportional gap represents a potential problem because expansion of alveolar bone, when not supported by basal bone, may be unstable and represent a risk of relapse.[14,15] Bone-borne expansion devices have a greater potential for proportional movement than do tooth-borne appliances. Furthermore, the procedure does not involve tooth movement, and more stable results can be expected.[33]

Assuming that the bone markers used for superimposition were stable, the lack of significant skeletal changes over the follow-up period confirmed stability of the expanded basal bone. This is important because orthodontic expansion, especially in nongrowing patients using lip bumpers[6-8] and functional appliances, has not demonstrated good stability.[10,11] Even though the distraction gap was larger in the dentoalveolar area than in the basal area, this type of osseous expansion is expected to provide greater stability than orthodontic expansion alone. Concomitantly, it provides the space needed to resolve crowding.

Proclination of the mandibular incisors during distraction is a clinical concern. Significant proclination was observed in patients who did not have orthodontic wires placed before the distraction procedure. Proclination was probably due to the distraction pattern of the tooth-borne device, which disproportionately rotated the segments laterally and anteriorly. Patients who had orthodontic wires in place at the time the postdistraction radiographs were taken showed no changes in incisor inclination, suggesting that orthodontic treatment compensated for the proclination produced by distraction.

Some important limitations affect the reliability and validity of this study. It is a retrospective study with a limited sample size that does not include complete records for all subjects. Future prospective longitudinal studies are necessary to precisely evaluate the distraction and postdistraction changes. Furthermore, the amount of distraction in the anterior region could not be reliably measured due to the lack of stable reference structures; the use of metallic bone markers is recommended. Submental vertical radiographs might be expected to provide a better measure of distraction. Future studies should also evaluate the quality and quantity of bone formed in the distraction gap, which could not be assessed with PA and panoramic radiographs. Periapical radiographs should be used for this purpose. Clinical periodontal assessment of the patients before and after distraction is necessary to evaluate the periodontal effects of mandibular symphyseal distraction osteogenesis. Finally, stability of the dental changes could not be addressed because the majority of the patients were still undergoing orthodontic treatment when the impressions were taken. Despite these limitations, this is the first study to quantify and confirm disproportional but stable transverse expansion of the mandibular segments with symphyseal distraction osteogenesis in human subjects.

CONCLUSIONS

Symphyseal distraction osteogenesis offers an alternative treatment strategy to resolve crowding and transverse mandibular deficiencies (Fig 7). Potentially, distraction provides the esthetic advantages associated with typical orthodontic expansion procedures but without the same risk of relapse.

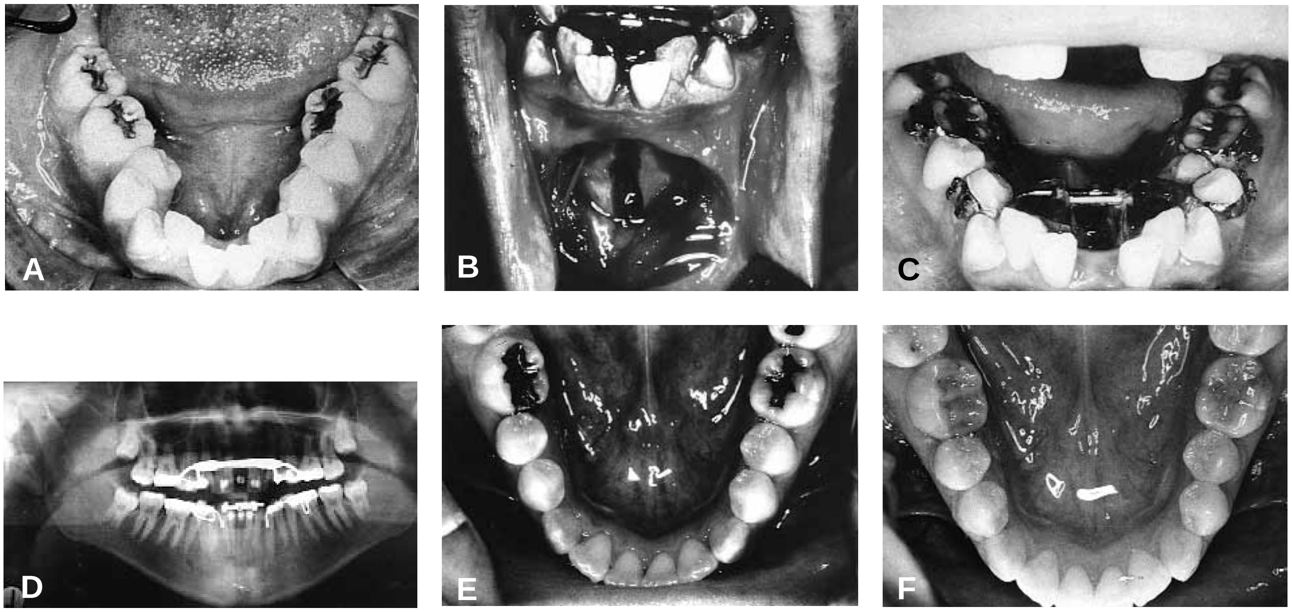

Fig 7. A, A 17-year-old female presenting with severe mandibular transverse deficiency and significant crowding; **B**, mandibular symphyseal distraction osteogenesis was performed; **C**, transverse increase was significant after activation of distraction appliance; **D**, radiographic evidence of distraction; **E**, after orthodontic treatment there was good incisor alignment with no interproximal spaces and suitable arch form was achieved; **F**, 10-year follow-up shows good stability of results; notice that amalgam filling of molars was changed by esthetic restorations.

Further, distraction eliminates the need for dental extraction. The results of this study demonstrated the following:

1. Osseous expansion achieved by symphyseal DO was stable over the period studied.
2. Two primary clinical concerns were identified: disproportional widening of the dento-osseous segments (alveolar bone was expanded more than basal bone) and lower incisor proclination.
3. Crowding can be partially corrected by dental movement into newly formed alveolar bone in the distraction gap.

REFERENCES

1. Wertz R, Dreskin, M. Midpalatal suture opening: a normative study. Am J Orthod 1977;71:367-81.
2. Haas AJ. Treatment of maxillary deficiency by opening the midpalatal suture. Angle Orthod 1965;65:200-17.
3. Mew J. Relapse following maxillary expansion: a study of twenty-five consecutive cases. Am J Orthod 1983;83:56-61.
4. Brunelle JA, Bhat M, Lipton JA. Prevalence and distribution of selected occlusal characteristics in the US population, 1988-1991. J Dent Res 1996;75(Spec Iss):706-13.
5. Kelly J, Harvey C. An assessment of the teeth of youths 12-17 years. Washington: National Center for Health Statistics, DHEW Pub HRA 77-1644;1977.
6. Nevant C. The effects of lip bumper therapy on deficient mandibular arch length [Master's thesis]. Dallas: Baylor College of Dentistry; 1989.
7. Werner S, Shivapuja PK, Harris EF. Skeletodental changes in the adolescent accruing from use of the lip bumper. Angle Orthod 1994;64:13-22.
8. Davidovich M, McInnis D, Lindaur SJ. The effects of lip bumper therapy in the mixed dentition. Am J Orthod Dentofacial Orthop 1997;111:52-8.
9. Schwarz AM, Gratzinger M. Removable orthodontic appliances. Philadelphia: WB Saunders Co; 1966.
10. Fränkel R, Fränkel C. Orofacial orthopedics with the function regulator. Karger: Basel; 1989.
11. Hime DL, Owen A. The stability of the arch expansion effects of Fränkel appliance therapy. Am J Orthod 1990;98:437-45.
12. Witzig JW, Spahl TJ. The clinical management of basic maxillofacial orthopedic appliances. Massachusetts: PSG Publishing Company Inc; 1987. p.279-417.
13. McNamara JA, Brudon WL. Orthodontic and orthopedic treatment in the mixed dentition. Ann Arbor: Needham Press; 1993. p. 171-8.
14. Strang RHW. The fallacy of denture expansion as a treatment procedure. Angle Orthod 1949;19:12-22.
15. Herberger RJ. Stability of mandibular intercuspid width after long periods of retention. Angle Orthod 1981;51:78-83.
16. Guerrero C, Contasti G. Transverse (horizontal) mandibular deficiency. In: Bell WH. Modern practice in orthognathic and reconstructive surgery. Philadelphia: Saunders; 1992. p. 2383-97.
17. Martin DL. Transverse stability of multi-segmented Le Fort I expansion procedures [Master's thesis]. Dallas: Baylor College of Dentistry;1998.

18. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues: Part 1. the influence of stability of fixation and soft tissue preservation. Clin Orthop 1989;238:249-81.
19. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues: Part 2. the influence of the rate and frequency of distraction. Clin Orthop 1989;238:263-85.
20. Peltonen JI, Kahri AI, Lindberg LA, Heikkila PS, Karaharju EO, Aalto KA. Bone formation after distraction osteotomy of the radius in sheep. Acta Orthop Scand 1992;63:599-603.
21. Sproul JT, Price CT. Recent advances in limb lengthening. Part 2: biological advances. Orthop Rev 1992;21:425-30.
22. Windhager R, Tsuboyama T, Siegl H, Groszschmidt K. Effect of bone cylinder length on distraction osteogenesis in the rabbit tibia. J Orthop Res 1995;13:620-8.
23. Snyder CC, Levine GA. Mandibular lengthening by gradual distraction. Plast Reconstr Surg 1973;51:506-8.
24. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. Plast Reconstr Surg 1992;89:1-10.
25. Monasterio FO, Molina F, Andrade L, Rodriguez C, Arregui JS. Simultaneous mandibular and maxillary distraction in hemifacial microsomia in adults: avoiding occlusal disasters. Plast Reconstr Surg 1997;100:852-61.
26. Havlik RJ, Bartlett SP. Mandibular distraction lengthening in the severely hypoplastic mandible: a problematic case with tongue aplasia. J Craniomaxillofac Surg 1994;5:305-10.
27. Guerrero CA. Expansion mandibular quirurgica. Rev Venez Ortod 1990;48:1-2.
28. Guerrero CA, Bell WH, Contasti GI, Rodriguez AM. Mandibular widening by intraoral distraction osteogenesis. Br J Oral Maxillofac Surg 1997;35:383-92.
29. Bell WH, Harper RP, Gonzalez M, Cherkashin AM, Samchukov ML. Distraction osteogenesis to widen the mandible. Br J Oral Maxillofac Surg 1997;35:11-9.
30. Hollis BJ, Block MS, Gardiner D, Chang A. An experimental study of mandibular arch widening in the dog using distraction osteogenesis. J Oral Maxillofac Surg 1998;56:330-8.
31. Dahlberg G. Statistical methods for medical and biological students. London: George Allen and Unwin Ltd; 1940.
32. Little RM. The irregularity index: a quantitative score of mandibular anterior alignment. Am J Orthod 1975;68:554-63.
33. Bell WH, Gonzalez M, Samchukov ML, Guerrero CA. Intraoral widening and lengthening of the mandible in baboons by distraction osteogenesis. J Oral Maxillofac Surg 1999;57:548-62