OPEN

ORIGINAL ARTICLE

Pediatric/Craniofacial

# External versus Internal Distraction Devices in Treatment of Obstructive Sleep Apnea in Craniofacial Anomalies

Adi Rachmiel, DMD, PhD*†
Saleh Nseir, DMD*
Omri Emodi, DMD*
Dror Aizenbud, DMD, MSc†‡

**Background:** Obstructive sleep apnea is often associated with congenital craniofacial malformations due to hypoplastic mandible and decreased pharyngeal airway. In this study, we will compare external and internal distraction devices for mandibular lengthening in terms of effectiveness, results, patient comfort, and complications.
**Methods:** Thirty-seven patients were treated by bilateral mandibular distraction osteogenesis for obstructive sleep apnea: 20 with external and 17 with internal distraction devices.
**Results:** Lengthening of the mandible and increase of the pharyngeal airway were obtained in all patients. Using the external devices, the average mandibular elongation was 30 mm versus 22 mm with the internal devices; however, after 1 year, the results were more stable with internal devices. External devices carried greater risk for pin tract infection than the internal devices (27.5% vs 5.88%). In addition, pin loosening in 22.5% required pin replacement or led to reduced retention period. Internal devices had a precise and predictable vector of lengthening and left less visible scars at the submandibular area but carried the disadvantage of requiring a second operation for device removal. In very young children with severe micrognathia, it was impossible to place internal devices, and external devices were used.
**Conclusions:** Internal devices should be the first choice because they are more comfortable to the patients, more predictable vector of lengthening, are less vulnerable to dislodgement, and leave reduced scarring, with the great disadvantage of second operation for removal. However, external devices still should be considered mainly in severely hypoplastic cases, and the surgeon should be prepared for both options. *(Plast Reconstr Surg Glob Open 2014;2:e188; doi: 10.1097/GOX.0000000000000147; Published online 29 July 2014.)*

Obstructive sleep apnea (OSA) is often associated with congenital craniofacial malformations due to the hypoplastic mandible and decreased pharyngeal airway.[1,2] In recent years, mandibular distraction osteogenesis has become the treatment of choice for pediatric patients with OSA that are associated with hypoplastic mandible.[1,3–8] Forward mandibular distraction causes advancement of the base of tongue and the hyoid bone, increasing the pharyngeal airway and improving the airway of patients who suffer from respiratory distress or permit decannulation of permanent tracheotomy.

*From the *Department of Oral and Maxillofacial Surgery, Rambam Health Care Campus, Haifa, Israel; †Bruce Rappaport Faculty of Medicine, Technion–Israel Institute of Technology, Haifa, Israel; and ‡Orthodontic and Craniofacial Center, Graduate School of Dentistry, Rambam Health Care Campus, Haifa, Israel.*
*Received for publication October 31, 2013; accepted June 3, 2014.*

DOI: 10.1097/GOX.0000000000000147

Mandibular distraction osteogenesis can be associated with a wide variety of minor and major complications.[9–15] Drawbacks of distraction devices may include accidental mandibular fracture during placement of device, tooth injury, inappropriate distraction vector, facial skin scars, local infection, pin loosening, device dislodgment, device failure, facial nerve paralysis, failure to improve airway, and relapse.

This study reviews 37 patients who underwent bilateral mandibular distraction osteogenesis as treatment for OSA as a result of mandibular micrognathia and glossoptosis. We compare external and internal devices for mandibular distraction in terms of effectiveness in use, result, patient comfort, and complications. Moreover, the advantages and disadvantages of both methods will be presented.

## MATERIALS AND METHODS

### Patient Demographics

Thirty-seven patients, aged between 6 months and 14 years old, underwent mandibular lengthening by bilateral mandibular distraction for OSA treatment in our hospital between 2002 and 2011. The patients had hypoplastic mandible and glossoptosis as manifestations of Treacher Collins syndrome, Goldenhar syndrome, or Pierre Robin sequence resulting in OSA (Table 1). Twenty-one patients suffered from respiratory distress and were tracheotomy candidates, and 16 patients were tracheotomy dependent. Polysomnographic sleep studies revealed respiratory disturbance index greater than 10 apneas per hour and oxygen saturation less than 85%.

All patients underwent endoscopy before the decision for distraction to fully evaluate the airway and to exclude tracheomalacia or other problems that cannot be corrected with distraction. Lateral cephalometric radiographs and computed tomography (CT) scans revealed mandibular hypoplasia that caused retroposition of the base of the tongue and inadequate pharyngeal space.

Twenty patients were treated with external distraction devices (Fig. 1) and 17 patients by internal distraction devices (Fig. 2). The surgical procedure was performed on both sides of the mandible under general anesthesia using either the tracheostomy or nasal endotracheal intubation.

**Disclosure:** *The authors have no financial interest to declare in relation to the content of this article. All devices were purchased from KLS Martin, Tuttlingen, Germany. The Article Processing Charge was paid for by the authors.*

**Table 1. Patient Demographics (37 Patients)**

| Age | 6 mo to 14 y (average, 5.5 y) |
|---|---|
| Syndrome | |
| Treacher Collins | 8 |
| Goldenhar | 14 |
| Pierre Robin Sequence | 15 |
| Tracheostomy | |
| Tracheostomy dependents | 16 |
| Tracheostomy candidates | 21 |

The decision to perform internal or external devices was based on preoperative and intraoperative considerations, such as anatomical bony characteristics affecting the possibility to place internal devices and patient cooperation.

The approach for the external devices was intraoral between the mental nerve anteriorly and gonial area posteriorly on both sides of the mandible. While protecting the tissue in the floor of mouth, a circumferential osteotomy was performed anterior to the gonial angle using a reciprocating saw. Great care was taken to avoid damage to the tooth roots, dental buds, and the inferior alveolar nerve.

The external devices were placed parallel to the mandibular body to advance the mandible forward (Fig. 3).

The approach for internal devices was by a skin incision at the submandibular retroangular area. While preserving the mandibular branch of the facial nerve, exposure of the mandible between the mental nerve anteriorly and gonial area posteriorly was made. Then the same circumferential mandibular body osteotomy was performed just anterior to the gonial angle. While performing reduction of the fracture in correct preoperative occlusion on both sides of the mandible, the 2 arms of the internal distractors (KLS Martin 20 or 25 mm) were fixed with monocortical miniscrews across the osteotomy line in a forward vector (Fig. 4). The distractor rods for activation were placed either intraorally along the lower vestibulum or extraorally posterior to the submandibular skin incision below the ear.

In both methods, after 3 days of latency period for callus organization, gradual lengthening of the mandible was performed at a rate of 0.5 mm twice a day for a total of 1 mm per day until class I occlusion was achieved. Distraction was continued up to 2–3 mm overcorrection anteriorly to class III dental occlusion (Figs. 5–7). If there was tendency to open bite or asymmetries during distraction, intermaxillary elastics were placed.

Patients were evaluated by polysomnography and lateral cephalograms, head and neck CT in axial and sagittal planes, and 3-dimensional reconstruction before and at completion of treatment. Radiographs

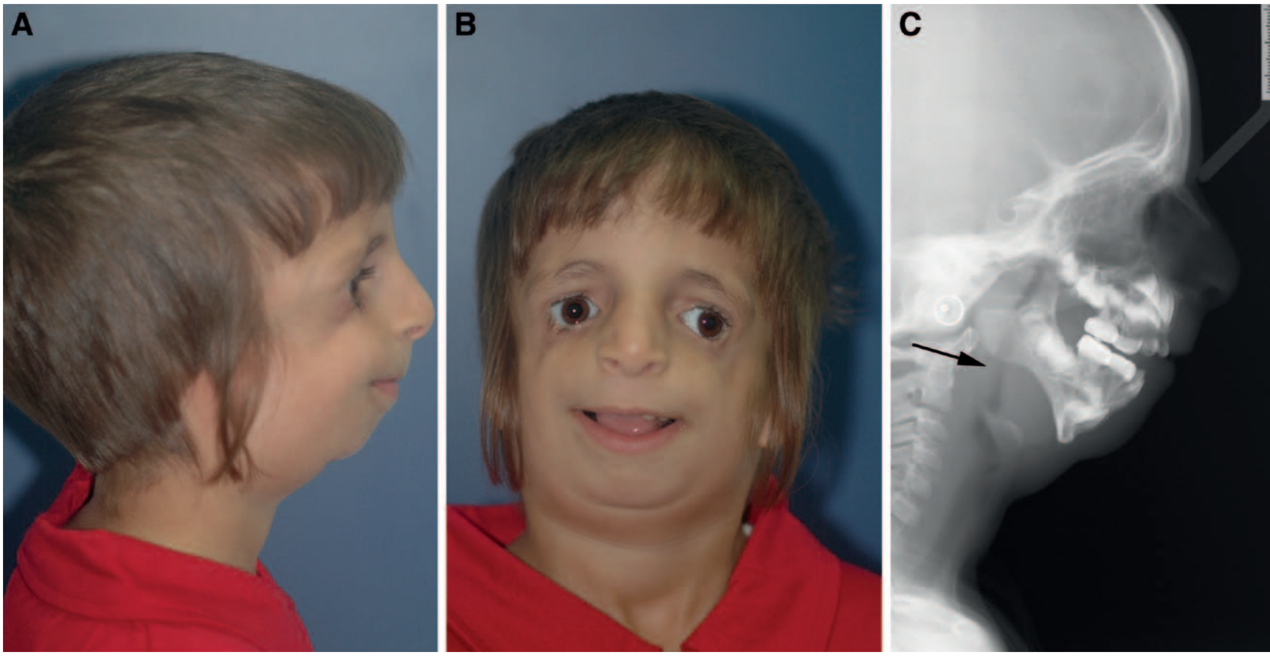

**Fig. 1.** Patient before treatment with external distraction device. A and B, Five-year-old boy with Treacher Collins syndrome associated with mandibular hypoplasia and obstructive sleep apnea. C, Preoperative lateral cephalometric x-ray demonstrating mandibular micrognathia and airway constriction (arrow).

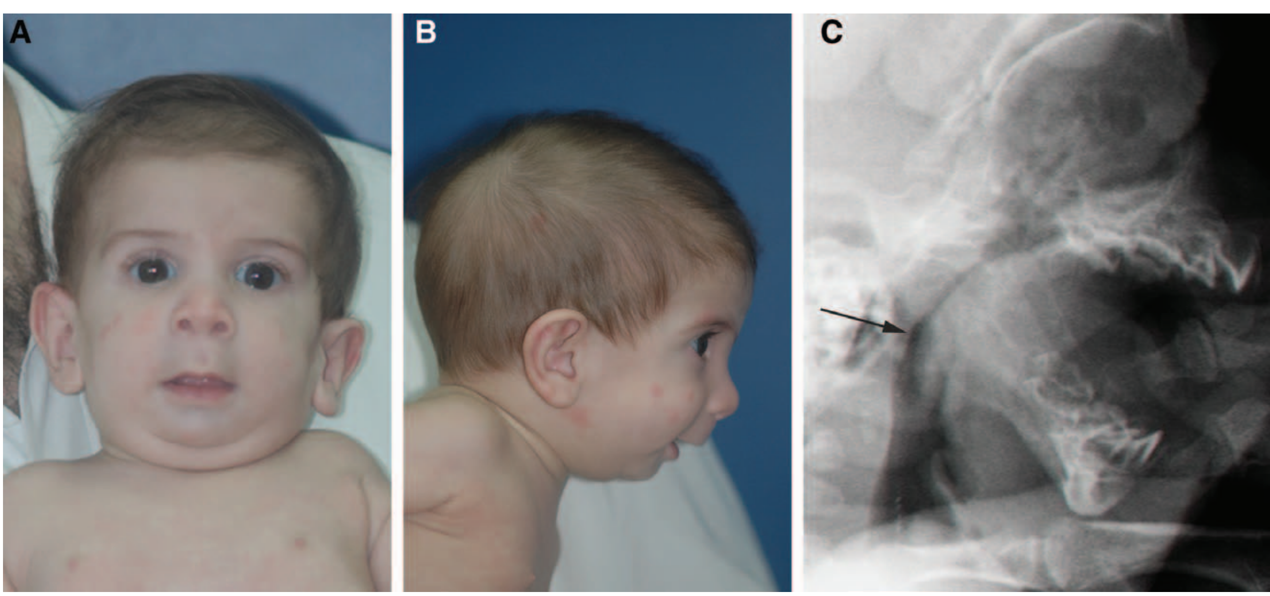

**Fig. 2.** Patient before treatment with internal distraction device. A and B, Seven-month-old boy with Pierre Robin Syndrome associated with severe mandibular hypoplasia and obstructive sleep apnea. C, Preoperative lateral cephalometric x-ray demonstrating mandibular micrognathia and airway constriction (arrow).

were used for operative planning and follow-up. As this article focuses on comparison between the methods of external and internal devices for mandibular distraction, the polysomnographies and the CT used for airway analysis[8,10] are not presented.

After a 4-month retention period for callus maturation, the distraction devices were removed. The external devices were removed by simple removal of the external pins (Fig. 8) and the internal distractors by an additional operation under general anesthesia through the previous submandibular scars.

## RESULTS

Mandibular distraction was successful in all 37 patients with marked advancement of the lower jaw and improved airway (Fig. 7, internal and Fig. 8,

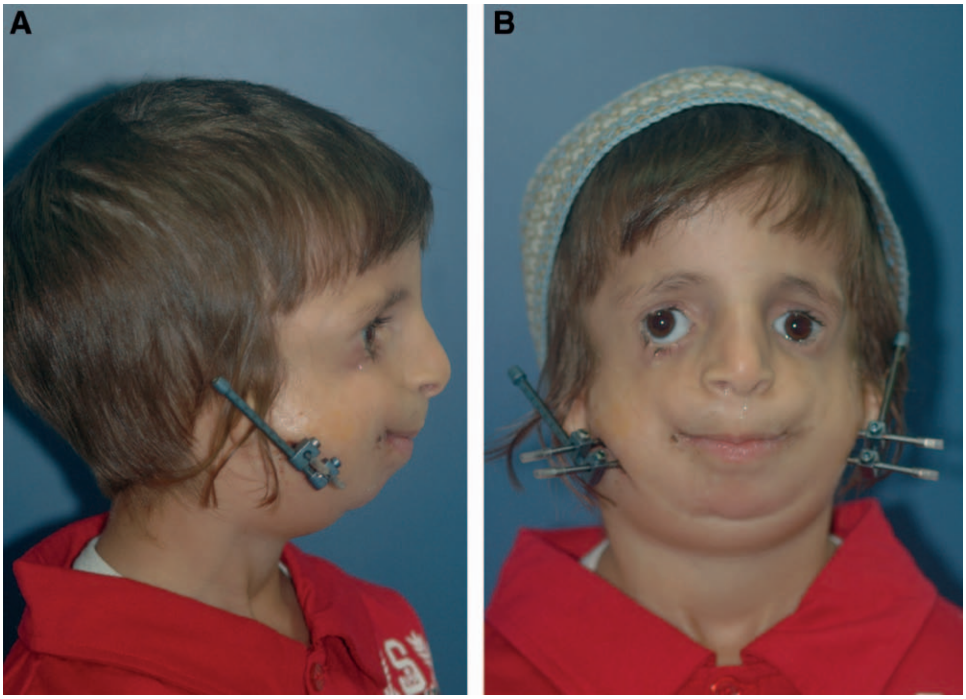


**Fig. 3.** At the end of the operation after the osteotomy and placement of the bilateral external distractors, before commencement of lengthening. A, Lateral view. B, Anterior view.

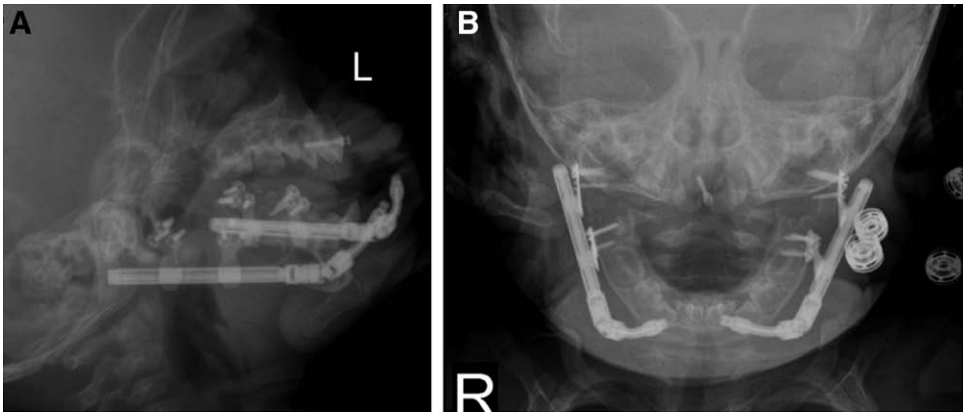


**Fig. 4.** A, Cephalometric x-rays. B, Bilateral mandibular distraction with internal device.

external). At the end of the retention period after distraction device removal, in all 16 tracheotomy-dependent patients, the tracheotomies were removed. In all 21 patients with respiratory distress, there was improved airway with improvement of signs and symptoms of OSA with oxygen saturation over 95%.

As a result of the lengthening, the occlusion was changed from class II to class I and then 2–3 mm overcorrection to class III (Figs. 7C and 8B). The mean lengthening with the external devices was 30 mm and with the internal devices 22 mm. The Sella-Nasion-B Point was changed using the external devices from a mean of 64° to 81° and with the internal devices from 65° to 80° (Table 2). After 1 year, the Sella-Nasion-B Point of the external devices had a mean of 77° (relapse of 23.52%) and with the internal devices a mean of 78° (relapse of 13.33%). During the 1-year follow-up, the dental occlusion returned to class I (Figs. 9, external and 10, internal). The complications are presented in Table 3.

**Placement and Device Stability**

External devices permitted longer distraction and could be changed to a longer distractor during lengthening. Placement of the external devices was simpler by intraoral approach and insertion of 2 external pins. In 4 cases, it was impossible to insert an internal device subperiosteally because of limited subperiosteal space or because the fixation screws

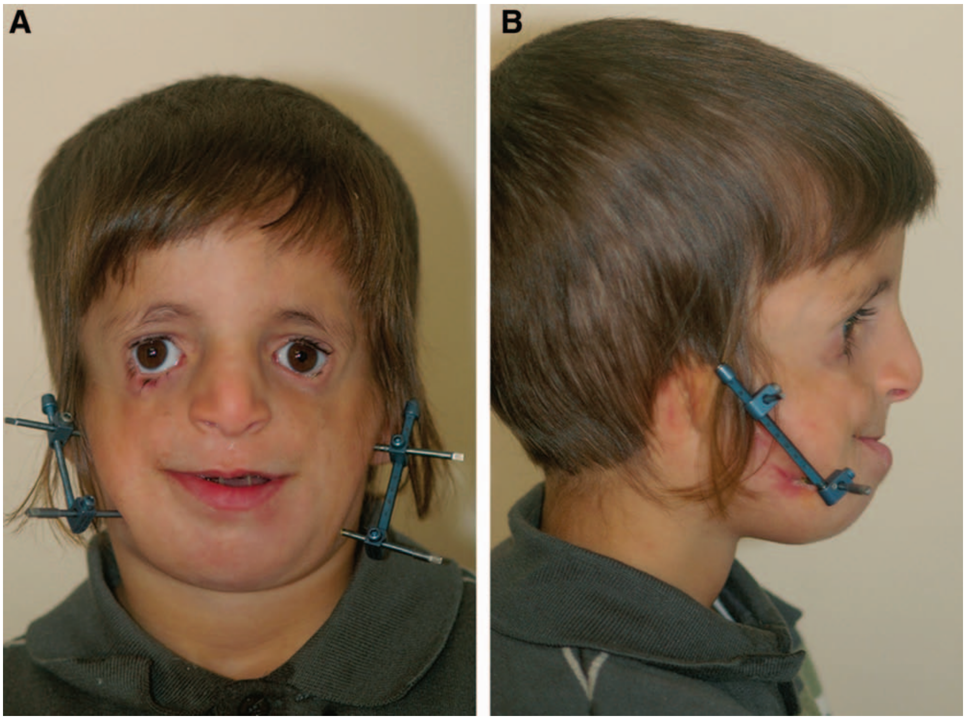


**Fig. 5.** Following bilateral mandibular forward distraction with external devices with slight overcorrection. A, Anterior view. B, Lateral view.

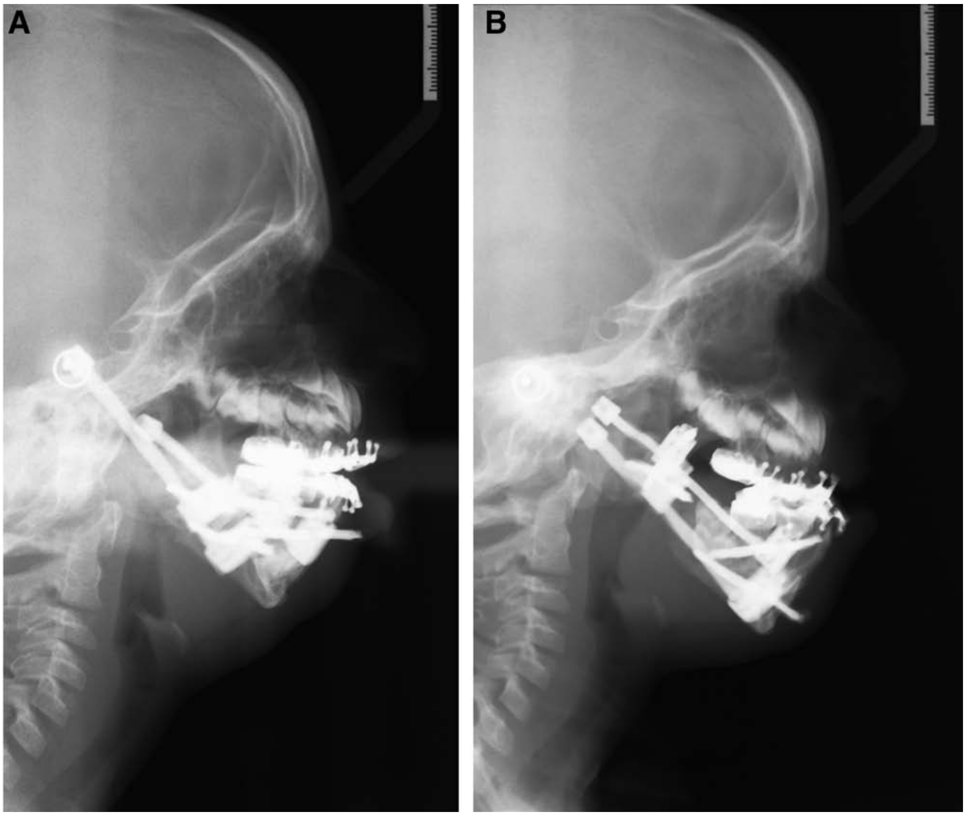


**Fig. 6.** Cephalometric x-rays: (A) during forward mandibular distraction with external device and (B) following distraction.

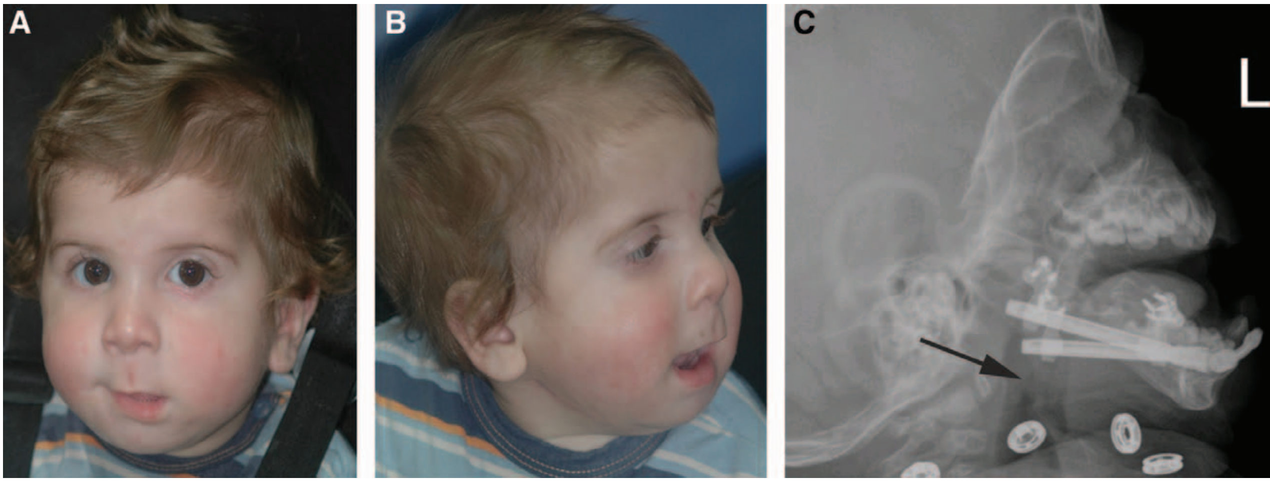


**Fig. 7.** At the end of forward distraction of the mandible with internal devices. A, Anterior view. B, Lateral view. C, Cephalometric x-ray at the end of forward distraction with slight overcorrection.

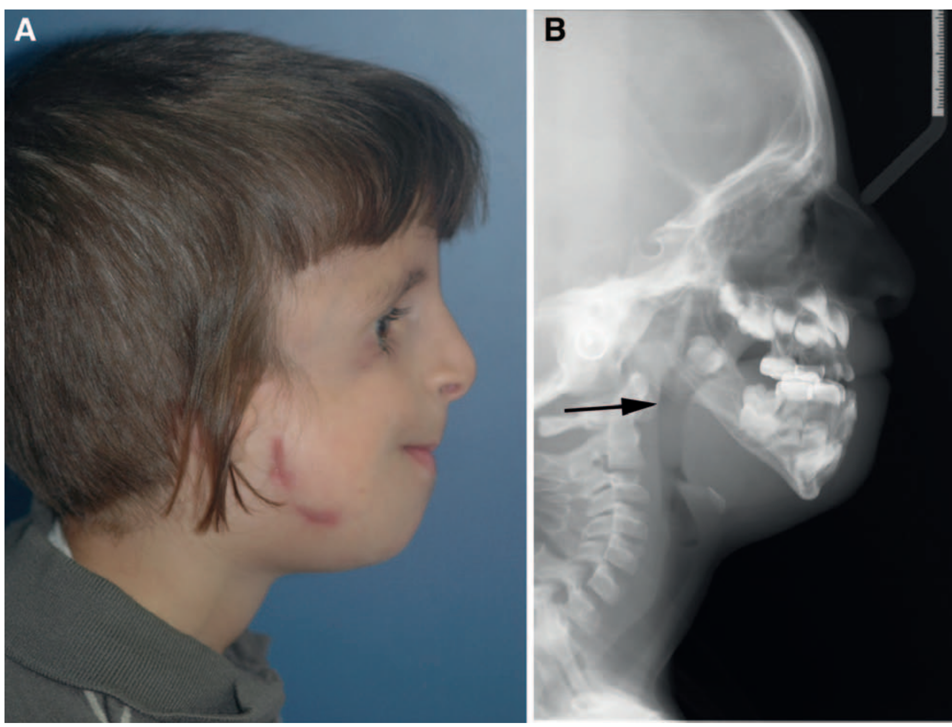


**Fig. 8.** A, Following mandibular distraction with external devices. Note the marked skin scars at the buccal area. B, Cephalometric x-ray after removal of the devices. Note the increased airway (arrow) and the slight overcorrection.

**Table 2. The Amount of Lengthening, Sella-Nasion-B Point, and Occlusal Changes Following Mandibular Distraction and 1 Year Later**

| | Amount of Lengthening (mm) | SNB | | | Occlusion | | |
|---|---|---|---|---|---|---|---|
| | | Pre | Post | After 1 y | Pre | Post | After 1 y |
| External | 30 | 64° | 81° | 77° (23.52%) | Class II | Class III | Class I |
| Internal | 22 | 65° | 80° | 78° (13.33%) | Class II | Class III | Class I |

SNB, Sella-nasion-B.

could not be secured. In these cases, we switched to external devices by using 2 bicortical pins across the osteotomy line that offered better initial bone stability. During the retention period, with external devices (20 patients, ie, 40 sides), 22.5% of the pins (9 sides) became loose and were removed earlier

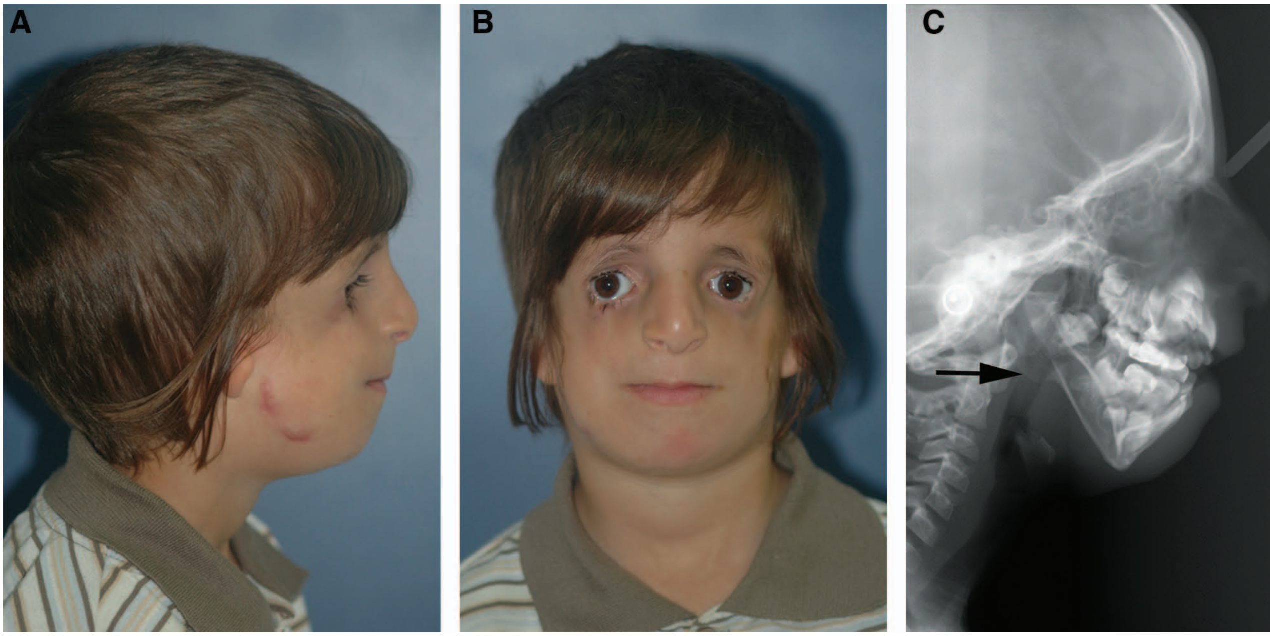


**Fig. 9.** One year post distraction with external devices: A and B, Note the visible skin scar. C, Class I occlusion and increased airway (arrow).

**Table 3. Complications of External and Internal Distraction Devices Used in Mandibular Lengthening for Correction of OSA**

| | External—20 Cases (40 Devices) | Internal—17 Cases (34 Devices) |
|---|---|---|
| Device fracture | No | 1 |
| Device instability: pin loosening | 9 (22.5%) | No |
| Relapse after 1 y | 23.52% | 13.33% |
| Facial nerve damage | No | 14.7% |
| Infection | 11 (27.5%) | 2 (5.88%) |

in 3 patients (6 sides). In 3 sides, at the beginning of the retention period when the new bone was not solid enough, they were replaced by new pins.

In all 17 cases with internal devices, the lengthening was performed until the maximum distraction length (20 or 25 mm), and during the retention period, the devices were stable at the distraction site. In 1 patient in 1 side, the device failed to distract resulting in device fracture, and an additional operation under general anesthesia was performed to remove and replace the broken distractor. The space for internal devices is more limited subperiosteally, and change to another device requires a second operation and the same extraoral dissection under general anesthesia.

### Precision of Lengthening

The external distraction is made by tension-stress. During the distraction, there was some bending of the pins with less precise lengthening that may lead to inferior bony generation and subsequent relapse. The internal devices offered more predictable and precise rate of lengthening due to direct contact of the device to the bony segments.

### Infection

Eleven sides (27.5%) with external devices suffered infection around the pins that was treated by local disinfection and per os antibiotics. Some of these pins became later loose and were removed. In only 2 sides (5.88%) with internal devices, there was some infection around the distraction rods that was treated by local disinfection and PO antibiotics.

### Patient Comfort

The external devices were less comfortable to young patients than the internal devices because of the need to wear several months 2 visible external devices, vulnerable to external trauma during daytime and even during sleep. The internal devices were invisible to the patient and to the society, not vulnerable to external trauma and permitted nearly complete jaw function.

### Facial Nerve Damage

External device insertion and use did not result in any facial nerve damage; however, in the internal device group in 5 sides (14.7%), there was some transient damage to the mandibular branch of the facial nerve that resolved with physiotherapy several months following the removal of the device.

### Scars

After removal of the external pins, 2 visible buccal skin scars lateral to the mandible remained (Figs. 8A

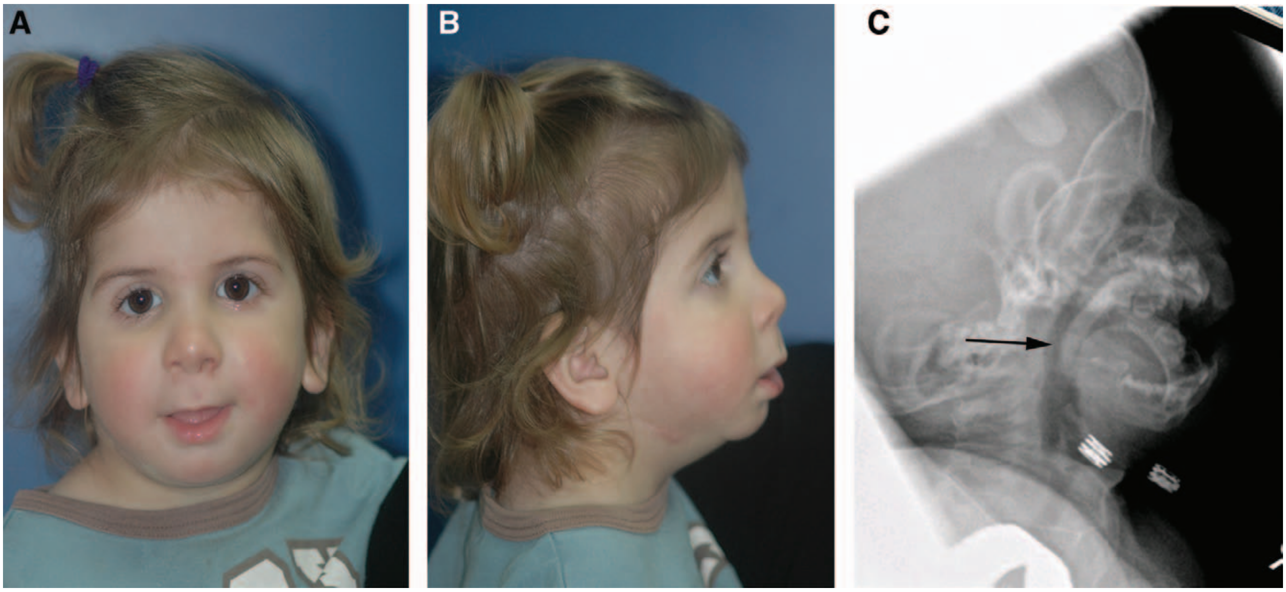


**Fig. 10.** One year post distraction with internal devices: A and B, Note the less visible skin scar. C, Class I occlusion and increased airway (arrow).

**Table 4. Summary of Advantages and Disadvantages of External and Internal Distraction Devices in Mandibular Lengthening for Correction of OSA**

| | External | Internal |
|---|---|---|
| Approach | Intraoral, 2 external pin insertion, simpler, shorter operation | Extraoral submandibular, with soft tissue dissection to the mandible |
| Osteotomy | Easier to perform and place the pins in various anatomic structures, more "freedom of osteotomy design" | According to local anatomy and device dimension |
| Placement | Easy to place in limited space as in micrognathic children | Limited by subperiosteal place for the distractor or difficulty in screw fixation |
| Distraction length | Permits longer distraction | Limited by subperiosteal space |
| Comfort | Uncomfortable, may be damaged by accidental external forces | Comfortable, safer |
| Vector of distraction | Less predictable | More predictable, pre fixed by the device |
| Precision of lengthening | Less precise | More precise |
| Change of device | Possible | Need additional operation |
| Device stability | Possible pin loosening may compromise retention period | Stable for longer retention period and better ossification |
| Relapse after 1 y | Greater relapse | Decreased relapse |
| Facial nerve damage | Less risk | Greater risk |
| Infection | More pin tract infection | Less pin tract infection |
| Device removal | Simple, by unscrewing the pins | Need second operation under general anesthesia |
| Skin scars | Two buccal—visible | One submandibular—less visible |

and 9A). The internal devices left a single, less visible submandibular scar on each side (Figs. 7B and 10B).

## DISCUSSION

Mandibular distraction osteogenesis is associated with a wide variety of minor and major complications[10–15]; however, the complications can be minimized by careful planning and technique.[9,14] Master et al,[12] in 2010, reviewed 66 articles from PubMed database and concluded that the complications of mandibular distraction osteogenesis include incidence of relapse 64.8%, tooth injury 22.5%, hypertrophic scarring 15.6%, nerve injury 11.4%, infection 9.5%, inappropriate distraction vector 8.8%, device failure 7.9%, fusion error 2.4%, and temporomandibular joint injury 0.7%.

Genecov et al,[10] in 2009, examined the use of external and internal distraction devices in 81 patients and observed that complications were mostly related to pin site infections requiring antibiotics, and the device failure was 3% with the internal devices and 10.2% with the external devices.

The advantages and disadvantages of external and internal distraction devices in mandibular lengthening for correction of OSA are summarized in Table 4.

In general, mandibular distraction can be performed in the ramus for ramus lengthening, in the mandibular angle for downward and forward advancement, or in the mandibular body.[5,6,14,16] Ramus or gonial angle distraction are mainly used to treat facial asymmetries as in hemifacial microsomia.[9,14] However, in OSA, for forward mandibular lengthening, the osteotomy should be performed slightly anterior to the gonial angle, and the distraction devices should be placed parallel to the body of the mandible, resulting in traction of the suprahyoid muscles and the hyoid bone forward and thus increasing the airway.[4,6–8]

Placement of the external devices is simple by intraoral approach and insertion of 2 external pins transbucally. The removal of the device is easy by unscrewing the pins. On the other hand, placement and removal of internal devices need extraoral submandibular approach with soft-tissue dissection to the mandible with some risk of damage to the facial nerve. However, the damage to the mandibular branch of the facial nerve using internal devices was transient and resolved after device removal. No damage to the mandibular branch of the facial nerve occurred in any patient treated with external devices.

The internal device needs more subperiosteal space, and the fixation by screws may pose a problem in pediatric micrognathic population. In our series, in 4 cases, it was impossible to insert the internal devices either because of limited subperiosteal space or because the fixation screws could not be secured. In those cases, we used external devices by placing 2 bicortical pins across the osteotomy line to obtain better initial bony stability. External devices are easy to fit in various anatomical structures such as dental buds, very small mandibles, when there is difficulty to place an internal device which is too long for the periosteum, and when there is soft bone that cannot permit stable screw retention but permits insertion of 2 external bicortical pins. Using external devices in these cases confers more "freedom of osteotomy design." Therefore, the surgeon should be prepared for both methods.

The main disadvantages of the external devices are patient discomfort to wear several months 2 visible external devices vulnerable to external trauma even during sleep that may result in loosening of the pins that need to be replaced under general anesthesia or to reduce the retention period that may result in greater relapse. By contrast, the great advantages of the internal devices are that they do not cause any discomfort to the child, they spare the patient the embarrassment of wearing 2 external facial devices in public with all of the attendant psychosocial sequelae, they are safer, more stable after placement, and remain during the whole retention period needed for better ossification and postoperative stability results.

An advantage of external devices is that they permit longer distraction length, an important consideration in severe cases of hypoplasia, and can be changed during lengthening to a longer distractor. The space for internal devices is more limited subperiosteally and permits smaller devices. However, any change to another device as a result of device failure or to a bigger device for greater distraction length needs an additional operation with the same extraoral dissection under general anesthesia.

It is important to treat pin tract infections using external devices immediately by local disinfection and antibiotics to avoid pin loosening and improper bone generation resulting in increased relapse. The internal devices offer the advantage of removal of the distraction rod at the completion of lengthening, reducing discomfort and risk of pin tract infection during the retention period.

Overall stability with internal devices is greater than with the external devices. The relapse rate was 23.52% with external versus 13.33% with internal devices. This can be explained by the fact that during distraction there is some bending of the pins with less precise rate of lengthening, resulting in compromised ossification during the retention period.[17–20] It is well established that for optimal bone generation, the distraction rate should be accurate, not more than 1 mm per day.[21–24] Moreover, the more common pin loosening during the retention period may contribute to increased relapse in the external device group. By contrast, internal devices offer more predictable vector of lengthening and more precise rate of lengthening due to direct contact of the device with the bony segment. Any device lengthening is transferred directly to the bone and creates better ossification.

In some cases with tendency to open bite or improper vector of lengthening, intermaxillary elastics were placed. In growing patients with compromised airway due to hypoplastic mandible, a slight overcorrection of 2–3 mm is recommended. With both methods, class II occlusion became class III. In all patients, the occlusion reverted to class I after 1 year. If needed, the slight overcorrection can be balanced by orthodontic treatment (chin cap).

After removal of the external pins, 2 visible buccal skin scars lateral to the mandible remained. The internal devices left a single, less visible submandibular scar on each side. It is possible that in the future, internal devices will be placed intraorally, avoiding the submandibular approach, skin scars, and facial nerve damage. In this series, we preferred to perform the submandibular operation extraorally for better control on the osteotomy, drilling, screw fixation, and control of device adaptation and forward device vector.

## CONCLUSIONS

Internal devices are more comfortable to the child with a precise and predictable vector of lengthening and lower risk of relapse. They leave less visible scars and should be considered first. Their main disadvantage is the second operation for device removal under general anesthesia. The external devices are easier to fit even in severely hypoplastic mandibles, permit greater distraction length, and can be removed simply by unscrewing the pins. Therefore, in cases where internal device placement is impossible or when there is need for greater distraction length, external devices may be used while considering greater child discomfort and risk of pin loosening that may compromise consolidation and increase risk of relapse. Mandibular distraction osteogenesis can be associated with a wide variety of minor and major complications that should be minimized by careful planning and technique.

***Adi Rachmiel, DMD, PhD***
Department of Oral and Maxillofacial Surgery
Rambam Health Care Campus
POB 9602, Haifa 31096, Israel
E-mail: adi_rach@netvision.net.il

## PATIENT CONSENT

*Parents or guardians provided written consent for the use of the patients' image.*

## REFERENCES

1. Cohen SR, Simms C, Burstein FD, et al. Alternatives to tracheostomy in infants and children with obstructive sleep apnea. *J Pediatr Surg.* 1999;34:182–186; discussion 187.
2. Guilleminault C. Obstructive sleep apnea syndrome and its treatment in children: areas of agreement and controversy. *Pediatr Pulmonol.* 1987;3:429–436.
3. Denny AD, Talisman R, Hanson PR, et al. Mandibular distraction osteogenesis in very young patients to correct airway obstruction. *Plast Reconstr Surg.* 2001;108:302–311.
4. Kaban LB, Seldin EB, Kikinis R, et al. Clinical application of curvilinear distraction osteogenesis for correction of mandibular deformities. *J Oral Maxillofac Surg.* 2009;67:996–1008.
5. Morovic CG, Monasterio L. Distraction osteogenesis for obstructive apneas in patients with congenital craniofacial malformations. *Plast Reconstr Surg.* 2000;105:2324–2330.
6. Rachmiel A, Aizenbud D, Pillar G, et al. Bilateral mandibular distraction for patients with compromised airway analyzed by three-dimensional CT. *Int J Oral Maxillofac Surg.* 2005;34:9–18.
7. Rachmiel A, Srouji S, Emodi O, et al. Distraction osteogenesis for tracheostomy dependent children with severe micrognathia. *J Craniofac Surg.* 2012;23:459–463.
8. Williams JK, Maull D, Grayson BH, et al. Early decannulation with bilateral mandibular distraction for tracheostomy-dependent patients. *Plast Reconstr Surg.* 1999;103:48–57; discussion 58.
9. Davidson EH, Brown D, Shetye PR, et al. The evolution of mandibular distraction: device selection. *Plast Reconstr Surg.* 2010;126:2061–2070.
10. Genecov DG, Barceló CR, Steinberg D, et al. Clinical experience with the application of distraction osteogenesis for airway obstruction. *J Craniofac Surg.* 2009;20(Suppl 2):1817–1821.
11. Lypka MA, Urata MM, Yen S, et al. Facial nerve paralysis: a complication of distraction osteogenesis of the mandibular ramus in the treatment of temporomandibular joint ankylosis. *J Craniofac Surg.* 2007;18:844–848.
12. Master DL, Hanson PR, Gosain AK. Complications of mandibular distraction osteogenesis. *J Craniofac Surg.* 2010;21:1565–1570.
13. Nørholt SE, Jensen J, Schou S, et al. Complications after mandibular distraction osteogenesis: a retrospective study of 131 patients. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2011;111:420–427.
14. Rachmiel A, Aizenbud D, Eleftheriou S, et al. Extraoral vs. intraoral distraction osteogenesis in the treatment of hemifacial microsomia. *Ann Plast Surg.* 2000;45:386–394.
15. Troulis MJ, Kaban LB. Complications of mandibular distraction osteogenesis. *Oral Maxillofac Surg Clin North Am.* 2003;15:251–264.
16. Rachmiel A, Manor R, Peled M, et al. Intraoral distraction osteogenesis of the mandible in hemifacial microsomia. *J Oral Maxillofac Surg.* 2001;59:728–733.
17. Cope JB, Samchukov ML, Cherkashin AM, et al. Biomechanics of mandibular distractor orientation: an animal model analysis. *J Oral Maxillofac Surg.* 1999;57:952–962; discussion 963.
18. 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;238:249–281.
19. 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;239:263–285.
20. Rachmiel A, Rozen N, Peled M, et al. Characterization of midface maxillary membranous bone formation during distraction osteogenesis. *Plast Reconstr Surg.* 2002;109:1611–1620.
21. Boccaccio A, Pappalettere C, Kelly DJ. The influence of expansion rates on mandibular distraction osteogenesis: a computational analysis. *Ann Biomed Eng.* 2007;35:1940–1960.
22. Cope JB, Yamashita J, Healy S, et al. Force level and strain patterns during bilateral mandibular osteodistraction. *J Oral Maxillofac Surg.* 2000;58:171–178; discussion 178–179.
23. Djasim UM, Wolvius EB, van Neck JW, et al. Recommendations for optimal distraction protocols for various animal models on the basis of a systematic review of the literature. *Int J Oral Maxillofac Surg.* 2007;36:877–883.
24. Paccione MF, Mehrara BJ, Warren SM, et al. Rat mandibular distraction osteogenesis: latency, rate, and rhythm determine the adaptive response. *J Craniofac Surg.* 2001;12:175–182.