mandibular distraction osteogenesis in infants younger than 3 months

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objectives: to examine the long-term outcomes and complications in infants with upper airway obstruction and feeding difficulty who underwent bilateral mandibular distraction osteogenesis (mdo) within the first 3 months of life and to identify any preoperative characteristics that may predict the long-term outcome following early mdo intervention for airway obstruction.

methods: an institutional, retrospective medical chart review was performed. inclusion criteria were bilateral mdo performed at an age younger than 3 months, with a minimum follow-up of 3 years. a quantitative outcome measures scale was developed, and patients were scored based on long-term postoperative complications as well as airway and feeding goals. factors such as need for an additional surgical procedure were also considered.

results: nineteen children were identified as having undergone mdo before 3 months of age and having more than 3 years of follow-up data. the mean age at distraction was 4.8 weeks (range, 5 days-12 weeks); the mean length of follow-up was 5.6 years (range, 37-122 months). of these 19 patients, 14 had isolated pierre robin sequence (prs) and 5 had syndromic prs. all patients with isolated prs had a good or intermediate long-term result. infants with comorbidities such as developmental delay, seizures, or arthrogryposis had the poorest outcomes.

conclusions: bilateral mdo is a relatively safe and effective means of treating airway obstruction and feeding difficulty in infants with prs. the effects of this procedure, which carries a relatively low morbidity, persist through early childhood in most patients.


micrognathia, characterized by a small and retrusive mandible, is an abnormality that is present at birth. the mandibular alveolus is posterior to the maxillary alveolus, and other mandibular abnormalities including a small mandibular body, an obtuse gonial angle, and a posteriorly located or diminutive mandibular condyle may be noted. the combination of micrognathia and glossoptosis frequently causes tongue base airway obstruction, leading to respiratory and feeding difficulty in the newborn. the degree of respiratory difficulty is dependent on the severity of the micrognathia and glossoptosis.

there are a variety of options available for airway management in the micrognathic child. typically, interventions begin with the most conservative and noninvasive measures. this includes prone positioning and placement of a nasal pharyngeal airway. the use of positive pressure mask ventilation through the nasal pharyngeal airway will provide some additional benefit in those children with continued obstruction. other options include glossopexy procedures or subperiosteal release of the floor of the mouth combined with glossopexy. traditionally, tracheotomy has been performed for the most severe or refractory cases of upper airway obstruction. long-term tracheotomy in children, however, is associated with significant morbidity and mortality. complications associated with tracheotomy include sudden airway obstruction from accidental decannulation or mucous plugging. recurrent airway infections, airway bleeding, stomal maintenance problems, and inhibition of proper speech and swallowing development are also concerns for these children.

in addition to the airway problems, many patients with micrognathia will not be able to sufficiently feed orally. upper airway obstruction prevents a normal swallow, and these children are unable to maintain...
Infants and older children. The analysis in this article deals with the relief of upper airway obstruction using MDO in 11 children treated with MDO for upper airway obstruction from January 1997 to January 2006. Inclusion criteria were bilateral MDO performed at an age younger than 3 months, with a minimum follow-up of 3 years. Thirty-seven patients who underwent bilateral MDO at an age younger than 3 months were identified. Twenty-five of these were performed more than 3 years ago. Of these 25 patients, 6 were lost to follow-up, leaving 19 patients who met the inclusion criteria for the study. Records were reviewed for outcomes data regarding airway maintenance, oral feeding, and speech intelligibility. In addition, incidence data were extracted regarding the long-term complications of MDO such as need for an additional MDO procedure, rate of anterior open-bite deformity, facial nerve damage, hypertrophic scarring, and tooth loss. A quantitative outcome measures scale was developed based primarily on functional outcomes, and patients were scored based on long-term postoperative complications as well as airway and feeding goals. A 10-point scale was created, with favorable results scoring highest and corresponding to the best functional level, based on the following outcomes: 1 point each was given on avoidance of a short-term or long-term complication such as postoperative open-bite deformity (defined as the inability of the maxillary incisors to overlap the mandibular incisors), hypertrophic scarring, facial nerve injury, mandibular tooth damage or development of mandibular cyst, development of unintelligible speech (as rated by a certified speech and language pathologist with experience in working with patients with cleft lip and/or palate), or eventual recommendation for an additional mandibular distraction procedure. Other outcomes such as tracheotomy decannulation and removal of G tube were also taken into consideration. Two points were allotted to patients who avoided tracheotomy or G tube placement altogether, and 1 point was given to a patient for eventual removal of a previously placed feeding tube or tracheotomy tube following MDO. Good outcomes were considered for those with scores of 9 or 10, intermediate outcomes for those with scores of 7 or 8, and poor outcomes for those with scores of 0 or lower (Table 1).

In 2001, Sidman et al issued a report documenting the relief of upper airway obstruction using MDO in 11 children. This introduced a new approach to tongue base airway obstruction from micrognathia, and early results were promising. Bilateral MDO proved to be especially useful in children with Pierre Robin sequence (PRS), in which the mandible lacks anterior projection, leading to glossoptosis and upper airway obstruction; these children have a U-shaped cleft palate as well, which is associated with these conditions.

Mandibular distraction osteogenesis (MDO) is a technique in which the mandible is gradually lengthened after an initial osteotomy. Following a short latency period, distraction begins at a slow steady rate. During the distraction phase, bone segments are separated by small increments, while induction of new bone formation takes place in the gap. After the desired lengthening has been achieved, a consolidation period ensues in which the bone segments are held securely in their advanced position. The regenerate of immature bone remodels and matures during this 4- to 8-week period, after which time the distraction hardware is removed. Because distraction proceeds at a slow pace, related muscles, blood vessels, nerves, and mucosa are also elongated. This concomitant soft-tissue expansion is one of the main advantages of MDO.

A retrospective medical chart review was performed to identify all children treated with MDO for upper airway obstruction from January 1997 to January 2006. Inclusion criteria were bilateral MDO performed at an age younger than 3 months, with a minimum follow-up of 3 years. Thirty-seven patients who underwent bilateral MDO at an age younger than 3 months were identified. Twenty-five of these were performed more than 3 years ago. Of these 25 patients, 6 were lost to follow-up, leaving 19 patients who met the inclusion criteria for the study. Records were reviewed for outcomes data regarding airway maintenance, oral feeding, and speech intelligibility. In addition, incidence data were extracted regarding the long-term complications of MDO such as need for an additional MDO procedure, rate of anterior open-bite deformity, facial nerve damage, hypertrophic scarring, and tooth loss. A quantitative outcome measures scale was developed based primarily on functional outcomes, and patients were scored based on long-term postoperative complications as well as airway and feeding goals. A 10-point scale was created, with favorable results scoring highest and corresponding to the best functional level, based on the following outcomes: 1 point each was given on avoidance of a short-term or long-term complication such as postoperative open-bite deformity (defined as the inability of the maxillary incisors to overlap the mandibular incisors), hypertrophic scarring, facial nerve injury, mandibular tooth damage or development of mandibular cyst, development of unintelligible speech (as rated by a certified speech and language pathologist with experience in working with patients with cleft lip and/or palate), or eventual recommendation for an additional mandibular distraction procedure. Other outcomes such as tracheotomy decannulation and removal of G tube were also taken into consideration. Two points were allotted to patients who avoided tracheotomy or G tube placement altogether, and 1 point was given to a patient for eventual removal of a previously placed feeding tube or tracheotomy tube following MDO. “Good” outcomes were considered for those with scores of 9 or 10, “intermediate” outcomes for those with scores of 7 or 8, and “poor” outcomes for those with scores of 0 or lower (Table 1).

Preoperative characteristics limited to diagnoses or traits that were recognized in the first few weeks of life were also noted. Patients were classified as having isolated PRS (iPRS) if they had no other syndromic features or neurologic deficits. Neonates with PRS as part of a named syndrome were considered to have syndromic PRS (sPRS), and these patients were further subclassified by the presence or absence of neurologic findings (hypotonia, seizures, or signs of developmental delay as determined by a pediatric neurologist) or musculoskeletal abnormalities (eg, arthrogryposis). Any chromosomal anomaly was also noted.

Patients were considered candidates for early MDO if they presented with micrognathia resulting in severe airway obstruction. These features were most commonly seen in pa-
Patients with iPRS and Stickler syndrome. All patients were observed in the neonatal intensive care unit. If the patient was able to ventilate without endotracheal intubation, a nasopharyngeal airway was inserted and the patient was monitored for improvement. Infants were monitored with continuous pulse oximetry, serial capillary blood gas evaluation, and cardiac telemetry. Polysomnography was not performed on these children because these patients demonstrated obvious upper airway obstruction even while awake. Only patients in whom these less-invasive, conservative measures failed were considered potential candidates for surgical intervention, that is, only children who were failing to thrive (with tracheotomy and/or G-tube placement as the only other viable alternative) were considered candidates for early MDO.

The detailed patient evaluation (including physical examination, airway endoscopy, and radiographic imaging), surgical technique, postoperative care, and distraction protocol used for this cohort of patients has been previously described.4

RESULTS

Descriptive features of the 19 patients included in this review and a comparison with those who were excluded from this study are given in Table 2. There were 11 male and 8 female infants. The mean age at time of MDO was 4.8 weeks (range, 5 days–12 weeks), with a median age of 4.0 weeks. The smallest infant undergoing distraction weighed 2100 g. The mean length of follow-up was 67 months (3.6 years) (range, 37-122 months). Fourteen infants had iPRS and 5 had sPRS. The sPRS group included patients with Stickler syndrome (n=1), Marshall-Stickler syndrome (n=1), Catel Manzke syndrome (n=1), Opitz C syndrome (n=1), Marshall-Stickler syndrome (n=1), and arthrogryposis multiplex congenita (n=1).

In general, 17 of the 19 patients (90%) achieved an outcome score of 8 or higher, corresponding to an intermediate or good outcome, with 12 of 19 (63%) achieving a good result (Figure 1). All 14 patients with iPRS achieved a good or intermediate outcome (score of ≥8). The 2 patients with poor outcomes (10%) had sPRS, one with arthrogryposis and the other with neurologic issues (seizure disorder, hypotonia, and developmental delay related to Opitz C syndrome) (Figure 2). The lowest scores were due to factors such as unintelligible speech, persistent G-tube dependence, open-bite deformity, as well as failure to decannulate in the child with arthrogryposis (Figure 3).

Only 1 of the 19 patients (5%) continues to be tracheotomy dependent. Of the 2 patients who had tracheotomy prior to MDO, 1 was able to be decannulated and has remained free of requiring tracheotomy over the long-term follow-up. The other 17 patients were able to avoid tracheotomy altogether, staying intubated throughout the latency and distraction phases until mandibular advancement adequately relieved tongue base airway obstruction.

Six patients (31%) who underwent bilateral MDO for micrognathia and upper airway obstruction required G-tube placement for feeding, while an additional 13 patients (69%) avoided G-tube placement and have been feeding orally without difficulty. In those who required a G tube, feeding tube removal was possible in 3 of these 6 patients after MDO. Three patients (16%) remain G-tube dependent.

Table 2. A Comparison Between Patients Meeting Inclusion Criteria With Those Who Were Excluded From the Study (Lost to Follow-up or < 3 Years of Follow-up)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Included</th>
<th>Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total patients</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>Males, No. (%)</td>
<td>11 (58)</td>
<td>9 (50)</td>
</tr>
<tr>
<td>Females, No. (%)</td>
<td>8 (42)</td>
<td>9 (50)</td>
</tr>
<tr>
<td>iPRS</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>sPRS</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>sPRS with seizures or developmental delay</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>sPRS with arthrogryposis</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Age at distraction, mean, wk</td>
<td>4.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Age at distraction, median, wk</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Length of follow-up, mean, mo</td>
<td>66.9</td>
<td>15.1</td>
</tr>
<tr>
<td>Length of follow-up, median, mo</td>
<td>60</td>
<td>13</td>
</tr>
</tbody>
</table>

Abbreviations: iPRS, isolated Pierre Robin sequence; sPRS, syndromic Pierre Robin sequence.

One patient (5%) had a residual anterior open-bite deformity after MDO. This patient had arthrogryposis with an anterior open-bite deformity prior to MDO, and the deformity was not corrected by the procedure.

Four patients (21%) experienced long-term tooth loss or malformation after MDO (Figure 4). A total of 3 patients (16%) had long-term injury to the marginal mandibular branch of the facial nerve. Three patients (16%) had hypertrophic scars on the skin over the mandibular body and angle from the pin entry sites. One patient (5%) required an additional MDO procedure later in life owing to failure of mandibular growth and relapsing upper airway obstruction.

COMMENT

In 2001, Sidman et al3 proposed MDO as an alternative to tracheotomy as a means of addressing upper airway obstruction in children with PRS. This report described 11 patients with micrognathia who were treated with MDO, and all achieved tracheotomy avoidance or decannulation. This report demonstrated that with mandibular advancement, the tongue base is brought forward and the supraglottic airway obstruction is relieved. Further work has also shown a decrease in the rate of...
feeding tube placement in some patients who undergo MDO as well.\textsuperscript{2}

Since then, several studies have been published that document the safe and effective use of MDO in treating patients with micrognathia causing upper airway obstruction.\textsuperscript{5-9} A recent comprehensive meta-analysis of MDO was conducted by Ow and Cheung.\textsuperscript{10} This thorough review retrieved 178 articles, yielding 1185 patients. A total of 646 patients had bilateral distraction osteogenesis in an effort to treat upper airway obstruction. Success in preventing tracheotomy was achieved in 91.3% of neonates, and distraction relieved symptoms of obstructive sleep apnea in 97% of children. This meta-analysis showed that a considerable number MDO cases have been performed to date and that evidence demonstrating successful clinical results is accumulating.

Still, because MDO is a relatively new technique, questions remain as to the long-term results and sequelae of this treatment method. While initial results show promise, there is still doubt about how the mandible and airway will react and grow after MDO. Furthermore, there are concerns that when the MDO procedure is performed on the very young, it will need to be revised and repeated if the mandible does not grow as the child matures. Obviously, the benefits of pediatric MDO significantly decline if the procedure needs to be repeated throughout childhood and adolescence. The present report attempts to address some of these questions.

Our long-term results demonstrate that MDO performed in infants younger than 3 months successfully addresses upper airway obstruction related to micrognathia in the neonatal period and has a sustained effect that continues into childhood (\textbf{Figure 5} and \textbf{Figure 6}). Eighteen of the 19 patients (95%) who were candidates for either tracheotomy or MDO in infancy and ultimately underwent MDO remain free of requiring tracheotomy over the long-term follow-up. Furthermore, 95% of our cohort did not require an additional distraction procedure over a mean follow-up period of 5.6 years (range, 3.0-12.1 years).

The impact of MDO on overcoming feeding difficulties in children with micrognathia is less dramatic but still positive. Sixteen of 19 patients (84%) are feeding well orally and do not require a G tube. The dysphagia experienced by micrognathic children is certainly multifactorial. Nevertheless, our results clearly support the hypothesis that glossoptosis and upper airway obstruction may be the primary components causing swallowing difficulty. Relieving upper airway obstruction allows for easier breathing during feeds and may improve coordination of oral intake and swallowing. Furthermore, following distraction, a child can feed more efficiently and expend less energy obtaining appropriate caloric intake. We have noted that MDO has altered the course from failure to thrive to healthy weight gain for many of our patients.

This report demonstrates a relatively low incidence of long-term complications (\textbf{Figure 3}). The most common complication was permanent dentition loss or malformation (21%). The damaged teeth were the first molars, second molars, and premolars (\textbf{Figure 4}), and injury was likely related to the location of the mandibular osteotomy. The complication of tooth loss can be avoided by planning the osteotomy posterior to the tooth buds; however, osteotomy placement is sometimes limited by the position of the mandibular angle. We advocate strongly...
that the osteotomy should not be made directly through the mandibular angle because this would cause significant blunting of an important facial landmark during distraction and lead to a more abnormal facial appearance. We therefore prefer to plan the osteotomy either superior or anterior to the angle of the mandible. Additional tooth damage is likely caused by pin placement, which may lead to necrosis of a developing tooth bud in the molar region and ultimately tooth loss later in development. Again, careful preoperative planning and modeling may limit such complications. With that said, unfortunately, there are incidents where tooth buds are knowingly injured to achieve the optimal vector of distraction for airway improvement.

Three patients (16%) in our series experienced long-term weakness of the marginal mandibular branch of the facial nerve. This was likely caused by injury during the surgical approach or during pin placement for the external MDO device. In more of our patients, injury to the marginal mandibular branch of the facial nerve was seen in the immediate postoperative setting and resolved during the perioperative period and is therefore not categorized as a long-term complication. In these instances, it is likely that the paresis was due to traction on the nerve rather than direct trauma. The resulting neurapraxia resolved as expected. Certainly, the position of this branch of the facial nerve overlying the angle and body of the mandible presents an obstacle to a clear surgical approach and retraction during surgery is always necessary. The effect of long-term damage to this nerve is an asymmetric movement of the lower lip at the corner of the mouth during mimetic facial movement. While this is an undesired complication, it likely has a relatively low impact on the overall quality of life in these children.

Finally, 3 patients (16%) experienced hypertrophic scarring at the pin sites. These patients were offered scar revision surgery, but all parents thus far have deferred the operation. Scarring is most prominent early in life but tends to improve over time (Figure 6).

Our results as they pertain to the nature and overall rate of complications following MDO are comparable to those recently published by Shetye et al.11 This retrospective study examined the records of 141 adult and pediatric patients treated over a 16-year period. They reported a major incident rate of less than 5%. Their most common complications were fibrous bony union and temporomandibular joint ankylosis, followed by damaged tooth follicle, unstable distraction device, and premature consolidation.11

Lin et al12 recently published their long-term quantitative results documenting relief of upper airway obstruction with MDO. This study involved 5 children with a mean follow-up of 47 months following MDO, and postoperative polysomnogram data on each patient was presented. The authors demonstrated long-term improvement of obstructive sleep apnea in 4 of these 5 children.

There are only a few other reports documenting the long-term results of MDO. Kleine-Hakala et al13 found that developing molars were adversely affected in 13 of 17 children reviewed. Other long-term complications that have been described include temporomandibular joint

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Figure 3. Complication rate and rate of unfavorable outcomes of early bilateral mandibular distraction osteogenesis. Complication rate for all 19 infants (A) and 14 with isolated Pierre Robin sequence (iPRS) (B) and unfavorable outcomes for 14 infants with iPRS, 3 with sPRS without neurologic comorbidities, and 2 with sPRS with developmental delay, seizures, or arthrogryposis (C).

Figure 4. Missing second molar (arrowhead) and malformed first molar (arrow) apparent on the right (R) side in a child 7 years after neonatal mandibular distraction osteogenesis. Compare with normal dentition on the left side, which was not affected by a similarly placed mandibulotomy (arrowhead, second molar; arrow, first molar).
abnormalities, ankylosis, and disruption of subsequent mandibular growth with resultant malocclusion.\textsuperscript{14-16} To our knowledge, this study is the first to examine long-term results and complications following neonatal mandibular distraction for upper airway obstruction. Because neonatal distraction is not a common procedure, it is difficult to amass enough cases to attain statistical power. Our results are therefore limited by the number of subjects and the retrospective nature of this study. Nevertheless, this case series is the largest of its kind to date with more than 3 years of follow-up.

Our data suggest that patients with iPRS or mild forms of sPRS (without neurologic comorbidities) tend to have favorable outcomes, while those patients with developmental delay, seizure disorder, or arthrogryposis did not achieve significant benefit from early mandibular distraction (Figure 2 and Figure 3C). It is difficult to draw any conclusions in regard to the utility of performing MDO on patients with neurologic sequelae based on 2 patients. Nevertheless, patients with seizures, hypotonia, and signs of developmental delay in the setting of micrognathia and glossoptosis likely have upper airway obstruction that is multifactorial in nature. This neurologic component of obstruction may not be adequately addressed by mandibular advancement alone. These children may also have chronic aspiration. While upper airway obstruction has been improved, the tracheotomy may need to remain for the purpose of improving pulmonary toilet. In evaluating our older patients and other younger children who have not yet reached 3 years of follow-up, signs of feeding difficulty and upper airway obstruction often persist, and a number of these patients remain G-tube and tracheotomy dependent (unpublished data, October 2009).

Children with arthrogryposis may also have vocal fold immobility, supraglottic narrowing, and laryngomalacia, among other sources of airway compromise.\textsuperscript{17} The dysphagia and airway issues in these patients similarly may require a multilevel approach that may not be cured solely by mandibular distraction. Three other children with arthrogryposis, who did not meet inclusion criteria for this study based on age or length of follow-up, show improved breathing and swallowing after MDO, but all remained G-tube and tracheotomy dependent after their first distraction procedure (unpublished data, October 2009). Finally some of these patients also have symptoms of chronic aspiration. The tracheotomy is maintained for pulmonary toilet, regardless of postoperative relief of upper airway obstruction.

In conclusion, bilateral MDO is an effective means of treating airway obstruction and feeding difficulty in infants with PRS that is relatively safe. The decision to perform early MDO on a child with sPRS must be weighed with additional patient comorbidities, especially given the potential long-term complications of this procedure. Our experience would suggest that children with neurologic difficulties, developmental delay, or multiple anomalies may not be optimal candidates for early intervention. Upper airway obstruction and dysphagia in these children is usually multifactorial and may not be definitively addressed by treating tongue base airway obstruction alone with mandibular advancement. To this end, we have al-

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tered our clinical practice, since other children with sPRS with neurologic features and insufficient follow-up for inclusion in this study (Table 2) also tend to have inter-
mediate and poor outcomes. We currently tend to re-
commend MDO in patients with apparent iPRS and are
more likely to consider tracheotomy for children with
hypotonia, seizures, and/or signs of neurodevelop-
mental deficits. We no longer offer early MDO for infants
with arthrogryposis and instead recommend tracheotomy
and supplementary G-tube feedings if necessary followed by
MDO later in childhood.

In regard to children with iPRS, the effects of MDO per-
sist through early childhood in most patients. This pro-
scedure seems to carry a relatively low morbidity, there is
a low relapse rate, and our data show that these patients
experience few noteworthy long-term complications. Nev-
evertheless, it remains important to further follow up these
patients to monitor the need for secondary reconstruc-
tive procedures as these children grow into adulthood.

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pretation of data: Scott, Tibesar, and Sidman. Drafting of
the manuscript: Scott and Tibesar. Critical revision of the manu-
script for important intellectual content: Tibesar, Lander,
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