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The Impact of Mandibular Distraction Osteogenesis on Cephalometric Measurements in Infants with Pierre Robin Sequence

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BACKGROUND: The obstruction of the upper airway (UAO) in infants diagnosed with Robin Sequence (RS) is caused by micrognathia, and in severe cases, it can result in obstructive sleep apnea (OSA). Mandibular distraction osteogenesis (MDO) is a secure and efficient remedy for significant UAO. However, there is insufficient data on the related cephalometric changes. Therefore, this study meticulously analyzes the mandibular cephalometric changes in infants with RS who have undergone MDO using internal devices. The aim is to gain a more comprehensive understanding of the short- and long-term impacts of distraction on the mandible. METHODS: The study examined 73 consecutive cases of mandibular distraction osteogenesis (MDO) performed by a single surgeon. Preoperative and postoperative lateral cephalograms, as well as CT scans of the mandible, were utilized to assess population averages for both time points. A two-sample T-Test with equal variance was used for this analysis. RESULTS: After the MDO procedure, 19 out of 21 cephalometric parameters exhibited significant morphological changes. On average, there were notable improvements of 20.3 mm (60.7%) in length, 9.8 mm (49.7%) in height, 12.6 mm (36.1%) in width, and 211% in airway parameters. However, most parameters showed only mild regression at the time of device removal and 6 to 12 months post-MDO. Nonetheless, the cephalometric parameters remained significantly improved compared to the preoperative measurements. CONCLUSIONS: The use of cephalometric measurement is a potent approach that provides a clear and measurable understanding of how MDO influences both immediate and long-term growth of the mandible. This quantitative assessment of the effects of mandibular distraction allows for the refinement of surgical techniques and the optimization of outcomes. Therefore, incorporating cephalometric measurements in the evaluation of patients undergoing MDO can lead to better surgical planning and more favorable results.

Robin sequence (RS), a congenital anomaly, often manifests with micrognathia, glossoptosis, and upper airway obstruction (1, 2). It has an incidence of 1 in 8,500 to 14,000 newborns (3). In RS, hypoplasia of the mandible causes posterior and superior displacement of the tongue (glossoptosis), resulting in failure of the fusion of the palatine shelves and subsequent cleft palate in 58% to 90% of infants (3, 4). Upper airway obstruction (UAO) in neonates with RS is attributed to glossoptosis, which reduces the oropharyngeal cross-sectional area and limits oxygen flow (5). This has potentially devastating sequelae, including feeding problems, sleep disturbances, developmental delay, failure to thrive, and death (6–10).

Surgical intervention is typically necessary for patients with severe upper airway obstruction (UAO). Tracheostomy was once a common treatment option; however, it was associated with significant morbidities such as chronic pneumonia, laryngeal stenosis, and tracheobronchial bleeding. As a result, tongue-lip adhesion (TLA) became a more favored and safer alternative (3, 11). TLA relieves tongue-based UAO by attaching the anterior tongue to the lower lip; however, long-term relief is dependent on the natural horizontal growth of the mandible as fundamental mandibular hypoplasia is not addressed (12, 13). Conversely, mandibular distraction osteogenesis (MDO) directly corrects mandibular hypoplasia through gradual lengthening via internal or external distraction. The goal of mandibular distraction is to decrease glossoptosis and fundamentally alleviate UAO (14). Following its widespread implementation, MDO has proven to produce less health care burden than tracheostomy and better outcomes than TLA (15, 16).

Previous studies have assessed the effects of MDO via cephalometric imaging (4, 17–19). While some studies have largely focused on changes in airway dimensions (4, 17, 18), few have evaluated the fundamental mandibular change (19) or specifically focused on RS patients. Here, we explore the mandibular change caused

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by MDO on 73 infants with RS by comparing 22 cephalometric parameters through pre- and post-operative lateral cephalograms and 3D-CT.

MATERIALS AND METHODS

From 2019 to 2022, 73 individuals (Table I) with RS underwent MDO in Hanoi, Vietnam. Implementation of surgical technique was developed in collaboration with senior craniofacial plastic surgeons from the United States. Individuals with RS were evaluated both preoperatively and for two years postoperatively by lateral cephalogram and CT imaging (n = 199). All patients had obstruction limited to the upper airway related to severe retrognathia and posterior tongue-base displacement confirmed with direct laryngoscopy. Every patient received bilateral mandibular corticotomy, the implantation of two percutaneous Kirchner wires, and extraoral distraction devices (20). To better understand the precise dimensions of growth vectors, 22 cephalometric measurements were calculated on CT imaging using lateral, AP, inferior, and superior views of 3D mandibular reconstructions (Figure 1).

Table I. Demographics and Clinical Characteristics

Characteristic	No.	(%)
Female	41	56.2
Avg. Age at Distraction, mo (SD)	1.7 (1.4)	
Pierre Robin Sequence	73	100.0
Isolated Pierre Robin	56	76.7
Velocardiofacial syndrome	3	4.1
Hemifacial microsomia	1	1.4
Treacher Collins syndrome	2	2.7
Prader-Willi syndrome	1	1.4
Stickler syndrome	4	5.5
Other syndrome	6	8.2
Postpartum respiratory failure	70	95.9
Postpartum circulatory failure	0	0.0
Cleft Palate	61	83.5
U-shaped	32	43.8
V-shaped	29	39.7
Shortness of breath	73	100.0
Supine	52	71.2
Prone	3	4.1
Lateral	18	24.7
Snoring	73	100.0
Supine	63	86.3
When sleeping	10	13.7
Sleep apnea before MDO	73	100.0
Avg. apnea-hypopnea index score (SD)	25.5 (10.8)	
Sleep apnea after MDO	10	13.7
Avg. apnea-hypopnea index score (SD)	1.7 (1.6)	
Preoperative breathing support		
None	1	1.3
Oxygen	14	19.2
Mask	24	32.9
Endotracheal	30	41.1
Continuous positive airway pressure	4	5.5
Preoperative nourishment		
Normal feeding	3	4.1
Support device	4	5.5
Gastric probe	66	90.4
Dysphagia	28	38.4
Malnutrition	62	84.9

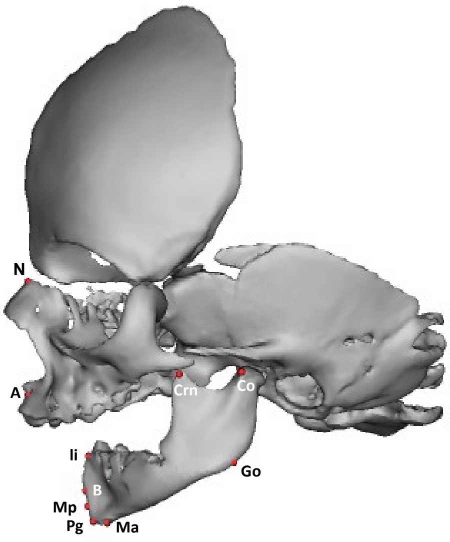

Figure 1. CT Image

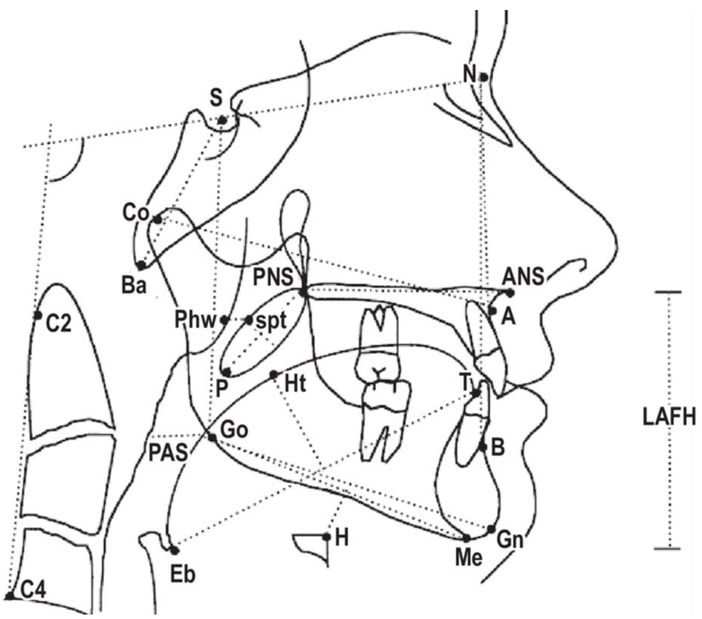

Figure 2. The ANB angle

CT studies were grouped as follows: prior to surgery, end of distraction, time of device removal, 6-9 months post-operative, and 9-12 months post-operative. To determine where the largest relative growth took place, percent increase was used. To determine relationship between growth and distraction, growth was divided by distraction distance (25mm). This is termed mm per mm of distraction (mm/mm[d]) and was calculated using the consistently obtained preoperative and device removal time points. In mandible-maxilla length difference, the SNA and SNB angle, the angle between the Sella/nasion plane and the nasion/A/B plane, was used (21). The ANB angle, the anteroposterior position between the maxilla and mandible, was used to examine the length difference between the mandible and maxilla (22). The description of the angles is shown in Figure 2 (23). The 6–9-month timeline was used to evaluate resolution of asymmetry and percent change. For each time point, population averages were calculated and compared using a two-sample T-Test with equal variance. $P < 0.05$ was considered significant.

RESULTS

Population averages are noted in Table II. Not all individuals received imaging at all time points, and population averages were only compared when scans were present for at least 25% of the total sample. All preand post-operative parameters except for angles SNA and Co-Go-Pg displayed significant differences. The same was true for the preoperative and 9-month comparison.

Table II. Cephalometric measures

Measure	Modality	Average ± SD (n)					Percent change at final timepoint (%)	Growth Per mm Distracted
		Preoperative	End of distraction	Device Removal	6-9 months post-MDO	9-12 months post-MDO		
Horizontal, Linear (mm)								
Mnd-Mx	Clinical	15 ± 1.1 (51)						
Mnd-Mx	3D-CT	14.3 ± 2.14 (50)		1.0 ± 0.84 (36)§	1.2 ± 1.13 (15)		−91.6§	−0.52
Co-Ma	3D	48.1 ± 4.62 (49)		67.3 ± 7.67 (34)§	71.7 ± 7.25 (15)†		49.06§	0.94
Go-Pg	3D	25.7 ± 2.84 (50)		40.9 ± 5.13 (36)§	42.1 ± 5.27 (16)		63.81§	0.66
Co-Pg	3D	40.9 ± 4.85 (50)		60.0 ± 7.01 (36)§	63.9 ± 6.94 (16)†		56.23§	0.92
Crn-Pg	3D	34.7 ± 4.25 (50)		52.8 ± 6.25 (36)§	56.6 ± 6.00 (16)†		63.11§	0.88
Co-Ii	3D	48.0 ± 4.39 (50)		67.1 ± 6.60 (36)§	71.0 ± 6.82 (16)†		47.92§	0.92
Crn-Ii	3D	40.2 ± 3.92 (50)		58.0 ± 5.25 (36)§	61.6 ± 6.14 (16)†		53.23§	0.86
Vertical, Linear (mm)								
Co-Go	3D	18.1 ± 2.99 (50)		23.8 ± 3.31 (36)§	27.1 ± 4.30 (16)§		49.72§	0.36
Crn-Go	3D	21.2 ± 2.81 (50)		27.6 ± 3.56 (36)§	31.7 ± 4.36 (16)§		49.53§	0.42
Width, Linear (mm)								
Co-Mp	3D	35.1 ± 3.57 (50)		42.9 ± 4.61 (36)§	46.7 ± 5.25 (16)‡		33.05§	0.46
Crn-Mp	3D	34.5 ± 4.12 (50)		43.8 ± 4.73 (36)§	48.0 ± 5.37 (16)‡		39.13§	0.54
Angular								
SNA	2D	77.2 ± 5.20 (38)	79.6 ± 4.01 (10)	79.9 ± 3.53 (30)		79.8 ± 4.65 (19)	3.37	0.10
SNB	2D	61.6 ± 4.80 (38)	80.6 ± 5.30 (10)§	75.3 ± 4.28 (30)†		74.9 ± 5.36 (19)	21.6§	0.53
ANB	2D	17.7 ± 9.06 (38)	−0.40 ± 3.43 (10)§	4.9 ± 2.42 (30)§		5.0 ± 1.83 (19)	−71.8§	−0.51
Co-Me-Co	3D	77.0 ± 7.41 (50)		69.0 ± 7.05 (36)§	70.0 ± 5.65 (16)		−9.09‡	−0.28
Co-Go-Pg	3D	137.8 ± 7.56 (49)		138.4 ± 7.36 (36)	139.6 ± 6.57 (16)		1.31	0.07
Airway								
Tongue base volume (cm^3)	3D-CT	1.0 ± 0.47 (45)		3.1 ± 0.98 (34)§	3.9 ± 1.4 (15)*		290§	116.00
Hyoid to inner surface of mandible (mm)	3D-CT	16.0 ± 3.39 (47)		24.2 ± 3.28 (34)§	25.2 ± 4.05 (15)		57.5§	0.37
Hyoid to cervical spine (mm)	3D-CT	16.9 ± 3.14 (48)		21.1 ± 2.57 (35)§	22.5 ± 2.65 (15)		33.1§	0.22
Hyoid to posterior pharynx (mm)	3D-CT	1.7 ± 1.2 (50)		8.2 ± 1.5 (35)§	9.6 ± 2.4 (16)*		465§	0.32

*P ≤ 0.05; †P ≤ 0.01; ‡P ≤ 0.001; §P ≤ 0.0001 (For the last two choices only). P value determined via 'blank' test comparing noted value to previous timepoint; exception is second to last column comparing final and preoperative timepoints.

Length

Mandible-Maxilla length difference was measured both via physical exam, 3D-CT and lateral cephalogram (Figure 3a). Clinical measurement found an average mismatch of 15.0 ± 1.1 mm. Preoperatively, the imaging modalities had similar findings of 14.3 ± 2.1 mm (CT) and 15.0 ± 2.3 mm (XR) of mandibular deficiency. Interestingly, the CT measurement was significantly different than the clinical measurement but not the XR. CT imaging measured a significant improvement of mismatch to 1.2 ± 1.1 mm at 9 months for a 92% reduction of deficiency. Likewise, XR measurements featured a significant improvement in mandibular deficiency to 1.1 ± 1.2 mm at 6 months for a 92% reduction. ANB angle was similarly significant at all time points, with an average preoperative angle of 17.7 ± 9.1o overcorrecting to −0.4 ± 3.4o postoperatively before relapsing to 4.9 ± 2.4o and 5.0 ± 1.8o at device removal and 9-12 month follow up, respectively. This relapse was largely due to a significant decrease in SNB which featured a measurement of 80.6 ± 5.3o following distraction and 75.3 ± 4.3o at the time of removal.

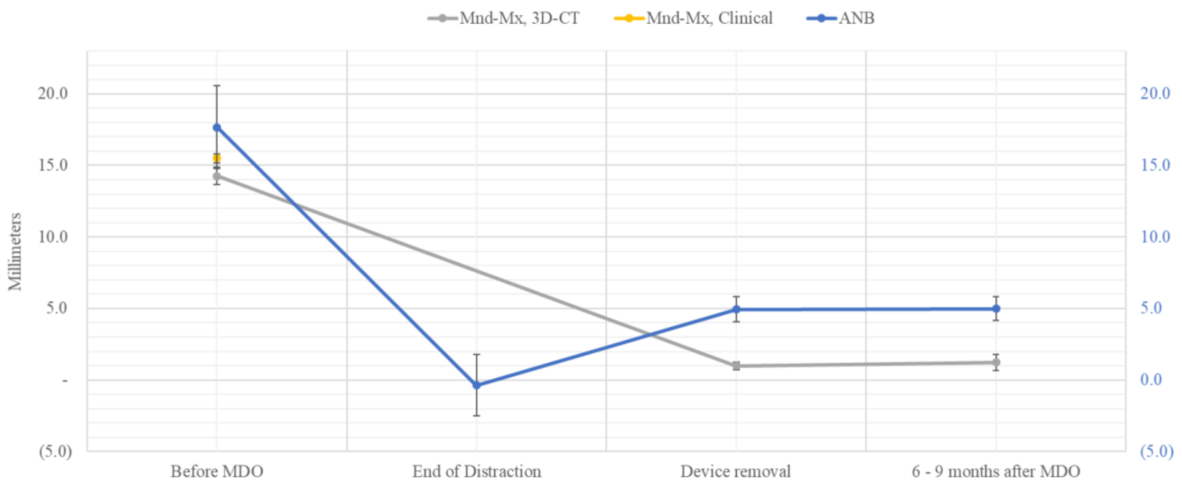

Figure 3a. Mnd-Max & ANB

Mandibular length was measured as the anterior growth of the mandible on a lateral, superior, and inferior view (Figure 3b). Mandibular length on lateral view was measured from the gonion (Go), condyle (Co), or coronoid (Crn) to the pogonion (Pg). Of note, these measures had increasing vertical components capturing some degree of vertical growth.

We found significant increases of 63.8%, 56.2%, and 63.1%, respectively, and 0.61 mm, 0.76, 0.72 mm of growth per 1 mm of distraction (mm/mm[d]). The distance from the Co to the menton (Ma) represents the body's elongation capturing both width and A/P growth from an inferior view. This measurement significantly increased by 49.1% and 0.77 mm/mm(d). The superior view similarly measured the distance from the Co or Crn to the central incisor (Ii) which underwent significant changes of 47.9% and 53.2% and 0.76 and 0.71 mm/mm(d), respectively. On average, mandibular length increased by 55.6% and 0.72 mm/mm(d).

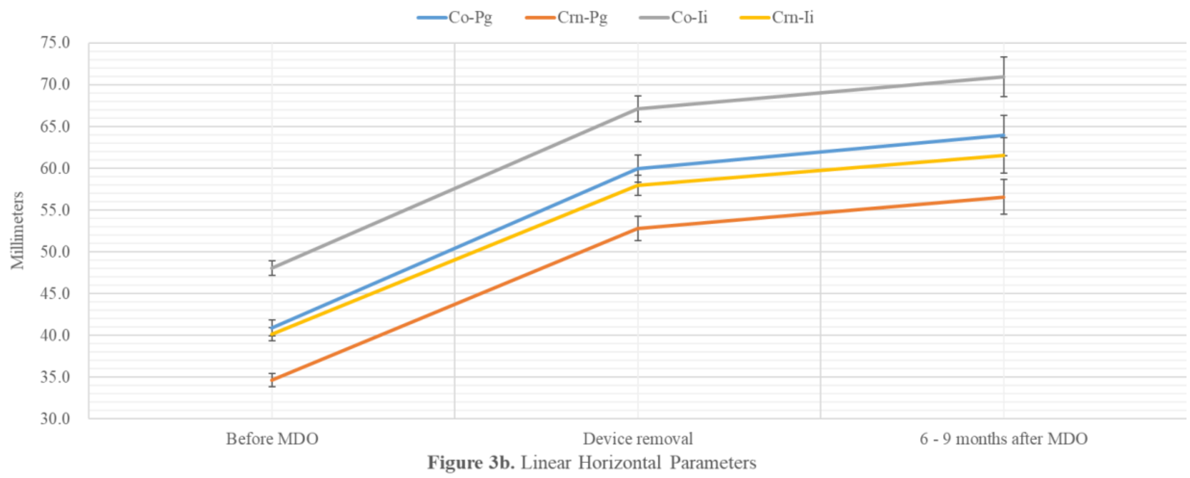

Figure 3b. Linear Horizontal Parameters

Height

Measurements capturing predominantly vertical growth were largely limited to the Ramus using the distance from the Co or Crn to the gonion (Go) (Figure 3c). These increased 49.7% and 49.5% respectively at 9 months. Relative to lateral growth, less increase was seen following distraction with each mm of distraction leading to 0.23 and 0.26 mm/mm(d). On average, mandibular height increased by 49.6% and 0.24 mm/mm(d). These changes preserved anatomic alignment as the angle between the Co-Go-Pogonion (Pg) did not change (137.8 ± 7.6o v 138.4 ± 7.4o v 139.6 ± 6.6o).

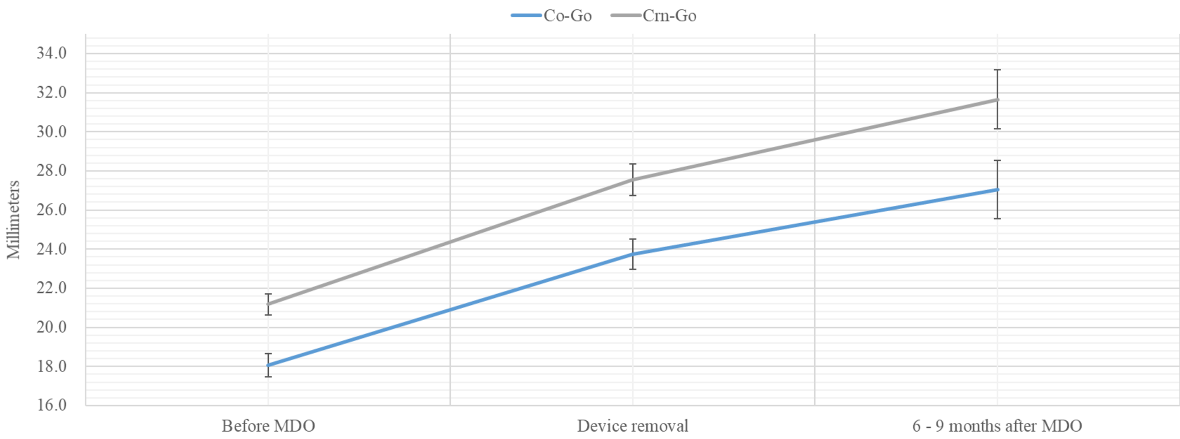

Figure 3c. Linear Vertical Parameters

Width

Anterior views capture changes in width using Co-Mental protuberance (Mp) and Crn-Mp distances. Co-Mp found a 33.0% and 0.31 mm/mm(d) increase, and Crn-Mp similarly found 39.1% and 0.37 mm/mm(d) increase. Average increases of both width measurements were 36% and 0.34 mm/mm(d). Width changed at a slower rate than length as the Co-mental (Me)-Co angle decreased by 9.1%. The comparison between Vertical and Width is presented in figure 3d.

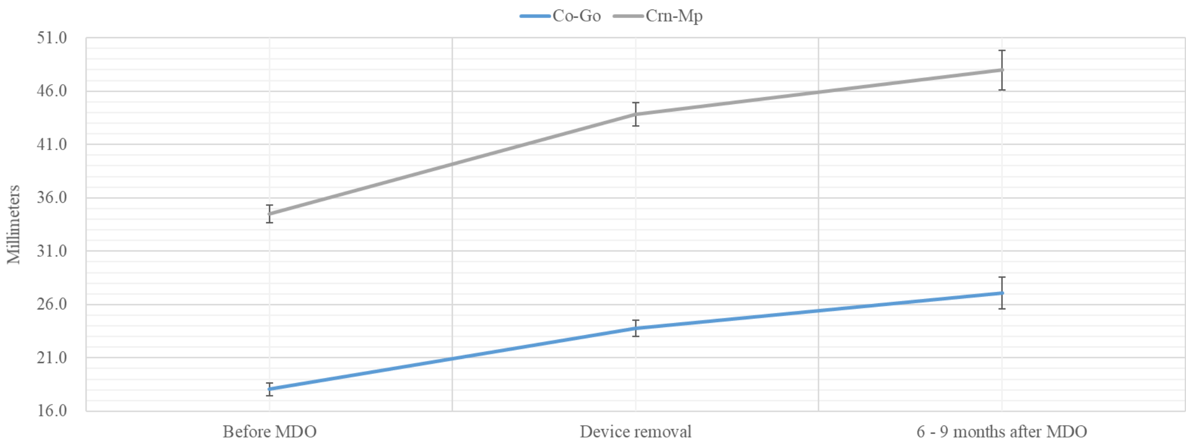

Figure 3d. Comparison of Vertical and Width Parameters

Airway

Distraction of the mandible led to improvement in airway dimension. The distance from the tongue base to the posterior pharynx significantly increased 0.32 mm/mm(d) and 465%. Airway volume posterior to the tongue base significantly increased by 290% or 116 mm/mm(d).

Asymmetry

The following cephalometric parameters had both left and right mandibular measurements: Co-Ma, Go-Pg, Co-Pg, Crn-Pg, Co-Ii, Crn-Ii, Co-Go, Crn-Go, Co-Mp, Crn-Mp, and Co-Go-Pg. For every patient, the percent difference between right and left mandibular measurements was calculated during the preoperative timepoint and at device removal. If the percent difference was greater or equal to 10%, the mandible was considered to be asymmetric. Table III depicts the frequency of asymmetric mandibles among applicable cephalometric parameters preoperatively and at device removal. Fischer's exact test was conducted for all parameters, and none had difference in asymmetry.

Table III. Post-distraction asymmetry

		Percentage of Asymmetry	
Measure	Modality	Preoperative (%)	Device Removal (%)
Horizontal, Linear (mm)			
Co-Ma	3D	2.0	11.8
Go-Pg	3D	4.0	8.3
Co-Pg	3D	6.0	2.8
Crn-Pg	3D	8.0	5.6
Co-Ii	3D	6.0	8.3
Crn-Ii	3D	4.0	13.9
Vertical, Linear (mm)			
Co-Go	3D	8.0	16.7
Crn-Go	3D	6.0	0.0
Width, Linear (mm)			
Co-Mp	3D	26.0	27.8
Crn-Mp	3D	6.0	16.7
Angular			
Co-Go-Pg	3D	0.0	0.0

DISCUSSION

Infants born with Pierre Robin sequence are vulnerable to various adverse consequences, such as respiratory distress, feeding difficulties, sleep apnea, developmental delays, and other severe outcomes (8–10, 20). The main cause of these adverse outcomes is thought to be upper airway obstruction (UAO) resulting from the classic presentation of micrognathia and glossoptosis in RS (21). Studies have demonstrated that for patients suffering from severe UAO, Mandibular Distraction Osteogenesis (MDO) has lower long-term mortality, morbidity, and healthcare burden compared to other surgical options (16, 22, 23). MDO improves airway patency by elongating the mandible, bringing the tongue and neighboring soft tissue forward to increase airway dimension (24). Previous research has shown improved airway dimension following distraction (25–31); however, the exact relationship between distance distracted and mandibular elongation has yet to be determined.

Our study revealed two significant findings related to planned mandibular distraction. Firstly, as seen in previous studies on mandibular distraction, mandibular elongation did not occur at an exact 1:1 ratio. Measures that were aligned with the mandible still showed mm/mm(d) of approximately 0.75 mm/mm(d). Similarly, measures that no longer included the width measurement but involved some aspect of height still maintained a similar 0.75 mm/mm(d) ratio. These findings suggest that the vector of distraction leads to equivalent increases in both the length and width dimensions. However, it's worth noting that it's practically impossible to reduce a measure to a single dimension as all measures have some contribution from a secondary dimension. For instance, the length on a lateral view also has some height contribution, while the length on an inferior view captures some degree of width. Therefore, capturing a true one dimension would exponentially increase the number of measurements and hinder interpretation.

An interesting finding in our study was the relapse of the ANB angle, which was influenced by a reduction in the SNB angle. Although linear measurements on CT imaging indicated a gradual increase in length, the angular measurements on cephalograms revealed that there was a loss of relative mandibular length during the consolidation period. However, it remains unclear whether this loss of relative mandibular length was caused by an actual decrease in mandibular length or a faster growth of the maxilla. Peacock et al. conducted a study similar to the results of a previous study conducted by (19), our study also revealed the occurrence of relapse, suggesting that a certain degree of over-distraction is necessary. Based on our findings, we recommend that a relative length of approximately 2 mm should be factored in when determining the endpoint of distraction.

Measurements following MDO have primarily focused on airway dimensions. Abramson et al. conducted a study using three-dimensional (3D) computed tomography (CT) to investigate changes in airway characteristics in congenital micrognathia patients. They found that 6 out of 15 airway parameters increased post-distraction. Ramieri et al. also used CT to compare pre- and post-operative airway volumes in 4 infants with syndromic micrognathia and glossoptosis from RS. They observed increases in retroglossal and retropalatal airway dimensions of 346% and 169%, respectively. Additionally, Mao et al. used cone-beam CT to study the impact of MDO on upper airway anatomy in 117 isolated RS patients.

They found that 8 airway size parameters were significantly increased. Similarly, the present findings suggest that, while much of the elongation occurs anterior to the hyoid, the generated intraoral space allows for forward movement of the tongue, which leads to substantial increases in airway dimensions. The study measured

2.9-4.6x increases in airway dimensions, which were clinically correlated with 88% of newborns in the cohort experiencing a reversal of sleep apnea (Table I).

Before the operation, we measured the discrepancy between the mandible and maxilla of newborns using three different modalities: X-RAY, CT scan, and clinical measurement. Although we observed significant differences between clinical and CT measurements, the average difference was only 0.13 mm. This finding suggests that while physical examination is not identical to imaging, it can still provide a reasonable estimation.

Our study has some limitations, one of which is the lack of a control group. It would have been ideal to compare cephalic and airway changes following MDO with age-matched controls who were undergoing normal development. Additionally, some data was missing due to limited radiographic imaging in pediatric populations. Although we managed to obtain sufficient data, the power of individual averages in our study was sometimes less than the full sample size of 73 patients, and the ranges may not fully represent the population's variation. Nonetheless, our study detected multiple significant differences between measurements. Another limitation is that the follow-up period was brief. As mandibular distraction is a relatively new surgical intervention for the region, further research is needed to better understand its long-term effects on mandibular growth through skeletal maturity in RS patients.

CONCLUSION

The utilization of Mandibular Distraction Osteogenesis presents a dependable method for remedying the hypoplastic mandible in RS. Analysis of radiographic data has demonstrated that excessive distraction leads to a low rate of growth relapse and facilitates the achievement of the desired end result. Additionally, distraction enhances mandibular morphology and expands airway dimensions. Our endeavor to clarify the cranial and soft tissue transformations following MDO serves to enhance our comprehension of how this procedure impacts the craniofacial development of RS patients.

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