



Three-dimensional airways volumetric analysis before and after fast and early mandibular osteodistraction



Valerio Ramieri ^a, Emanuela Basile ^{a,*}, Giulio Bosco ^a, Elena Caresta ^b, Paola Papoff ^b, Piero Cascone ^a

^a Dipartimento di Scienze Odontostomatologiche e Maxillo Facciale (Head: Prof. Ersilia Barbato), "Sapienza" Università di Roma, Italy

^b Dipartimento di P.I.C.U., "Sapienza" Università di Roma, Italy

ARTICLE INFO

Article history:

Paper received 22 October 2015

Accepted 6 December 2016

Available online 18 December 2016

Keywords:

Pierre Robin sequence

Airways

Mandibular osteodistraction

Syndromic micrognathia

ABSTRACT

Purpose: Newborns with Pierre Robin sequence (PRS) and syndromic micrognathia show microgenia and glossoptosis, which cause reduction of the airway and breathing difficulty from birth. Our goal is to analyze quantitative and qualitative volumetric changes before and after fast and early mandibular osteodistraction (FEMOD) and to compare radiological data.

Methods: The sample was composed of 4 patients, who satisfied inclusion criteria for completeness of data. Computed tomography pre- and post-operation were performed, then a volumetric assessment was made with Dolphin Imaging. Polysomnography was performed before and after FEMOD.

Results: Pre- and post-operative CT scan data were compared. The analysis of all three sections showed a significant increase of volumetric parameters. The retroglossal volume average increase was 346%, and the retropalatal volume average increase was 169%. These data matched the improvement recorded by polysomnography.

Conclusions: The data confirm FEMOD as an efficient treatment to improve airways and breathing problem in patients affected by Pierre Robin sequence and syndromic micrognathia. The three-dimensional volume rendering could be a useful method to evaluate and quantify the increase in airways volume.

© 2016 European Association for Cranio-Maxillo-Facial Surgery. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Pierre Robin sequence (PRS) is defined as the association of micrognathia, glossoptosis, and airway obstruction. This condition is often associated to wide U-shaped cleft palate. The incidence of cleft palate is reported to be 73–90% of cases (Caouette-Laberge et al., 1994; Marques et al., 2005; Butow et al., 2009). It may be isolated or part of a complicated syndrome. The genetic syndrome that most frequently occurs is Stickler syndrome, characterized by skeletal abnormalities, joint pain, congenital myopia, and retinal detachment (Marques et al., 2005; Shprintzen, 1992). However, a recent review recognized more than 50 syndromes with PRS features (Tan et al., 2013).

In the past, mortality was very high (Butow et al., 2009) due to pulmonary sepsis, cerebral anoxia, malnutrition, and cor pulmonale. Prolonged hypoxia has also been reported to place many infants at risk for permanent brain damage.

Several treatments are described in the literature to prevent hypoxia, such as prone position, O₂ therapy, continuous positive airway pressure (CPAP), long intubation, tongue–lip adhesion, tracheostomy, and mandibular distraction. No international guidelines exist about the management of PRS (Mackay, 2011; Cicchetti et al., 2012; Butow et al., 2009). In our experience we have adopted fast and early mandibular osteodistraction (FEMOD) (Cascone et al., 2014). FEMOD has clinical and anatomical indications, such as respiratory distress, persisting of feeding difficulties, glossoptosis, and the distance from the post-pharyngeal wall to the lingual root.

The goals of mandibular lengthening are the improvement in breathing and oxygenation by normalizing the upper airway size and shape. Twelve parameters of upper airway size and 4

* Corresponding author. Viale del Policlinico 155, 00165 Roma, Italy. Fax: +390 649979162.

E-mail address: emanuela.basile1985@gmail.com (E. Basile).

parameters of shape for adults and children have been defined, and their normal value have been published. Upper airways are subject to quantitative and qualitative changes during growth. Concerning shape, adults show larger and more elliptical airways, with less uniformity in shape, compared with children (Abramson et al., 2009, 2010a). Concerning size, the pediatric airway was found to increase in airway volume, surface area, length, and average cross-sectional area. The purpose of the present study is to quantify changes in airway size and shape in children with PRS and Obstructive Sleep Apnea hypoapnea Syndrome (OSAHS) who undergo FEMOD.

2. Materials and methods

The authors considered patients affected by severe micrognathia, who were seen between 2011 and 2014 at “Dipartimento di Scienze Odontostomatologiche e Maxillo Facciali” showing mandibular hypoplasia, glossoptosis, respiratory distress, and U-shaped cleft palate.

Inclusion criteria were the mean features of severe micrognathia, FEMOD protocol, and pre and long-term post maxillofacial computed tomography (CT) scan with three-dimensional (3D) reconstruction.

A total of 46 patients were identified, but only four patients met inclusion criteria. These four patients were included in the study. All of them had undergone mandibular advancement by FEMOD, and had pre and post maxillofacial CT scan with 3D airways analysis. Three of the four patients had a syndromic form of Pierre Robin sequence: one was affected by Larsen syndrome, one was affected by Marshall-Smith syndrome, and the last one was affected by lymphedema–distichiasis syndrome (Table 1).

No patients in the sample were tracheostomy dependent before FEMOD.

FEMOD was performed at a mean age of 16 days old (range 10–24 days old).

A Molina Unidirectional Distractor (KLS Martin) was used in all patients.

All the patients underwent a 3D CT scan before FEMOD, at the end of the distraction phase, to assess the progress of distraction and the correct position of the pin. Follow-up 3D CT scans were performed at a mean of 2 years after distractor removal to assess the changes in upper airways and the physiological mandibular growth.

Maxillofacial noncontrast CT scans consisting of 0.625-mm axial tomograms, with reconstructions in the coronal and sagittal planes, were obtained before and 1–3 years postoperatively for each subject. The scans were imported into a CT-analyzing computer software program, Dolphin imaging.

A digital 3D model of the upper airways was created. Superior and inferior upper airway boundaries were defined: the level of the hard palate and the base of the epiglottis. The sagittal slice that best visualized the posterior nasal spine was the superior boundary. The inferior boundary was the sagittal slice that intersected with the inflection point made by the base of the epiglottis and the anterior pharyngeal wall. The lateral and posterior boundaries were

pharyngeal walls, and the anterior boundary, the anterior wall of the pharynx, base of tongue, and soft palate.

This studies evaluated measurement of airway size and shape parameters as assessed before and after distraction (Table 2).

Airway size parameters included the following: volume surface area (V), length (L), average cross-sectional area (avgCSA), minimum retropalatal area (RP), minimum retroglossal area (RG), minimum cross-sectional area (minCSA), lateral dimension of retroglossal airway (LAT), and anteroposterior dimension of the retroglossal airway (AP). The measures of airway shape included the lateral/anteroposterior ratio in the retroglossal region (LAT/AP); and the ratio of the retropalatal airway diameter to the retroglossal airway diameter (RG/RP) (Abramson et al., 2010b, 2011).

3. Results

The retroglossal anteroposterior diameters increased 69.07%, from $6,425 \pm 1,510$ mm to $10,575 \pm 5,406$ mm, whereas the retroglossal lateral diameters increased 27.54%, from $13,875 \pm 4,519$ to $17,6 \pm 6,380$ mm. The surface area increased 158.36%, from $231,45 \pm 97,16$ mm² to $433,25 \pm 152,23$ mm².

The mean airway volume showed a 346.33% increment. This value pre distraction was $2475,5 \pm 1107,15$ mm³ and was $6458,725 \pm 1853,01$ mm³ post distraction. Both the minimal retroglossal ($12,875 \pm 5,49$ mm² vs $36,325 \pm 21,76$ mm²) and minimal retropalatal ($59,35 \pm 54,22$ mm² vs $143,525 \pm 63,52$ mm²) areas increased after distraction. The minimal cross-sectional area also increased from $10,875 \pm 8,11$ mm² before distraction to $31,475 \pm 22,28$ mm² after distraction. The airway length decreased from a pre distraction value of $36,7 \pm 61,65$ mm to a post distraction value of $5,00 \pm 15,05$ mm (Table 3).

Concerning the airway shape, a light decrease in LAT/AP pre distraction and a light increase in RP/RG ratio were recorded.

These values were supported by polysomnographic data for evaluation of OSAHS post surgery. Every patient underwent polysomnography after FEMOD; the mean apnea-hypopnea index (AHI) index post distraction was 7.9.

The application of the FEMOD protocol allowed us to achieve a mandibular elongation of 14–20 mm (average 18.0 mm) in these patients. Tracheostomy was avoided in all patients in the sample (Fig. 1A and B).

4. Discussion

Pierre Robin sequence (PRS) and syndromic micrognathia are characterized by micrognathia, glossoptosis, and upper airway obstruction, associated with a U/V-shaped cleft palate (Caouette-Laberge et al., 1994; Robin, 1934).

The clinical expression of PRS is quite heterogeneous, but airway obstruction and micrognathia are common in all severe cases.

Micrognathia causes upper airway obstruction due to the posterior collapse of the tongue and physical obstruction of the oropharyngeal and hypopharyngeal regions (Papoff et al., 2013). Management of affected newborns is complicated by breathing and feeding problems; however the priority must be the maintenance of basic life support. The level of invasive intervention is based on the clinical presentation of the infant, the level of stability of the airway, and the presence of other complications, such as an associated syndrome.

Severe cases should be treated by more invasive interventions: tongue-lip adhesion, mandibular osteodistraction, or tracheostomy (Demke et al., 2008; Stanley and Seymour, 1985).

Tracheostomy has been considered a life-saving measure in neonatal patients; however, it is associated with increasing health care costs, frequent morbidity, prolongation of hospital stays,

Table 1
Characteristics of the study population.

Patient no.	Age (days)	Sex	Diagnosis	Distraction type	Magnitude of advancement
1	16	F	Larsen syndrome	Linear	20 cm
2	24	F	Marshall–Smith syndrome	Linear	18 cm
3	17	F	Lymphedema–distichiasis syndrome	Linear	18 cm
4	10	M	PRS	Linear	14 cm

Abbreviation: PRS, Pierre Robin sequence.

Table 2
Definition of airway parameters.

Airway parameter	Abbreviation	Type	Units	Definition
Airway size				
Volume	VOL	3D	mm ³	Volume of airway from base of epiglottis to hard palate
Surface area	SA	2D	mm ²	Surface area of airway
Length	L	1D	mm	Length from hard palate to base of epiglottis
Average cross-sectional area	avgCSA	2D	mm ²	Average cross-sectional area, equal to VOL/L
Minimum retropalatal area	RP	2D	mm ²	Minimum cross-sectional area of retropalatal airway (from inferior aspect of soft palate to level of hard palate)
Minimum retroglossal area	RG	2D	mm ²	Minimum cross-sectional area of retroglossal airway (from base of epiglottis to inferior aspect of soft palate)
Minimum cross-sectional area	minCSA	2D	mm ²	Lowest value among RG and RP, lowest cross-sectional area of airway
Retroglossal lateral dimension	LAT	1D	mm	Lateral dimension of cross-section of airway in middle of retroglossal area (between base of epiglottis and inferior aspect of soft palate)
Retroglossal anteroposterior dimension	AP	1D	mm	Anteroposterior dimension of cross-section of airway in middle of retroglossal area (between base of epiglottis and inferior aspect of soft palate)
Genial tubercle to hyoid bone distance	GH	1D	mm	Distance from genial tubercle to hyoid bone in midsagittal plane
Airway shape				
Lateral/anteroposterior dimension ratio	LAT/AP	Ratio	NA	
RP/RG ratio	RP/RG	Ratio	NA	Ratio of RP and RG cross-sectional areas
Airway uniformity	U	Ratio	NA	Airway uniformity, defined as minCSA divided by avgCSA

Abbreviations: 3D, 3-dimensional; 2D, 2-dimensional; 1D, 1-dimensional; NA, not applicable.

Table 3
Airway parameters before and after.

Variable	Standard deviation		Change (%)	Direction
Airways size				
SA			158,3659406	Increase
Pre DO	231,45	231,45		
Post DO	433,925	152,2329219		
LAT			27,54645282	Increase
Pre DO	17,6	6,380177636		
Post DO	10,575	5,406400528		
AP			69,07375741	Increase
Pre DO	6,425	1,510794493		
Post DO	14,0875	5,406400528		
VOL			346,3383526	Increase
Pre DO	2475,5	1107,15441		
Post DO	6458,725	1853,017757		
RG			169,4937919	Increase
Pre DO	12,875	5,499924242		
Post DO	36,325	21,76072532		
RP			1706,016461	Increase
Pre DO	59,35	54,22302709		
Post DO	143,525	63,52009525		
minCSA			563,859734	Increase
Pre DO	10,875	8,114749945		
Post DO	31,475	22,28921638		
L			70,89833647	Increase
Pre DO	36,7	61,65		
Post DO	5,008659169	15,05910577		
avgCSA			86,09151162	Increase
Pre DO	65,34295209	23,92179644		
Post DO	104,0448934	14,80945632		
Airways shape				
RP/RG				
Pre DO	5,196219139	6,092310228		Decrease
Post DO	5,357267668	4,534997373		
LAT/AP				Decrease
Pre DO	2,34	1,012269797		
Post DO	2,18	1,628009121		

Abbreviations: Pre DO, pre osteodistraction; Post DO, post osteodistraction; SA, surface; LAT, lateral dimension of retroglossal airway; AP, anteroposterior dimension of the retroglossal airway; VOL, volume; RG, minimum retroglossal; area minCSA, minimum cross-sectional; LAT/AP, lateral/anteroposterior ratio in the retroglossal region; RG/RP, ratio of retropalatal airway diameter to retroglossal airway diameter.

occasionally mortality, and problems with care outside the hospital. It should be regarded as the final treatment option (Laville et al., 1994).

Distraction osteogenesis was introduced in 1905 as a surgical orthopedic technique for lengthening a femur by axial distraction,

based on the principle that the tension stimulates histogenesis with bone formation (Cetta et al., 1979). Mandibular osteogenic distraction (MOD) was introduced by McCarty et al. to correct craniofacial abnormalities without the need for bone grafting (McCarthy et al., 1992).

To date, an international guideline does not exist. The FEMOD protocol allows the lengthening the mandible, providing an alternative method for airway management.

Indications for FEMOD are clinical and anatomical: respiratory distress and persistence of feeding difficulties, and the distance from the post-pharyngeal wall to the lingual root.

The FEMOD protocol foresees overcorrection of the skeletal position of the mandible. The authors emphasize the necessity of an overcorrection in order to preserve an adequate airway area in case of relapse. The mechanism by which mandibular lengthening improves the symptoms in children with OSA has not been definitively established. To better understand this mechanism, accurate and reliable 3D evaluations of the airway and assessments of sleep and breathing both pre and post distraction are necessary (Abramson et al., 2013).

A study performed by Williams et al. demonstrates expansion of the mandibular framework with advancement of the base of tongue, which leads to an increase in the pharyngeal airway for early decannulation of tracheostomy-dependent patients. This is determined on the basis of cephalometric studies measuring the advancement of the hyoid bone along the axis of the mandibular body post distraction (Williams et al., 1999; Rachmiel et al., 2005).

Looby et al. (2009) reported an increase in the mean cross-sectional area after distraction, from 41,35 to 127,77 mm² in a mixed group of patients with syndromic and nonsyndromic micrognathia.

The present study showed that the greatest percentage of increase in size was seen in the parameters related to the anteroposterior diameter of the airways, a measure parallel in orientation to the distraction vector.

In addition, the vertical airway length decreased significantly after distraction. Since resistance to airflow is directly proportional to the airway length, a decrease in airway length would be expected to decrease resistance. In addition, the airway length that can collapse is smaller in a shorter airway. The combination of decreased airway length and increased airway diameter results in decreased resistance to airflow and improved breathing and sleep quality.

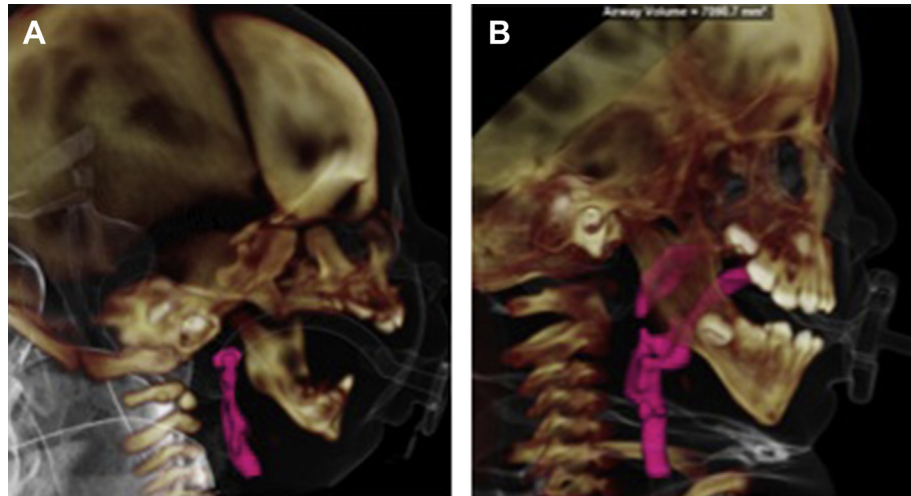


Fig. 1. (A) 3D CT scan and airways study of newborn affected by Pierre Robin sequence before FEMOD. (B) 3D CT scan and airways study of child affected by Pierre Robin sequence 3 years after FEMOD.

Interestingly, the retropalatal cross-sectional area increased significantly post distraction. This finding is likely the result of the forward movement of the tongue. Moreover, all patients underwent the Veau–Wandell–Kilner palatoplasty technique at 6 months of age, which contributed the forward movement of the tongue and the increment of the retropalatal cross-sectional area. Limits to this study were identified: the small sample of patients, and the use of X-rays in a pediatric population.

5. Conclusions

The results of this study support that distraction of the micrognathic mandible increases the volume and improves the shape of the upper airway, and advances the hyoid bone. The synergistic improvement in glossoptosis and airway obstruction eliminate symptoms of OSA, along with the need for tracheostomy.

A FEMOD protocol should consider a valid therapy to improve the airway pattern of Pierre Robin and syndromic micrognathia patients, avoiding tracheostomy.

Conflicts of interest

The authors declare that there are no conflicts of interest.

References

- Abramson Z, Susarla S, August M, Kaban L: Three-dimensional computed tomographic analysis of airway anatomy in patients with obstructive sleep apnea. *J Oral Maxillofac Surg* 68: 354, 2010b
- Abramson Z, Susarla S, Troulis M, Kaban L: Age-related changes of the upper airway assessed by 3-dimensional computed tomography. *J Craniofac Surg* 20: 657, 2009
- Abramson Z, Susarla SM, Lawler M, Kaban L: Three-dimensional computed tomographic airway analysis of patients with obstructive sleep apnea treated by maxillomandibular advancement. *J Oral Maxillofac Surg* 69: 677, 2011
- Abramson ZR, Susarla S, Tagoni JR, Kaban L: Three-dimensional computed tomographic analysis of airway anatomy. *J Oral Maxillofac Surg* 68: 363, 2010a
- Abramson ZR, Susarla SM, Lawler ME, Peacock ZS, Troulis MJ, Kaban LB: Effects of mandibular distraction osteogenesis on three-dimensional airway anatomy in children with congenital micrognathia. *J Oral Maxillofac Surg* 71(1): 90–97, 2013
- Bütow KW, Hoogendijk CF, Zwahlen RA: Pierre Robin sequence: appearances and 25 years of experience with an innovative treatment protocol. *J Pediatr Surg* 44(11): 2112–2118, 2009
- Caouette-Laberge L, Bayet B, Laroque Y: The Pierre Robin sequence: review of 125 cases and evolution of treatment modalities. *Plast Reconstr Surg* 93: 934–942, 1994
- Cascone P, Papoff P, Arangio P, Vellone V, Calafati V, Silvestri A: Fast and early mandibular osteodistraction (FEMOD) in severe Pierre Robin sequence. *J Craniomaxillofac Surg* 2(7): 1364–1370, 2014
- Cetta G, Lenzi L, Ruggeri A, Tenni R, Boni M: Biochemical and structural abnormalities of the connective tissue in Larsen's syndrome. *Int Orthop* 3(1): 47–53, 1979
- Cicchetti R, Cascone P, Caresta E, Papoff P, Miano S, Cerasaro C, et al: Mandibular distraction osteogenesis for neonates with Pierre Robin sequence and airway obstruction. *J Matern Fetal Neonat Med* 25(Suppl. 4): 141–143, 2012
- Demke J, Bassim M, Patel MR, Dean S, Rahbar R, van Aalst JA, et al: Parental perception and morbidity: tracheostomy and Pierre Robin sequence. *Int J Pediatr Otorhinolaryngol* 72(10): 1509–1516, 2008
- Laville JM, Lakermance P, Limouzy F: Larsen's syndrome: review of the literature and analysis of thirty-eight cases. *J Pediatr Orthop* 14: 63–73, 1994
- Looby JF, Schendel SA, Lorenz HP, Hopkins EM, Aizenbud D: Airway analysis: with bilateral distraction of the infant mandible. *J Craniofac Surg* 20(5): 1341–1346, 2009
- Mackay DR: Controversies in the diagnosis and management of the Robin sequence. *J Craniofac Surg* 22(2): 415–420, 2011
- Marques IL, de Sousa TV, Carneiro AF, Peres SP, Barbieri MA, Bettiol H: Robin sequence: a single treatment protocol. *J Pediatr (Rio J)* 81: 14–22, 2005 [3]
- McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH: Lengthening the human mandible by gradual distraction. *Plast Reconstr Surg* 89: 1–8, 1992 discussion 9–10
- Papoff P, Guelfi G, Cicchetti R, Caresta E, Cozzi DA, Moretti C, et al: Outcomes after tongue-lip adhesion or mandibular distraction osteogenesis in infants with Pierre Robin sequence and severe airway obstruction. *Int J Oral Maxillofac Surg* 42: 1418–1423, 2013
- Rachmiel A, Aizenbud D, Pillar G, Srouji S, Peled M: Bilateral mandibular distraction for patients with compromised airway analyzed by three-dimensional CT. *Int J Oral Maxillofac Surg* 34: 9–18, 2005
- Robin P: Glossoptosis due to the atresia and hypotrophy of the mandible. *Am J Dis Child* 48: 541–547, 1934
- Shprintzen RJ: The implications of the diagnosis of Robin sequence. *Cleft Palate Craniofac J* 29: 205–209, 1992
- Stanley D, Seymour N: The Larsen syndrome occurring in four generations of one family. *Int Orthop* 8: 267–272, 1985
- Tan TY, Kilpatrick N, Farlie PG: Developmental and genetic perspectives on Pierre Robin sequence. *Am J Med Genet C Semin Med Genet* 163C: 295–305, 2013
- Williams JK, Maull D, Grayson BH, Longker MT, McCarthy JG: Early decannulation with bilateral mandibular distraction for tracheostomy-dependent patients. *Plast Reconstr Surg* 103: 48–57, 1999