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Upper airway changes in syndromic craniosynostosis patients following midface or monobloc advancement: Correlation between volume changes and respiratory outcome☆

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ABSTRACT

In syndromic craniosynostosis patients, respiratory insufficiency may be a pressing indication to surgically increase the patency of the upper airway by midface or monobloc advancement. In this study the volume changes of the upper airway and the respiratory outcome following midface (Le Fort I or III) or monobloc advancement in ten syndromic craniosynostosis patients are evaluated. Pre- and postoperatively, the airway volume was measured using a semi-automatic region growing method. Respiratory data were correlated to the volume measurements.

In nine patients the outcome of upper airway volume measurements correlated well to the respiratory outcome. Three of these patients showed a minimal airway volume gain or even volume loss, and no respiratory improvement was found. In one monobloc patient improvement of the respiratory outcome without an evident volume gain of the upper airway was found.

The majority of patients with Le Fort III advancement showed respiratory improvement, which for the greater part correlated to the results of the volume analysis. In monobloc patients the respiratory outcomes and volume measurements were less obvious. Preoperative endoscopy of the upper airway is advocated to identify the level of obstruction in patients with residual obstructive sleep apnoea.

1. Introduction

Patients with syndromic craniosynostosis (SCS) often present with elevated intracranial pressure (ICP), obstructive sleep apnoea (OSAS), severe exorbitism, Class III malocclusion and aesthetic problems. In accordance with our protocol, children with Apert, Crouzon or Pfeiffer syndrome with signs of raised ICP are primarily considered for posterior cranial vault expansion at the age of 6–9 months. Patients presenting with severe OSAS and/or exorbitism, are candidates for monobloc (MB) or Le Fort (LF) III advancement. The timing of midface advancement is dictated by the indication.

In SCS patients almost 50% of the cases present with OSAS (Hoeve et al., 2003). A recent study by Al-Saleh et al. showed that almost 75% of patients with SCS had abnormal PSG results (Al-Saleh et al., 2010). Obstruction may occur at various levels, although midface hypoplasia resulting in a distorted nasopharyngeal airway (NPA) is a common feature (Hoeve et al., 2003; Nixon et al., 2005). A positive correlation between OSAS and raised ICP has been reported (Gonsalez et al., 1997). In selected cases, OSAS is considered to be an indication for midface advancement on LF I, II, and III level and MB advancement. Recent research from our group has shown that advancement of the midface on LF III level in SCS patients significantly increases the airway volume of the nasal cavity, naso-, oro- and hypopharynx (Bannink et al., 2010; Nout et al., 2010). The main increase of airway volume was detected at the level of nasal cavity and nasopharynx. Nelson et al. have shown that LF III distraction osteogenesis (DO) reduces airway obstruction in SCS patients (Nelson et al., 2008). Al-Saleh et al showed that

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sleep-related disordered breathing in patients with SCS can be improved by maxillofacial surgical intervention in the majority of patients (Al-Saleh et al., 2010). About 30% of patients with SCS showed no improvement or worsening of the sleep-related disordered breathing. Although the aim of midface advancement for SCS patients with OSAS is to resolve the breathing problems, it remains unclear to what extent an increase in airway volume improves the dynamics of breathing in SCS patients. In this study, three-dimensional (3D) volumetric changes after midface and MB advancement were evaluated, by analysing pre- and postoperative computed tomography (CT) scans from SCS patients. Respiratory outcome was evaluated using polysomnography (PSG) and clinical evaluation and correlated to the volumetric airway changes.

2. Material and methods

2.1. Patients

Patients with Apert, Pfeiffer or Crouzon syndrome, who underwent midface or MB advancement between 2003 and 2009, were retrospectively identified. Patients were included in the study, when both pre- and postoperative respiratory data and CT-scans were available.

2.2. Distraction protocol

A latency period of 7 days was applied in all patients. The distraction rate was 1 mm per day for midface advancement and 0.5 mm per day for MB advancement. Vector modifications (only possible with the external devices) were performed when necessary. A consolidation period of 3 months for the LF III and 6 months for the MB was respected.

2.3. CT-scans

All scans were performed in Sophia Children's Hospital using the same scanner (Emotion 6, Siemens, Munich, Germany) with a fixed slice thickness of 1.25 mm. General anaesthesia was indicated in two cases (patient nr eight and ten) depending on the patient's cooperation and age. All scans were carried out in a supine position.

2.4. Data-analysis

The software program (MevisLab, MeVis Medical Solutions AG, Bremen) was used to import and analyse the CT-scans by means of a custom-designed tool. By manually masking for each scan in each slice the maxillary, ethmoidal, frontal, sphenoidal sinuses and the oral cavity (posterior boundary defined by a transversal plane from the uvula to the tongue base), the inactive respiratory airways were excluded (Fig. 1). Two compartments were marked according to predefined strict anatomical boundaries. Compartment A, containing hypopharynx and oropharynx, ranged from the lower part of the hyoid bone to halfway along the length of the uvula visualized in midsagittal view. Compartment B, containing nasopharynx and nasal cavity, ranged superiorly from compartment A to the most superior point of the nasal cavity. Both compartments were segmented using a semi-automatic region growing method with a fixed Hounsfield threshold value. The volumes of the segmented compartments were computed pre- and postoperatively. By adding the two volumes A and B, a total volume was calculated pre- and postoperatively. Previous research from our group has shown that the method used was highly reproducible (Nout et al., 2010).

2.5. Respiratory outcome

The respiratory outcome was assessed after evaluating the outcome of PSG together with clinical evaluation of the patient. In patients with a tracheal cannula, PSG data were not recorded.

2.6. PSG

PSG was performed ambulatorily or during admission to the hospital. In patients with a tracheostomy due to severe OSAS requiring immediate airway intervention, no PSG could be recorded. The analysis was expressed in apnoea-hypopnoea-index (AHI), the number of apnoeas (absence of airflow for more than two breaths) and hypopnoeas (reduction of >50 % in nasal flow signal

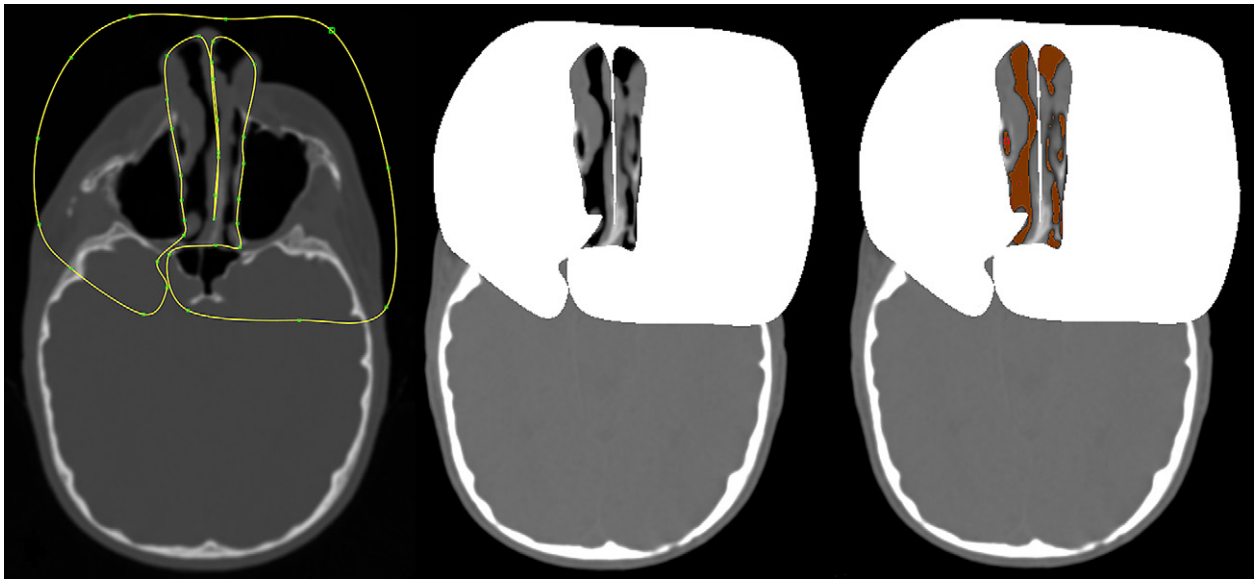

Fig. 1. Example representing the step-by-step exclusion of paranasal sinuses. By manually creating a contour in each slice (left), a mask can be computed (middle). By segmentation of the selected areas, indicated by placing seeding points (right), and use of a semi-automatic region growing method with a fixed Hounsfield threshold value, volumes can be computed for areas of interest. Exclusion of the oral cavity took place in a similar way.

amplitude) per hour and an oxygen-desaturation-index (ODI), representing the number of desaturations (≥4% decrease with respect to the baseline) per hour. For all indices a score of less than one is considered to be normal, between one and five is defined as mild, between six and 25 as moderate and over 25 as severe OSAS (Guilleminault et al., 1995). By recording both nasal flow and thoracic movements, central apnoeas could be distinguished from obstructive apnoeas. Manual analysis of the recordings was performed to exclude central apnoeas.

2.7. Clinical evaluation

All patients were seen in the outpatient clinic by the multidisciplinary craniofacial team pre- and postoperatively. During the postoperative reviews the effects of surgery and OSAS therapy are assessed by clinical evaluation. Based upon this evaluation, decisions are being made concerning further treatment.

3. Results

Patient data are summarized in Tables 1 and 2. In total 27 LF III, one LF I and five MB advancements were performed during the study period of which 23 patients had insufficient data for analysis; this left ten patients to include in the study: five patients underwent LF III DO, one patient LF I DO and four patients MB DO. LF III patients were operated on at an average age of 15.2 years (sd 4). Unfortunately, due to irregularities in nasal flow, in some patients AHI's could not be scored. Except for the cannulated patients, pre- and postoperative ODI's were recorded in all patients. Besides OSAS (eight patients), indications in this patient cohort for LF III advancement were severe midface hypoplasia (all patients) and exorbitism (one patient). Raised ICP was considered an indication for monobloc advancement. The MB patients were operated at an average age of 8.4 years (sd 10.2). The LF I patient underwent surgery at the age of 20. Preoperative scans were obtained on average 9 months (sd 11.5 months) before surgery. Postoperative scans were obtained on average 7 months (sd 4 months) after surgery. In two patients (number eight and ten) general anaesthesia was indicated during scanning. Insufflation was performed using the present trachea-cannula. Preoperative PSGs were obtained on average 10.6 months (sd 13.4 months) before surgery. Postoperative PSGs were obtained on average 19.5 months (sd 20.3 months) after surgery. Patients one, eight and ten were diagnosed as severe OSAS because of tracheostomy-dependency.

3.1. Respiratory outcome

Six patients showed an improvement of the PSG of at least one category, in two patients the OSAS was completely resolved. Four patients showed no improvement of the PSG, of which two patients were still dependent on the tracheostomy. In three LF III patients with residual mild or moderate OSAS, a stable situation was

Table 1
Overview of the patient cohort with respect to the upper airway volume measurements. The columns with volume gains represent the postoperative volume gain or loss expressed as a percentage of the preoperative airway volume.

Patient nr	Syndrome	Age at time of surgery (yrs)	Preoperative airway volume oro-/hypopharynx (mm^3)	Postoperative airway volume oro-/hypopharynx (mm^3)	Volume gain oro-/hypopharynx (%)	Preoperative airway volume nasal cavity and nasopharynx (mm^3)	Postoperative airway volume nasal cavity and nasopharynx (mm^3)	Volume gain nasal cavity and nasopharynx (%)	Total volume gain (%)
Le Fort I									
1	Crouzon	19.4	6.4	7.9	23.5	35.9	33.2	−7.7	−3.0
Le Fort III									
2	Apert	12.1	13.3	14.8	11.2	20.1	32.9	63.4	42.6
3	Apert	10.4	4.6	5.5	19.3	13.1	19.5	48.8	41.1
4	Crouzon	16.2	9.2	6.0	−34.8	19.7	20.7	5.0	−7.7
5	Crouzon	16.5	4.7	5.1	7.1	15.7	26.3	67.5	53.4
6	Crouzon	20.7	3.7	6.1	65.1	20.1	32.7	62.2	62.6
Monobloc									
7	Apert	23.2	15.1	10.8	−28.3	20.8	38.7	91.3	41.0
*8	Apert	1.5	0.8	0.7	−18.7	1.1	1.1	0.0	−7.7
9	Crouzon	7.2	10.2	4.0	−60.7	7.2	20.2	180.0	38.9
*10	Crouzon	1.7	2.2	2.3	3.9	3.4	3.2	−3.9	−0.8

Data marked with an asterisk represent the patients that were insufflated via the tracheal tube during scanning.

Table 2
Overview of the patient cohort with respect to polysomnographic data. Oxygen-desaturation indices are expressed categorical and as numeric values. Apnoea-hypopnoeahypopnoea indices are expressed as numeric values only. In case apnoea-hypopnea indices were not recorded, n.r. is depicted.

Patient nr	Syndrome	Preoperative cannula	Preoperative CPAP	OSA preoperative	ODI preoperative	AHI preoperative	Postoperative cannula	Postoperative CPAP	OSA postoperative	ODI postoperative	AHI postoperative
Le Fort I											
1	Crouzon	Yes	No	Severe	n.r.	n.r.	Yes	No	severe	n.r.	n.r.
Le Fort III											
2	Apert	No	No	Moderate	18	n.r.	No	No	mild	1.9	1.2
3	Apert	No	No	Severe	32	40	No	No	mild	8.5	8
4	Crouzon	No	Yes	Moderate/severe	25	n.r.	No	Yes	moderate/severe	22	26
5	Crouzon	No	No	Mild	1.5	0	No	No	no	0	0.5
6	Crouzon	No	Yes	Severe	56	66	No	No	mild	3.3	5.5
Monobloc											
7	Apert	No	No	Moderate	13.9	8	No	No	moderate	6.5	3.2
*8	Apert	Yes	No	Severe	n.r.	n.r.	Yes	No	severe	n.r.	n.r.
9	Crouzon	No	No	Moderate	7	n.r.	No	No	no	0.7	0.6
*10	Crouzon	Yes	No	Severe	n.r.	n.r.	No	Yes	mild	3.8	n.r.

Data marked with an asterisk represent the patients that were insufflated via the tracheal tube during scanning.

achieved with the use of nasal glucocorticosteroid application in two (patients two and three) and without any medication in one (patient six).

3.2. Airway volume versus respiratory outcome

3.2.1. Increased airway volume and matching improved respiratory outcome

If upper airway volumes increased on the level of the nasopharynx and nasal cavity, a similar improvement of the PSG measurements was noted in six patients (four LF III patients, number two, three, five, six and two MB patients, number seven and nine). In patient number seven, advancement revealed a significant volume gain on the level of nasal cavity and nasopharynx while only a slight improvement in the PSG measurements was observed. Endoscopy of the upper airway revealed a deviation of the nasal septum and an obstruction at the level of the hypopharynx. A BSSO was performed to advance the mandible and simultaneously correct the nasal septum. A postoperative PSG revealed an ODI of 0.8, while postoperative volume measurements showed an upper airway volume gain of 50.1% at the level of the hypo-/oropharynx, while at the level of the nasal cavity and oropharynx the upper airway volume remained nearly unchanged (−2.7%).

3.2.2. Unchanged airway volume and respiratory outcome

In three patients (one LF I patient (number one), one LF III patient (number four) and one MB patient (number eight)) the upper airway volume measurements showed only a minimal volume gain or even volume loss, while the respiratory outcome revealed no change. Patient one had a congenital tracheal stenosis with a cartilaginous sleeve which resulted in an irreversible obstruction of the upper airway for which tracheostomy was performed and a permanent tracheal cannula was placed. There was persistent OSAS following MB advancement. LF I advancement was performed to achieve class I occlusion. The patient is still dependent on the tracheal cannula. In patient four, who is still dependent upon continuous positive airway pressure (CPAP) after LF III, the postoperative endoscopy revealed an obstruction at the level of the hypopharynx. Patient eight was insufflated during scanning via the tracheal cannula. Despite the absence of airway volume gain, an evident advancement of the midface was clinically noted after monobloc advancement. Pre- and postoperatively the patient is tracheostomy-dependent.

3.2.3. Discrepancy between airway volume and respiratory outcome

In one MB patient (patient number ten) a discrepancy was observed between the respiratory outcome and the volume measurements. In this patient, the advancement did not result in upper airway volume gain while a distinct improvement of the respiratory status was observed. Analysis of the pre- and postoperative radiographs and clinical images showed only a minimal advancement of the MB segment in this patient. Postoperative decannulation caused nocturnal deoxygenations to around 90%; it was decided to start CPAP. Despite nocturnal CPAP, moderate OSAS persisted. Naso- and hypopharyngeal endoscopy revealed a narrow pharynx. To widen the pharyngeal space an adenotonsillectomy was performed which, most likely, was responsible for the respiratory improvement.

4. Discussion

In general, a significant decrease of OSAS is found after LF III and MB advancement (Holmes et al., 2002; Elwood et al., 2003; Meling et al., 2004, 2006; Fearon, 2005; Mathijssen et al., 2006; Arnaud et al., 2007; Nelson et al., 2008; Flores et al., 2009). In nine subjects of the study cohort the outcomes of the upper airway volume measurements correlated to the respiratory outcome. Interestingly, four of the five LF III patients showed an increase of the upper airway volume and simultaneous improvement of the PSG measurements, whereas in the MB group only two of the four patients showed comparable results (Fig. 2) which might be due to the younger age of three of the four children in the MB group compared to the LF group. Considering the CT-scans of the two MB patients with endotracheal cannulas (patient number eight and ten) who were insufflated during scanning, the collapse of the airway is evident both pre- and postoperatively (Fig. 3). Hypothetically, insufflation of air via the tracheal cannula might cause a collapse of the upper airway cranial of the tracheal cannula. This is supported by the findings of Fricke et al., who measured a significant decrease in volume of the naso- and hypopharyngeal airway in children with tracheostomy tubes after uncapping the tubes (Fricke et al., 2007). Conceivably, in these patients requiring insufflation during scanning, the compliance of the airway is higher due to breathing through the tube instead of the upper airway. This may lead to increased collapsibility of the upper airway regardless of anatomical factors. In these patients, advancement of the forehead and midface might not overcome this enhanced collapsibility although the anatomical factors are sufficiently (over-)corrected.

Concerning the outcomes of OSAS after LF III advancement, several studies have been published of which only a few have evaluated the airway changes using cephalometrics (Holmes et al., 2002; Elwood et al., 2003; Meling et al., 2004, 2006; Fearon, 2005; Mathijssen et al., 2006; Arnaud et al., 2007; Nelson et al., 2008; Flores et al., 2009). However, to the best of our knowledge, only one study has been published in which the OSAS outcomes were correlated to 3D airway changes after LF III advancement (Xu et al., 2009). In the present study, 50% of the study group did not show enough respiratory improvement after midface or MB advancement to be independent of tracheostomy or CPAP or were in need of additional surgical treatment. This can be explained by the multifactorial aetiology of OSAS. Despite advancement of the midface and creating airway volume, the patency of the upper airway is dependent on the nature of the airflow (turbulent or lamellar flow), velocity of the airflow and pressure gradient among others. The influence of midface advancement on these parameters is still unknown. In general, we recommend preoperative naso-endoscopy, nasopharyngoscopy and hypopharyngoscopy to identify the level of airway obstructions and incorporate the findings in the treatment plan. In case of anatomical airway obstruction and resistance to non-surgical interventions, additional orthognathic surgery or septal surgery might be indicated to reduce OSAS. The outcome of volume measurements should be considered together with the state of the patient during scanning; was the patient awake or was insufflation necessary?

This retrospective study has limitations. Ideally, there was a fixed time interval between the pre- and postoperative CT-scans and PSG measurements. Unfortunately, the analysis of the pre- and postoperative time interval showed a considerable standard deviation, which varied between the pre- and postoperative CT-scans and PSG measurements. In addition no data were available concerning intraluminal pressure and airflow. Moreover concerning the PSG measurements only a portion of the patients had both ODI and AHI analysed while ODI measurements were solely conducted and used as an OSAS-indicator in the majority of patients. By measuring ODI, sole deoxygenations are scored and used for the definition of OSAS whereas the AHI is based on deoxygenations followed by apnoeas; AHI represents a more strict definition of OSAS. In the present study the ODI's correlated well to the AHI's.

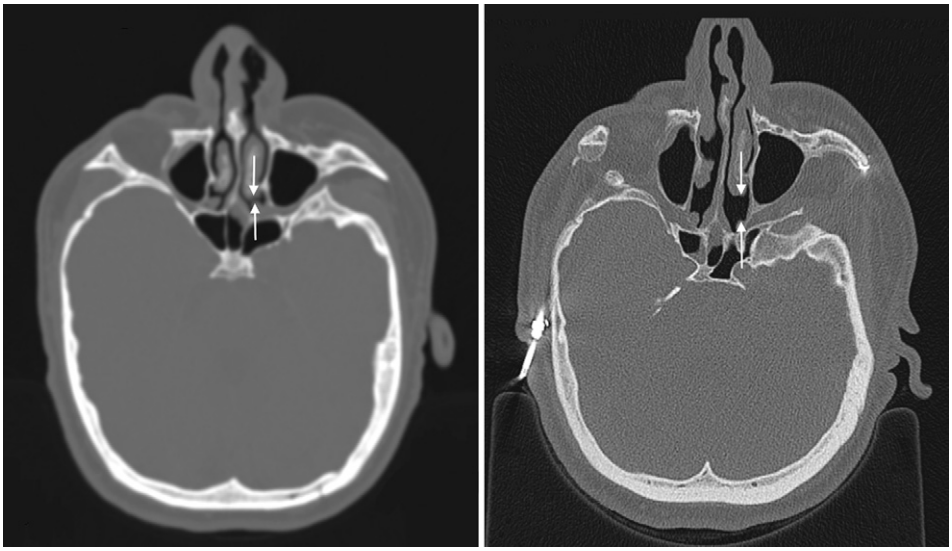

Fig. 2. Pre- (left) and postoperative (right) axial slice at comparable levels of a patient with Apert syndrome. In this patient monobloc distraction was performed with internal distractors. A significant upper airway volume gain is visualized (white arrows).

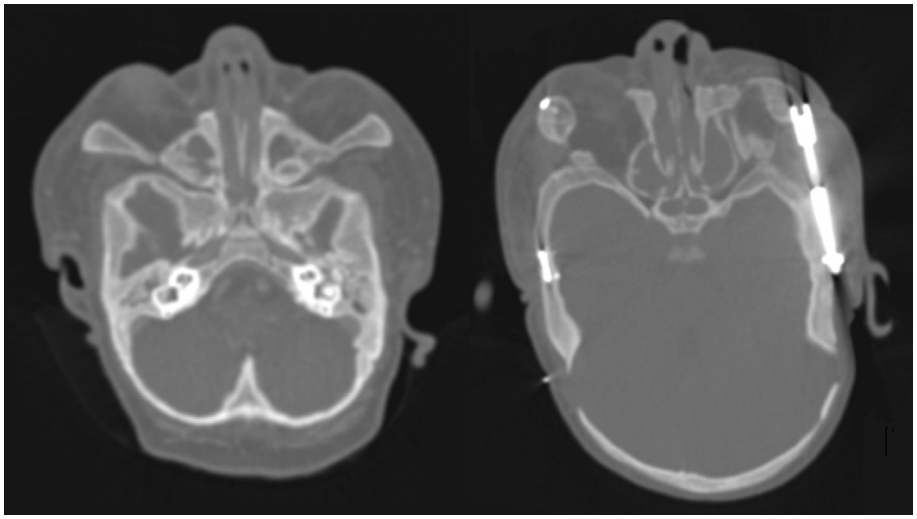

Fig. 3. Pre- (left) and postoperative (right) axial slice at different levels, of a patient with Crouzon syndrome. In this patient monobloc distraction was performed with internal distractors. This patient was anesthetized and insufflated via the tracheal cannula during scanning. In both slices the collapse of the airway is evident.

Despite a good interobserver agreement, upper airway volume measurements are known to contain some errors (Bannink et al., 2010; Nout et al., 2010).

5. Conclusion

The majority of patients showed an improvement of respiratory outcome after LF III advancement, which for the greater part, correlated to the results of the 3D volume measurements. In MB patients the correlation between the outcome of volume measurements and the respiratory outcomes were less obvious. Prior to (mid-)face advancement, naso-endoscopy, nasopharyngoscopy and hypopharyngoscopy are advocated to identify the level of obstruction. Airway volume measurements may help to gain insight in the complex mechanisms underlying the aetiology of OSAS on level of the airway. Acquisition of airway pressure and airway flow data, i.e. airway resistance measurements, may aid in interpreting the respiratory outcomes. Long-term follow-up is needed to monitor the course of OSAS, especially in patients undergoing MB advancement at a young age to elucidate the mechanisms of OSAS.

Conflict of interest

This study has been carried out by the authors only. No external financial sources have been used. There are no relations that could be construed as a conflict of interest.

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