Journal of Cranio-Maxillo-Facial Surgery 48 (2020) 825–831

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

Alterations of upper airway volume caused by Le Fort III osteodistraction in children

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ARTICLE INFO

Article history:
Paper received 13 December 2019
Accepted 20 June 2020
Available online 29 June 2020

Keywords:
Distraction osteogenesis
Le fort osteotomy
Airway remodelling
Apert syndrome
Crouzon syndrome
Obstructive sleep apnea

ABSTRACT

Purpose: The aim of the study was to assess changes in the upper respiratory tract and sleep quality in patients who were suffering from midfacial hypoplasia and treated with the movement of underdeveloped middle segment of the face with an Le Fort III osteotomy and distraction.

Methods: In this study patients aged 7–19, suffering from Crouzon syndrome, Apert syndrome, or other craniosynostosis were treated with Le Fort III osteotomy and midface distraction. Patients were subjected to radiological examination and polysomnography before and after the treatment. Typical anthropometric points were identified on lateral cephalograms, and were used to take linear and angular measurements. The surface and the volume of the upper respiratory tract were measured with the Dolphin Imaging software. Apnoea Hypopnea Index (AHI) was used to assess the sleep quality.

Results: In all 18 patients the analysis showed statistically significant changes of the AHI and in the linear, angular and volumetric measurements. Mean change of the volume of the upper respiratory tract was 12,4 ± 11,3cm3(p = 0,0001) and of the surface was 615 ± 521 mm^2 (p = 0,0000000002). Mean improvement of AHI was 9 ± 6,2 (p = 0,00006). In three cases patients had tracheostomy prior to operation and none of them required tracheostomy after the operation.

Conclusions: The use of distraction osteogenesis of the middle segment of the face combined with Le Fort III osteotomy results in dilation of the upper respiratory tract at the nasopharyngeal level and at the soft palate level resulting in elimination of sleep and respiration disorders. Further studies with polysomnography are necessary, as well as observation of patients over time and monitoring of treatment stability.

1. Introduction

In cases such as Crouzon syndrome, Apert syndrome or Pfeiffer syndrome, where craniosynostosis combines with hypoplasia of the middle segment of the face, major symptoms include respiratory, visual, facial and occlusal disturbances associated with poor facial aesthetics. As a result patients often develop psychological and emotional problems. What is more, in approximately 50% of patients(Bannink et al., 2010), the syndrome of apnoea develops and surgical intervention is necessary.

Patients affected by sleep apnoea associated with congenital defects of the facial skeleton usually require multispecialty treatment and use of specific methods(Kakitsuba et al., 1994) These may include non-surgical options, such as a system of oxygen administration at night, as well as surgical procedures, such as tonsillectomy, adenoidectomy or tracheostomy, performed in 17–50% cases(Corbett et al., 2007).

Le Fort III osteotomy with distraction osteogenesis is a well-known therapeutic method used to treat children with respiratory disturbances caused by narrowing of the upper respiratory tract(Flores et al., 2009). There are many advantages of this treatment method: it gives stable results, the surgery time is shorter than using other methods, intraoperative blood loss is reduced, it eliminates the need to use bone grafts and allows the midface to advance to a greater extent. It is associated with gradual overcoming of natural resistance of soft tissues as a result of stretching

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https://doi.org/10.1016/j.jcms.2020.06.007
1010-5182/

and adapting to new conditions(Engel et al., 2019; Shetye et al., 2010). In addition, during treatment, deformations of the facial skeleton are reduced and the nasopharynx is simultaneously unblocked(Flores et al., 2009). Unlike in adults, symptoms of sleep apnoea are less pronounced in children and therefore diagnosis is more difficult. When left untreated, sleep apnoea in children may lead to chronic fatigue, nutritional problems, recurrent infections, impaired cognitive functioning, pulmonary heart disease and sudden death(Laya and Lee, 2012).

It has been confirmed that frequent changes in blood oxygenation levels, blood pressure and reduced blood flow through the cerebral blood vessels cause visual disturbances. What is more, exposure of the conjunctiva, common in patients with hypoplasia of the midface, may result in dry eyeball and is consequently associated with possible conjunctival ulcers, cataract or vision loss (Grover, 2010).

The best moment for the surgery depends on the patient's condition and severity of disorders(Klammert et al., 2009) Indications for early osteodistraction include respiratory difficulties and severe exophthalmos(Caterson et al., 2013). If disorders are not severe and there are no urgent indications, the procedure should be performed when the molars have already erupted(Santiago et al., 2005). If possible ENT surgery should be considered prior to facial advancement in order to delay the osteodistraction procedure (Khonsari et al., 2020).

The paper aims to present a three-dimensional (3D) analysis of changes in the surface and volume of the upper respiratory tract and analysis of changes of sleep quality in eighteen patients treated with Le Fort III distraction osteogenesis.

2. Material and methods

This study was approved by the Medical University of Lodz medical ethics review committee (RNN/414/14/KB). The guidelines as stated in the Declaration of Helsinki were followed.

The criteria for inclusion were: syndrome affecting the midface skeleton, dysgenesis of the maxillofacial region and obstructive sleep apnoea syndrome. The criteria for exclusion were non-syndromic midface hypoplasia and lack of appropriate medical documentation. All participants provided informed written consent.

Lateral cephalograms and computerised tomography (CT) scan of the skull and facial skeleton were performed and analysed a month before the surgery and 8 weeks after the end of distraction osteogenesis.

The anatomic bone points A, B, basion (Ba), sella (S), nasion (N), posterior nasal spine (PNS) and anterior nasal spine (ANS) were identified on X-ray scans (Fig. 1). Point A is defined as the most deeply positioned point on the curvature between the anterior nasal spine and the maxillary alveolar process(R. Ricketts, 1961), point B is defined as the most posterior point in the concavity between the chin and the mandibular alveolar processes(R. Ricketts, 1961). Point Ba is the midpoint on the anterior margin of the foramen magnum(Steiner, 1959). The S point refers to the middle of the sella(Downs, 1948), while the N point refers to the most anterior point on the nasocranial suture in the midline(Downs, 1948). The PNS point is positioned most posteriorly on the palatal bone(R. Ricketts, 1961), while the ANS point is positioned the most anteriorly on the maxilla on the plane of the palatal bone(Ludlow et al., 2009). Measurements of Ba-PNS, S-PNS and N-ANS were recorded in mm (Fig. 1), while the S-N-PNS and S-N-ANS angles were recorded in grades (Fig. 1).

CT scans were taken with GE Bright Speed Elite (GE Healthcare, Chicago, US) to conduct a 3D analysis of the upper respiratory tract with Dolphin Imaging software (Dolphin Imaging 11.7, Dolphin Imaging and Management Solutions, Chatsworth, USA) (Fig. 2). The axial plane going through the apex of the epiglottis was recognized as the lower border of the respiratory tract. Therefore, the respiratory tract was marked on CT scans above this plane, excluding ethmoid sinuses, and delineated with a tool available in the Dolphin software for sagittal, coronary and frontal planes. In all cases, the sensitivity of measurements was set at 70 on the Hounsfield scale and the software filled the air space automatically (Fig. 2). The images were then analysed scan by scan in all planes so that the aerated space in the upper respiratory tract was identified in all scans. The analysis was performed by two independent readers with experience in operating the software(Olszewski et al., 2018).

All patients underwent LeFort III osteotomy with positioning an external RED II distractor (KLS Martin, Tuttlingen, Germany). After the surgery distraction was performed with the following protocol: 3 days of latency, osteodistraction of 1 mm daily (it was continued for a varying period depending on the desired correction) and a stabilisation period of 8 weeks. After this period, the distractor was removed.

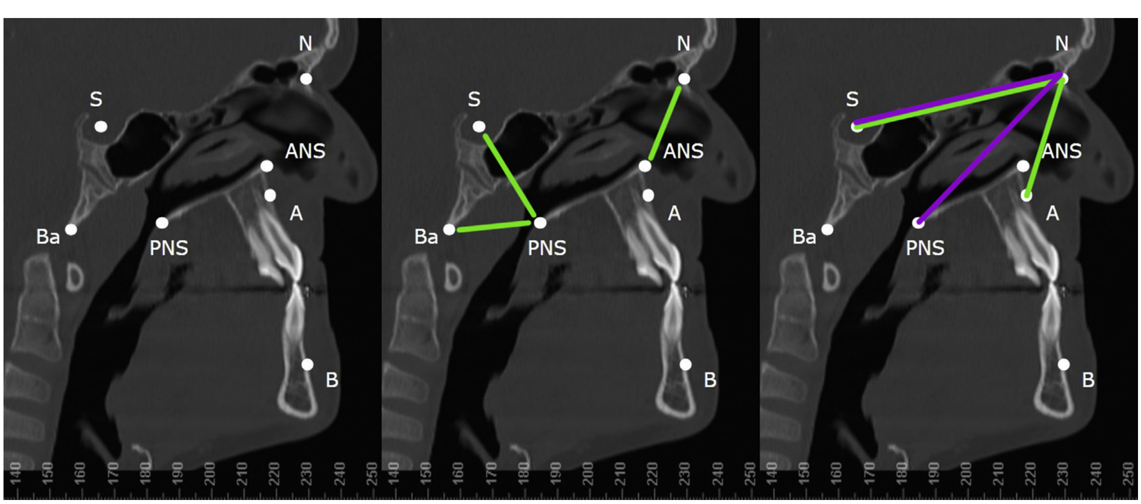

Fig. 1. Lateral cephalometry points used. Abbreviations: Ba-basion, S-sella, N-nasion, PNS-posterior nasal spine, ANS-anterior nasal spine, A-alveolar point A, B-alveolar point B. Distances measured: Ba-PNS (mm), S-PNS (mm), N-ANS (mm). Angles measured S-N-A and S-N-PNS.

Fig. 2. Measurements of the volume and surface of the upper respiratory tract, an arrow indicates sensitivity settings for respiratory tract imaging tests.

Polysomnography and a clinical examination were performed in combination with collection of the patient's medical history. Patients apnoea symptoms were measured the month before and 1 year postoperatively with polysomnography with the apnoea–hypopnea index (AHI) (Ettinger et al., 2011).

Statistical analysis was performed in Statistica 12 (Tulusa, USA). One-way analysis of variance (ANOVA) was applied to investigate the data of treated patients. Regression analysis was used to determine the relation between cephalometric measurements and airway volume and their relation to measured changes. The level of significance was established as $p < 0.05$.

3. Results

Results are shown in Tables 1–3. The sample comprised eighteen patients aged between 7 and 18 years. Changes in distances Ba-PNS (mm), S-PNS (mm), N-ANS (mm), angles S-N-A and S-N-PNS and also changes in the volume and surface of the upper respiratory tract were assessed.

ANOVA revealed that after the surgical procedure there was a statistically significant increase in: the airway volume and surface, the Ba-PNS distance, the N-ANS distance, the S-PNS distance, the S-N-A angle and the S-N-PNS angle (Table 2).

Linear regression analysis revealed no correlation between pre-osteotomy cephalometric measurements and airway volume, but the post-operational results showed a moderately strong relationship between increase of the Ba-PNS distance and the final post-operative airway volume (correlation coefficient = 0.78, $R^2 = 62\%$, $p = 0.03$). Increase of Ba-PNS distance also strongly affects observed differences of the airway volume (correlation coefficient = 0.90, $R^2 = 81\%$, $F = 29.85$, $p = 0.0006$). Moreover, analysis of changes in pre- and post-distraction measures revealed a relatively strong relationship between the increase in airway volume and the increase in S-PNS distance (correlation coefficient = 0.83, $R^2 = 69.5\%$, $F = 15.97$, $p = 0{,}002$).

The post-operative improvement in respiratory function was observed in all cases with $p = 0{,}00006$ (Table 3) Mean improvement of AHI was $9 \pm 6{,}2$. In three cases patients had tracheostomy prior to operation. None of the treated patients required tracheostomy after the operation. However, there was no correlation between change of airway volume and AHI.

4. Discussion

Advancement of the midface after LF III osteotomy with simultaneous bone grafts is possible in adults and is associated with limitations in the advancement of the midface up to 1 cm on average(Bachmayer et al., 1986; Guichard et al., 2013; Kaban et al., 1984; Marchac, 2000; Tessier, 1971). With distraction osteogenesis, it is possible to treat severe hypoplasia of the midface in younger patients who need early intervention due to severe symptoms of apnoea or exophthalmos (Shetye et al., 2013). In such cases, it is necessary to advance the midface by more than 2 cm (Nout et al., 2012, 2010). Based on specific points (S, N, PNS, ANS, A and Ba), angles (S-N-A) and linear measurements (N-ANS, S-PNS and Ba-PNS), it is possible to determine the required advancement and the effect of treatment on skeletal and upper respiratory tract (Bouw et al., 2015).

Fearon(Fearon, 2005) reported advancement of 26 mm on average (range 14–44 mm) in a group of 41 patients on whom distraction osteogenesis was performed. The S-N-A angle changed from 70° to 87° and the vertical change of the A point was 7 mm. Moreover, 12 patients were examined with polysomnography before and after treatment and improvement was observed in four of them. In addition, tracheostomy was removed in four of them.

Flores et al.(Flores et al., 2009) reported anteroposterior changes in the palatopharyngeal distance from 2 to 5.9 mm and of the

Table 1
Patients and values measured.

PATIENT	AGE	SYNDROME	S-N-A PRE (DEG)	S-N- PNS PRE (DEG)	S-PNS PRE (MM)	N-ANS PRE (MM)	Ba-PNS PRE (MM)	AIRWAY AREA PRE (MM^2)	AIRWAY VOLUME PRE (CM^3)	S-N-A POST (DEG)	S-N-PNS POST (DEG)	S-PNS POST (MM)	N-ANS POST (MM)	Ba-PNS POST (MM)	AIRWAY AREA POST (MM^2)	AIRWAY VOLUME POST (CM^3)	AHI PRE-OP	AHI 1 YEAR POST OP
1	7	Crouzon	67,7	38,2	30,7	31,3	24,0	1174,7	19,8	88,0	43,2	45,1	42,1	39,9	1578,2	44,5	10	9
2	10	Apert	65,1	30,0	38,5	42,6	36,9	1200,0	34,7	25,0	32,8	40,5	44,1	40,4	1375,0	29,8	16	10
3	10	Crouzon	77,1	41,8	32,7	37,1	20,4	711,0	19,5	85,2	45,7	46,7	44,8	32,9	2035,0	37,2	28	11
4	11	achondroplasia	84,3	39,0	44,0	29,3	32,1	1074,4	22,6	89,0	50,6	51,9	47,7	39,5	1371,7	32,0	Tracheostomy	44
5	12	Hypoplasia	66,6	16,4	44,0	38,5	43,2	1537,1	32,1	88,5	41,0	44,5	48,4	48,3	1669,6	41,0	21	12
6	12	Crouzon	82,7	28,8	23,3	38,5	25,5	927,0	20,9	75,6	75,6	33,7	54,7	40,2	1360,0	32,8	12	6
7	13	Hypoplasia	63,9	28,4	24,6	22,0	21,0	313,4	23,2	82,0	54,6	52,0	52,5	37,7	1177,0	50,9	Tracheostomy	23
8	13	Apert	72,8	44,1	39,1	38,5	32,1	1009,0	30,9	72,1	41,2	47,2	51,6	34,2	1311,0	42,2	24	11
9	13	Pfeifer	75,8	37,5	34,8	40,1	25,1	1742,2	45,1	95,9	35,1	44,3	61,7	39,8	2333,3	52,2	Tracheostomy	32
10	14	Apert	60,4	24,7	33,8	27,7	26,6	1743,1	43,6	83,3	44,0	46,6	43,4	39,7	3526,0	70,7	18	13
11	14	Rubinstein Taybi	61,0	35,1	43,9	36,5	40,5	1020,5	26,2	95,7	48,6	55,1	45,5	46,0	1259,5	35,8	45	34
12	14	Apert	70,7	57,1	41,0	41,3	28,3	1158,5	33,8	92,0	59,3	63,0	51,2	60,0	1313,0	34,7	21	12
13	14	Pfeifer	80,9	34,6	35,7	49,2	20,7	1136,2	27,9	86,0	44,4	49,1	42,1	40,5	2593,6	56,1	23	15
14	16	Apert	56,3	25,0	37,6	36,3	41,5	1152,3	33,4	90,3	39,0	38,9	32,0	46,2	1390,0	35,5	3	3
15	17	Apert	64,9	32,0	37,0	45,9	33,0	1520,0	38,7	75,0	37,5	49,0	43,0	44,3	2206,0	71,3	17	6
16	17	Crouzon	67,8	32,4	36,6	40,0	38,0	1596,0	42,5	68,0	35,0	38,0	42,0	40,0	1625,0	43,2	3	1
17	18	Crouzon	66,8	40,3	40,0	39,8	18,1	1777,8	41,9	95,7	39,3	46,1	48,0	33,8	2466,0	49,6	34	20
18	19	Apert	78,6	37,3	43,2	35,2	29,3	689,0	36,2	97,1	47,1	55,7	46,7	45,1	1964,0	36,8	35	12
MEAN VALUES	**13,6**		**70,2**	**34,6**	**36,7**	**37,2**	**29,8**	**1193,5**	**34,0**	**82,5**	**45,2**	**47,1**	**46,8**	**41,6**	**1808,6**	**42,1**	20,7	15,2

Table 2
Changes in individual patients.

PATIENT	SYNDROME	AIRWAY VOLUME CHANGE (CM^3)	AIRWAY AREA CHANGE (MM^2)	S-N-A CHANGE (DEG)	S-N-PNS CHANGE (DEG)	S-PNS CHANGE (MM)	N-ANS CHANGE (MM)	Ba-PNS CHANGE (MM)
1	Crouzon	24,7	403,5	20,3	5,0	14,4	10,8	15,9
2	Apert	−4,9	175,0	−40,1	2,8	2,0	1,5	3,5
3	Crouzon	17,7	1324,0	8,1	3,9	14,0	7,7	12,5
4	achondroplasia	9,4	297,3	4,7	11,6	7,9	18,4	7,4
5	Hypoplasia	8,8	132,5	21,9	24,6	0,5	9,9	5,1
6	Crouzon	12,0	433,0	−7,1	46,8	10,4	16,2	14,7
7	Hypoplasia	27,7	863,6	18,1	26,2	27,4	30,5	16,7
8	Apert	11,3	302,0	−0,7	−2,9	8,1	13,1	2,1
9	Pfeifer	7,1	591,1	20,1	−2,4	9,5	21,6	14,7
10	Apert	27,1	1782,9	22,9	19,3	12,8	15,7	13,1
11	Rubinstein Taybi	9,6	239,0	34,7	13,5	11,2	9,0	5,5
12	Apert	1,0	154,5	21,3	2,2	22,0	9,9	31,7
13	Pfeifer	28,2	1457,4	5,1	9,8	13,4	−7,1	19,8
14	Apert	2,1	237,7	34,0	14,0	1,3	−4,3	4,7
15	Apert	32,6	686,0	10,1	5,5	12,0	−2,9	11,3
16	Crouzon	0,7	29,0	0,2	2,6	1,4	2,0	2,0
17	Crouzon	7,7	688,2	28,9	−1,0	6,1	8,2	15,7
18	Apert	0,6	1275,0	18,5	9,8	12,5	11,5	15,8
MEAN VALUES		12,41 ± 11,33	615,09 ± 521,71	12,28 ± 17,66	10,63 ± 12,44	10,38 ± 7,02	9,54 ± 9,44	11,79 ± 7,53
p value		0,0000001	0,0001	0,009	0,002	0,000008	0,0005	0,000004

Table 3
Polysomnography results of individual patients measured preoperatively and 1 year post operation. Values are shown in AHI - Apnoea Hypopnea Index, showing a mean number of incidents per hour of sleep. In three cases patients had tracheostomy prior to operation. None of treated patients required tracheostomy after operation.

PATIENT	AHI PRE-OP	AHI 1 YEAR POST OP	DIFFERENCE
1	10	9	1
2	16	10	6
3	28	11	17
4	Tracheostomy	44	-
5	21	12	9
6	12	6	6
7	Tracheostomy	23	-
8	24	11	13
9	Tracheostomy	32	-
10	18	13	5
11	45	34	11
12	21	12	9
13	23	15	8
14	3	3	0
15	17	6	11
16	3	1	2
17	34	20	14
18	35	12	23
MEAN VALUES	20,7 ± 13,2	15,2 ± 11,4	9,0 ± 6,2

nasopharyngeal distance from 3.9 to 13.0 mm. Tests were conducted on 3D CT scans of the upper respiratory tract. The study group included 20 patients, with 10 diagnosed with significant airway compromise. Improvement and reduction in the symptoms of apnoea were observed in 9 patients, and even one of the two patients with a preoperative tracheostomy was decannulated successfully after distraction.

Lauritzen(Lauritzen et al., 1986) described a group of three patients with syndromic craniosynostoses in whom decannulation after advancement of the midface ended with a failure. In two of those patients the advancement was only 10 mm and 8 mm, respectively. However, the mean advancement was 16 mm, which suggests that it is necessary to obtain larger advancement to attain improved respiration.

Ettinger et al.(Ettinger et al., 2011) showed a group of 14 patients with the preoperative AHI value >5. Improvement was observed in 10 patients and symptoms of apnoea regressed in 9 patients; no improvement was observed in 4 patients. According to the authors, the angle of movement may be more significant than linear advancement itself. In patients undergoing LeFort III distraction due to the obstructive sleep apnoea it is necessary to increase the S-N-A angle above 12° and advance the middle segment of the face. However, due to the individual structure of the cranial base and facial structures, it is not possible to plan a distraction only on dilation of the upper respiratory tract with no regard to facial aesthetics(Ettinger et al., 2011).

Nout et al.(Nout et al., 2010) found no distinct relationship between advancement and airway volume changes. From CT data they segmented the upper respiratory tract, which was divided into two parts: Compartment A-containing the hypopharynx and oropharynx and Compartment B - containing the nasopharynx and nasal cavity. Compartment A was enlarged by 20 ± 39,5% on average, whereas Compartment B was enlarged by 48 ± 28%. The total volume of the respiratory tract increased by 37 ± 20,7% on average. The mean anterior advancement of the midface was 13,2 ± 4,7 mm and the angle was 12,4 ± 5,4°. The mean downward advancement was 6,7 ± 4,6 mm. However, observed relations between advancement and volume increase of the upper respiratory tract were not statistically significant.

Our results (Tables 2 and 3) can be compared to those of Ettinger et al. (2011) and Nout et al. (2010). Apart from the clinical effects associated with increased respiratory volume, the following changes were observed: increase of Ba-PNS, N-ANS and S-PNS distances. There was a correlation between increase of volume of the upper respiratory tract and the Ba-PNS distance increase. Greater change in the Ba-PNS distance compared to a smaller change in the N-ANS distance indicates greater movement of the posterior part compared to the anterior part, meaning dropping of the posterior part of the maxilla. These elements allow the volume of the upper respiratory tract to increase, therefore it can be concluded that posterior advancement is more effective than anterior advancement and it may significantly reduce obstruction of the upper respiratory tract.

It is also visible in changes of the S-N-A and S-N-PNS angles, where S-N-A has a smaller increase (17%) compared to the S-N-PNS angle (24%). As can be seen on a chart (Fig. 3) presenting a relationship between a change in the volume of the upper respiratory tract and the S-N-A angle, a significant increase is visible when an

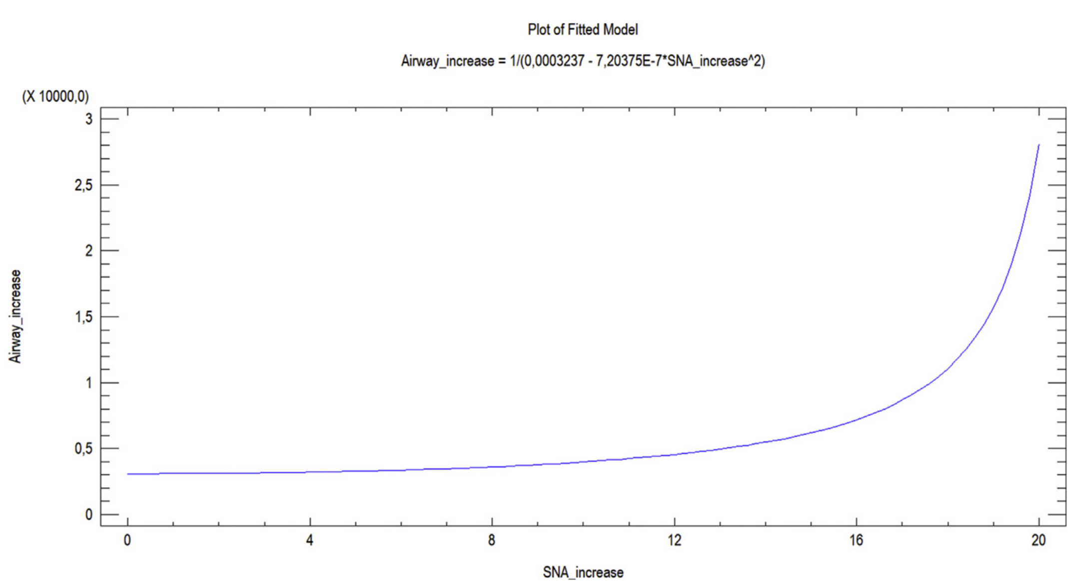

Fig. 3. Change in the S-N-A angle and volume of the upper respiratory tract.

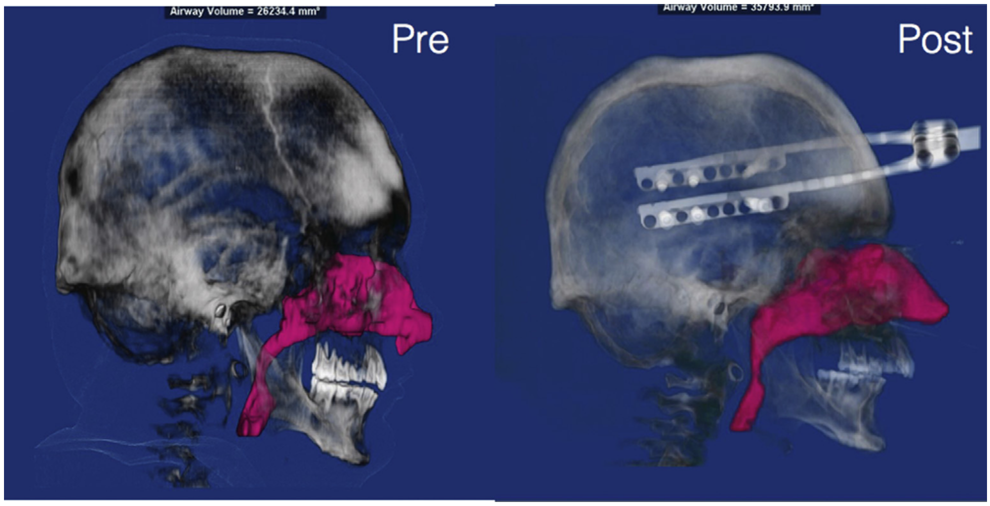

Fig. 4. The patient IM before and after osteodistraction.

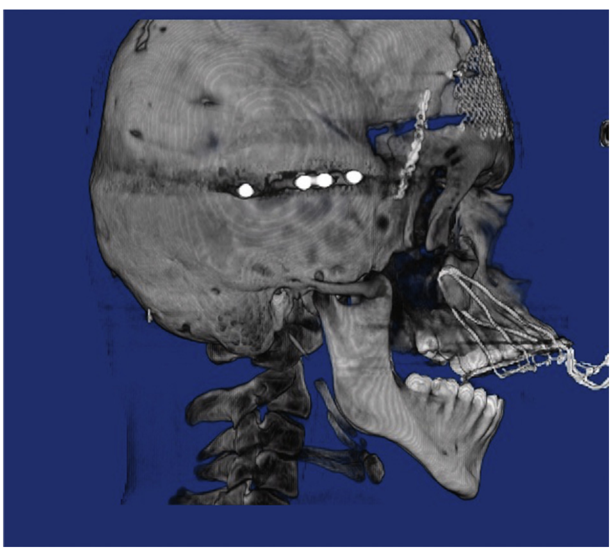

Fig. 5. Unfavourable advancement of the midface. Patient 13.

S-N-A increase greater than 12° is achieved. The S-N-A angle describes advancement of the facial skeleton anteriorly and this change should be proportional to N-ANS change. In our study the N-ANS advancement is 21% average, whereas the mean change of the S-N-A Angle is 17%. The S-N-PNS angle is more useful for describing enlargement of the posterior nasopharyngeal cavity associated with the increased S-PNS distance. The results obtained indicate that as the angle increases, the volume of the upper respiratory tract grows too. However, it is also associated with the dropping of the posterior part of the maxilla which indicates uneven translation of the midface resulting in the occlusal opening. Increase in the Ba-PNS measurement is not associated with similar enlargement of the volume of the upper respiratory tract, as was confirmed by other authors(Ettinger et al., 2011; Nout et al., 2012, 2010). In this study, all patients were treated from sleep disorders and there was a relationship between the increased volume of the upper respiratory tract and an increase in the S-N-A angle (Fig. 3), along with changes in the Ba-PNS and S-PNS distances. It can certainly be concluded that the changes presented affect the volume of the upper respiratory tract and help to achieve good clinical outcomes, however it is not possible to conclude that a change in the angles and distances is directly proportional to changes in the surface and volume. To identify a direct relationship, it would be necessary to study a larger group and combine outcomes with functional tests.

As presented by Ettinger et al. (2011), a completely disturbed structure of the cranial base and, associated with it, insufficient angular advancement may be the reasons for the varying results of increased volume of the upper respiratory tract for different patients. Table 2 presents gathered results for each individual in the measured parameters, such as the increased volume of the upper respiratory tract. Typical results are shown in Fig. 4. In patient 13, there was the largest advancement of the Ba-PNS distance combined with quite a large change in the S-N-A angle and reduction in the N-ANS distance; the volume changed by 28.1 cm^3. From a clinical perspective, we know that in this patient there was unfavourable advancement of the midface and large rotation associated with an abnormal vector of osteodistraction. This is an excellent example of changes associated with LF III distraction and its effects on angles and distances (Fig. 5). It should be pointed out that a small increase in the Ba-PNS distance due to distraction results in a considerable widening of the upper airway ($p < 0.001$) as can be seen in patient 11, where change in the volume of the upper respiratory tract, by 9,55 cm^3, was achieved with the advancement of the Ba-PNS distance just at 5.5 mm. This is the best evidence for the effectiveness of Le Fort III distractive osteogenesis, which influences not only the midface, but also mandible advancement in children.

Respiration and symptoms of sleep apnoea improved in all treated patients, although there was no correlation between change of airway volume and AHI. Not only is relief of the symptoms of apnoea and respiratory disturbances associated with anteroposterior enlargement of the respiratory tract, but also it is known that an appropriate shape and unblocked airflow through the upper respiratory tract is of utmost significance. According to articles by Nout et al.(Nout et al., 2012, 2010), unblocking the upper respiratory tract may be more important than its absolute enlargement.

5. Conclusion

Distraction osteogenesis of the middle segment of the face combined with subcranial Le Fort III osteotomy results in dilation of the upper respiratory tract at the nasopharyngeal level and at the soft palate level. The S-PNS distance extended surgically is directly proportional to the increased volume of the upper respiratory tract. There is a relationship between the increased volume of the upper respiratory tract and an increase in the S-N-A angle especially if the S-N-A increase is greater than 12°. With Le Fort III distraction osteogenesis, it is possible to achieve significant unblocking of the upper respiratory tract.

Further studies with polysomnography are necessary, as well as observation of patients over time and monitoring of treatment stability and the consequences associated with growth of the facial skeleton.

Declaration of Competing Interest

Authors declare that there is no conflict of interest.

Compliance with ethical standards

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

All procedures performed in studies involving human participants were in accordance with the ethical standards of Medical University of Lodz medical ethics review committee (RNN/414/14/KB) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent was obtained from all individual participants included in the study.

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