European Archives of Oto-Rhino-Laryngology (2019) 276:1065–1073
https://doi.org/10.1007/s00405-018-05277-5

RHINOLOGY

Impact of Le-Fort I osteotomy on anatomical and functional aspects of the nasal airway and on quality of life

Karim Zaoui[1] · Reinald Kuehle[2] · Ingo Baumann[1] · Dorothee Laura Schuessler[3] · Oliver Ristow[2] · Michaela Plath[1] · Christian Freudlsperger[2]

Received: 25 October 2018 / Accepted: 29 December 2018 / Published online: 14 January 2019

Abstract

Objectives Orthognathic surgery is a well-established procedure for skeletal deformities. Beneficial influences to the posterior airway space (PAS) have been described, but little is known about the subjective aesthetical and functional nasal aspects after orthognathic surgery. The aim of this study was to evaluate nasal airflow by anterior rhinomanometry and volumetric changes in the nasal airway space after mono- or bimaxillary surgery using cone-beam computed tomography (CBCT) and a new segmentation software. Furthermore, changes of patient's quality of life (QoL) should be assessed.

Methods Ten patients (9 skeletal class malformation III, 1 skeletal class malformation I) were included. CBCT images, rhinological inspections and anterior rhinomanometries were performed before (T0) and after surgery (T1). All patients completed the FROI-17, the ROE and the SF-36 questionnaires.

Results A significant postoperative gain for nasal airway volume compared with the baseline was shown ($p<0.014$). No statistically significant differences between pre- and postoperative flow rates were found ($p=0.114$). Pre- and postoperative cohorts did not differ in responses of disease-specific (ROE and FROI-17) and generic QoL questionnaires (SF-36).

Conclusion Maxillary relocation surgery leads to a significant increase in nasal airway space. Subjectively, orthognathic patients did not experience any functional but psychosocial aspects after bimaxillary surgery.

Keywords Le Fort-I-osteotomy · Nasal airway space · Orthognathic surgery · Rhinomanometry · Quality of life

Introduction

Since its' first description, the Le-Fort I maxillary osteotomy, has been well-established, and is used as an operation on its own or as a part of bimaxillary surgery. Relocation of the maxilla causes significant changes to the midfacial anatomy. Relevant literature addresses effects on nasal breathing, nasal anatomy and sinus drainage in patients undergoing orthognathic surgery only in a subjective way, and to a limited extend [1–4]. Maxillary movement always affects nasal breathing post-operatively, by changing the intranasal dimensions. Furthermore, common nasal airway deformities (septal deviation, inferior turbinate enlargement) are often concomitant with maxillary deformity. Since the introduction of the 'down-fracture' technique as a standard method in orthognathic surgery, numerous studies have measured nasal airway resistance before and after Le Fort I osteotomy. First operative displacements of the maxilla were originally described by Wassmund and Axhausen [5], although this was only established as standard procedure after modification of the downfracture method in 1977. To date, only a few studies have attempted to explore the effect of bimaxillary surgery on the pharyngeal airway space (PAS) in class III malocclusions [6]. Harada et al. found increases in both nasopharyngeal depth and velar length after maxillary distraction osteogenesis (MDO) [7]. The distraction procedure not only changes the volume of bone

Michaela Plath, Reinald Kuehle, Karim Zaoui and Christian Freudlsperger contributed equally to the paper.

✉ Michaela Plath
michaela.plath@med.uni-heidelberg.de

1 Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital Heidelberg, Ruprecht-Karls-University, Im Neuenheimer Feld 400, 69120 Heidelberg, Germany

2 Department of Oral and Maxillofacial Surgery, University Hospital Heidelberg, Heidelberg, Germany

3 Department of Restorative Dentistry, University Hospital Heidelberg, Heidelberg, Germany

tissue, but also modifies the surrounding structures such as nasal cavity (NC). Since the maxilla defines the caudal border of the nasal cavity, it can be assumed that relocation of it should result in measurable volumetric changes. There is little evidence as to whether efforts to improve occlusion and facial aesthetics always have a beneficial influence on patient's quality of life [8]. Health-related quality of life measurements (HRQoL) can be used to assess the quality and effectiveness of various treatment approaches [9]. The term "quality of life" is defined as "a person's sense of well-being that stems from satisfaction or dissatisfaction with the areas of life that are important to him/her" [10].

Studies have shown that the patients' interest focuses more on aesthetic results, rather than functional outcomes [9]; and patients' expectations can vary significantly from those of their surgeons' [11]. It is crucial to use a suitable and validated tool for measuring the functional as well as the aesthetic quality of life after mono- or bimaxillary surgery. Therefore, the Rhinoplasty Outcome Evaluation (ROE) and the Functional Rhinoplasty Outcome Inventory-17 (FROI-17) as disease-specific and validated instruments for measuring HRQoL after septorhinoplasty are suitable [12].

The aim of this single-center study was to directly compare subjective and objective means of measurement regarding anatomical and functional aspects of the nasal airway and quality of life after Le-Fort I osteotomy.

To our knowledge, this is the first prospective study evaluating nasal airflow and volumetric changes in the nasal airway space using CBCT and a novel segmentation software in patients with dysgnathic skeletal deformities after mono- or bimaxillary osteotomy without simultaneous rhinosurgical intervention, in combination with QoL measurement tools.

Materials and methods

The Ethics Committee of the Medical Faculty at the University of Heidelberg granted permission to conduct this study (project no S-533/2017) according to the Declaration of Helsinki on biomedical research involving human subjects. Informed consent was obtained from all patients. All patients were fully aware of the aims and protocol of the study.

Ten patients, aged between 18 and 31 years (mean age 23.6 ± 4.5 years), were included in this monocentric prospective study. All patients underwent orthognathic surgery at the Department of Oral and Maxillofacial Surgery, University of Heidelberg, Germany, between September 2015 and May 2016 for correction of Class I ($n = 1$) or Class III ($n = 9$) deformities. Treatment consisted of bimaxillary orthognathic surgery ($n = 8$) and maxillary relocation surgery ($n = 2$). Exclusion criteria were pre-existing mental illnesses, high-grade respiratory risks for anaesthesia, cardiovascular or infectious diseases, uncontrollable blood coagulation disorders or refusal to participate in the study.

After orthodontic shaping of maxillary and mandibular dental arches by multi-bracket appliances, the extent of the surgical procedure required to achieve an Angle Class I occlusion was planned on the basis of a model operation as well as clinical findings. All patients had dysgnathic deformities, which could not be treated by conventional orthodontic therapy. The active phase of the pre-surgical orthodontic treatment was completed at least 2 weeks prior to surgery and the status achieved was maintained with interlocked, passive, sufficiently sized arch wires (at least 0.016 × 0.22).

Standard preoperative examinations included a manual centric registration, a facebow to determine the maxillary position and the centric condylar position, a CBCT, photo documentation, 3D photoscan and dental impressions for the model operation.

One day before the operation, patients were hospitalized and consulted by ENT specialists. During this consultation, an anterior and a posterior rhinoscopy were performed. The oropharyngeal anatomies, as well as the palatine tonsil size were assessed according to Friedmann et al. [13, 14]. An anterior active rhinomanometry, to objectively assess nasal breathing, and a sniffing sticks test, to evaluate the sense of smell, were performed. General demographic and clinical information (age, gender, body mass index, allergies, and medication, medical and surgical history) were obtained from all study participants. As part of the full otolaryngological exam, which was always performed by one of the authors (M.P.), the patients were asked to complete questionnaires including two disease-specific (FROI-17 and ROE), and one generic questionnaires (SF-36). A follow-up took place 8.3 ± 5.0 months post-operatively. Further CBCT image data acquisition was conducted 16.2 ± 5.0 months after surgery to confirm bone consolidation, and to schedule the surgery for removal of the osteosynthesis material.

To objectively quantify nasal airway resistance, the nasal airflow of each patient was assessed using anterior active mask rhinomanometry (ATMOS 2000; Medizintechnik GmbH, Lenzkirch, Germany). Rhinomanometry is a well-established and reliable technique that measures nasal patency in terms of nasal airflow and resistance to airflow. The pressure-flow relationship detected during respiration reflects the functional status of the nasal airway. According to the proposals of the 'International committee on standardization of rhinomanometry' we used the flow measurements at $\Delta p = 150$ because at this pressure difference there is a laminar airflow during inspiration [15].

Nasal flow rates were calculated from the pre- and post-surgical rhinomanometric measurements of the whole nose (including left and right side). Mean nasal flow rates before and after decongestion were not included, as the focal points of this study were anatomical and functional changes of nasal airway space attributed to the osseous, and not to the mucosal changes after Le Fort I maxillary osteotomy. Mean nasal airflows classified as follows: no nasal obstruction (> 800 ml/s), mild nasal obstruction (500–800 ml/s), moderate nasal obstruction (300–500 ml/s), severe nasal obstruction (100–300 ml/s) and total nasal obstruction (100 ml/s) [16].

The operation was carried out under general anesthesia and the maxillary Le-Fort I osteotomy conducted in the predescribed, standardized way. The position of the maxilla was defined by splints, which had been previously manufactured during the model operation. Osteosynthesis was performed using Medartis Modus 1.5 Orthognatics plates and, when required, the lower jaw was relocated by the use of a sagittal split osteotomy, as described by Obwegeser et al., modified by Hunsuck et al. [17]. All orthognathic surgery was performed by one of the authors (C.F.). Intermaxillary immobilization was maintained for 3–5 days using strong elastics, and for 2–4 weeks using soft elastics. Orthodontic treatment was resumed 6 weeks postoperatively at the earliest. To verify the surgical success and correct positioning of the osteosynthesis material, a further CBCT scan took place during the inpatient stay.

All CBCT images were obtained using GALILEOS Comfort (Sirona, Bensheim, Germany), which features a high-frequency X-ray source with a constant potential (98 kV at 3e8 mA pulsed operation), and a cone-beam profile. The scanning time was set to 14 s with an isotopic voxel size of 0.25 mm to ensure a reasonable degree of resolution. Images were captured by full-circle rotation. A spherical volume of 15.4 cm was recorded to include the entire craniofacial anatomy. To enhance comparability all data acquisition followed a standardized routine protocol: during the scan, patients were standing upright with the head positioned along the Frankfurt horizontal plane (defined by the inferior borders of the bony orbits and the upper margin of the auditory meatus), and further stabilized by a head and chin support. All patients were instructed to keep their mouths closed with habitual tooth contact, leaving the lips and tongue in a resting position. Patients were instructed not to swallow and not to move their head or tongue.

All anonymized DICOM (Digital Imaging and Communications in Medicine)-datasets were visualized and analyzed for volumetric measurements and changes of the nasal airway space (NAS) by one of the authors using Sicat Air® (Sicat GmbH & Co. KG, Bonn, Germany).

The evaluation of the NAS volume, consisting of nasal cavity and nasopharyngeal airway space (NPAS), was conducted using the CBCT acquired preoperatively and immediately before removal of the osteosynthesis post-operatively. DICOM-datasets were oriented based on the following reference planes usingSicat Air® software: Frankfurt horizontal plane, midsagittal plane and coronal plane.

To determine the volume of nasal space affected by movement of the maxilla, at least two reproducible points of orientation are required. To the best of our knowledge, there are no such marker points defined in the current literature. To define these marker points, CBCT scans were scanned for anatomical landmarks to set the volume analysed by automated segmentation in Sicat Air®. The dens of axis tip and the nasion in the mid-sagittal plane were found to be the most consistent points on the anterior cranial and posterior caudal border. The lateral borders were set as the most lateral part of the nasal cavity. These markers were used to define the cubic region of interest (ROI), which includes the space cranial to the maxillary base (Fig. 1). The complex anatomy

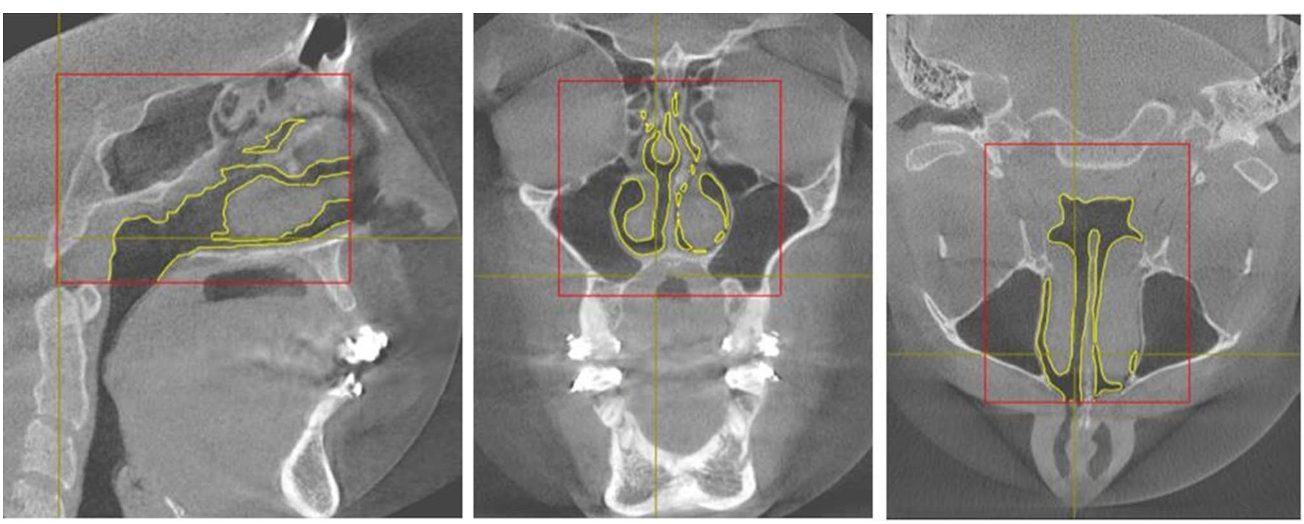

Fig. 1 CBCT Scans: Definition of the region of interest (ROI) as cubical volume from the most cranial point of the dens axis and nasion (shown in red). Only intranasal volumes are isolated and segmented (shown in yellow)

of the nasal cavity, with the occurrence of smaller spaces in the region of the conchae, called for additional manual identification of adherent volumes in all reconstructed slices. Using the software, volumes falsely counted as or left out of the NAS could be readily added or removed manually. Thereafter, the software's automatic algorithm for segmentation was applied, computing all air-filled areas within the ROI. These areas are clearly demarcated from bony- and soft-tissue structures, presenting a defined volumetric analysis of the airways. All NAS volumes were calculated in cubic millimetres, and 3D models of the airway in relation to bony- and soft-tissue structures were created (Figs. 2, 3).

The Rhinoplasty Outcome Evaluation (ROE) has been in use since 2001 and is a comprehensive questionnaire with a total of six items. Five of these six items focus on aesthetic issues of septorhinoplasty and one item assess functional outcomes. Each response is graded between zero (worst) and four (best). The sum of the scores is then converted into percentages, with a lower score indicating higher levels of dissatisfaction.

The second disease-specific questionnaire, the Functional Rhinoplasty Outcome Inventory-17 (FROI-17), detects more functional aspects than the ROE [18]. It includes 17 items, which are graded between zero [no impairment and five (worst possible)]. The overall score is then transformed to a 0–100% scale, by dividing the sum of the raw scores of the items by the sum of ranges of the items, followed by a multiplication by a factor of 100. A lower score indicates higher levels of satisfaction.

The SF-36 Health Survey consists of 36 items, grouped into eight aspects: physical functioning, role-functioning physical, bodily pain, general health, vitality, social functioning, role functioning, emotional, and mental health. Rules for item scoring and scales are available in the SF-36 scoring manual. Higher scores indicate a more positive rating [19].

The descriptive statistics are given as mean with standard deviations. The data were analysed using SPSS statistical software (version 22, SPSS Inc., Chicago, IL, USA). The volume measurements are expressed as the mean sum of all processed NAS volume analysis for all patients at T0 (pre-op) and T1 (post-op). Mean nasal flow rates by anterior rhinomanometry were also tested at T0 and T1. In addition to the descriptive statistics, the changes in airway parameters were compared using a paired *t* test, with 95% confidence intervals. The intergroup preoperative and post-operative comparisons of the FROI-17, ROE, and SF-36 scores were performed using a paired *t* test and one-way ANOVA analysis of variance. Associations between quality of life questionnaires were analysed using the Chi-square test. In all statistical tests, a p value of ≤ 0.05 was considered statistically significant.

Results

Le-Fort I procedures were conducted in ten patients (six women and four men). Of these, eight were carried out as part of bimaxillary relocation surgery. At the time of surgery, patients were on average 23.6 ± 4.5 years old, and had a mean body mass index of 25 (range 18–32). None of the patients had undergone previous surgery on the internal or external nose, although four had had a tonsillectomy, an adenoidectomy, or both before (Table 1).

All patients ($n = 10$) received a post-operative CBCT 2 days after surgery to confirm regular positioning of the

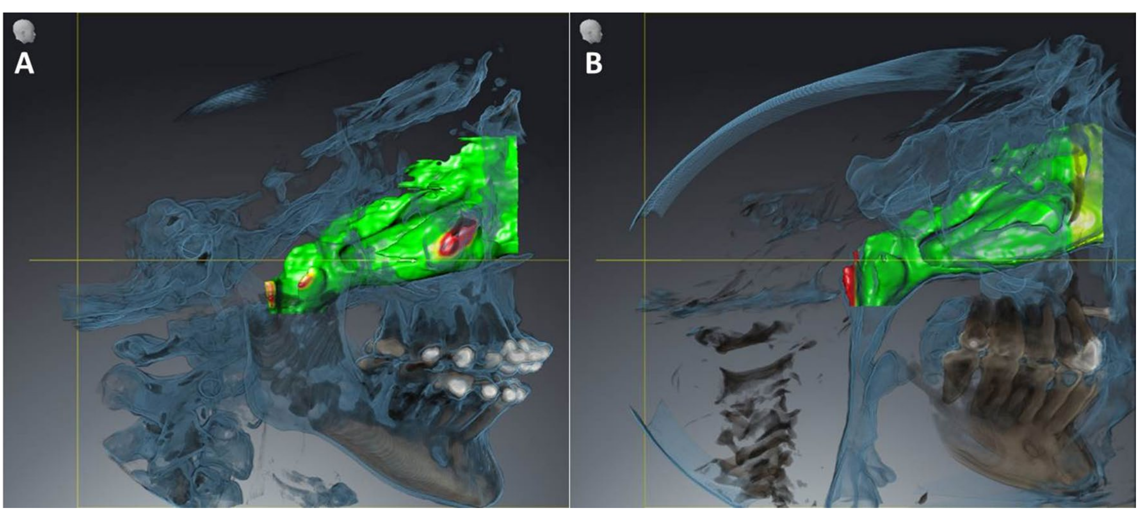

Fig. 2 **a** Three-dimensional reconstructions of the Nasal Airway Space preoperatively. Nasal airway space volume at T0: 18,672 mm^3. **b** Three-dimensional reconstructions of the nasal airway space post-operatively. Nasal airway space volume at T1: 20,950 mm^3

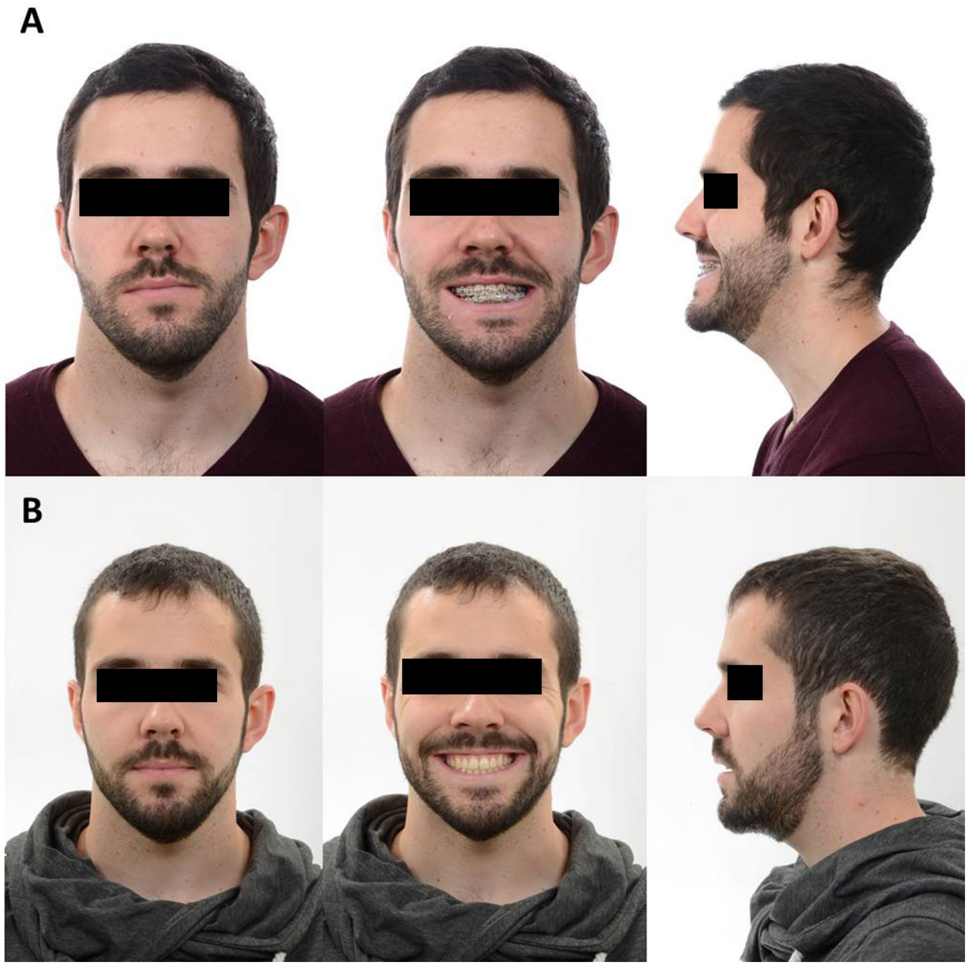

Fig. 3 Photo documentation. Frontal views in repose, frontal views with a smile and profile views before (**a**) and after treatment (**b**)

osteosynthesis material. No major complications, such as infection or dislocation of the osteosynthesis plates were observed. Patients were dismissed 3–4 days after the operation, and orthodontic treatment was reinitiated 4–6 weeks after surgery. Removal of the osteosynthesis plates was scheduled 8–14 months after primary surgery (Figs. 4, 5).

Before the orthognathic surgery nine patients classified their nasal breathing as good; one patient declared his nasal function as bad. All patients had documented septal deviation and inferior turbinate enlargement before operation. After orthognathic surgery, three patients claimed that their nasal patency had decreased, whilst seven patients reported no change. Endoscopically, there were fewer septal deviations (10 pre-op./5 post-op.) and one septal perforation (10%). There was no olfactometric effect, as assessed by sniffing sticks (scores of 12.9 (range 10–16) pre-op. and 12.7 (range 8–16) postop.). The mean nasal airflow increased by 22% from 402.73 ml/s (range 115–1091) to 493.13 ml/s (range 196–847), corresponding to moderate nasal obstruction (reference: 300–500 ml/s). No statistically significant difference between pre- and postoperative flow rates was found ($p = 0.114$).

The nasal airway space was 17022.5 ± 3912.9 mm^3 at T0, and 19609.6 ± 3912.9 mm^3 at T1. The mean volume increase of 2587.1 ± 2841.2 mm^3 was statistically significant (paired t test $p = 0.015$). There was no significant association between nasal airway space volume and the rhinomanometric measurement post-operatively (Chi-square $p = 0.236$).

The QoL assessment response rate 8.3 ± 5.0 months after surgery was 100%. Compared with preoperative results, all scales of FROI-17 (overall score, nasal symptoms, general symptoms and self-confidence), and the ROE overall score, showed no significant improvements 8 months after surgery. The same result was found for all scales of SF-36 in which one higher scores indicate higher levels of satisfaction.

However, when comparing the SF-36 results after orthognathic surgery to a normal control population ($n = 2914$), we found a statistically significant improvement in physical functioning (normal: 83.6, pre-op.: 96.0, post-op.: 97.0; one-way ANOVA, $p = 0.053$); a significant increase in the bodily pain score (normal: 77.0, pre-op.: 92.2, post-op.: 96.7; one-way ANOVA, $p = 0.023$); and a significant decrease in the social functioning sub score (normal: 87.7, pre-op.: 52.5, post-op.: 46.3; one-way ANOVA, $p < 0.001$) (Table 2).

Table 1 Surgical and clinico-pathological characteristics of the study population

Characteristics	Entire cohort ($n = 10$)
Age	23.6 (18–31)
Gender	
Male	6 (60%)
Female	4 (40%)
Angle classification	
Skeletal class I	1 (10%)
Skeletal class III	9 (90%)
BMI	25 (18–32)
Allergy	
No allergy	9 (90%)
Allergy	1 (10%)
Previous surgeries	
State after tonsillectomy (TE)	1 (10%)
State after adenoidectomy (AT)	1 (10%)
State after TE + AT	2 (20%)
No operation	6 (60%)
Nose breathing	
Nasal obstruction preoperative	1 (10%)
No nasal obstruction preoperative	9 (90%)
Nasal obstruction postoperative	3 (30%)
No nasal obstruction postoperative	7 (70%)
Clinical examination	
Tonsils hyperplasia (Friedmann score)	
Class 0	3 (30%)
Class I	5 (50%)
Class II	1 (10%)
Class III	1 (10%)
Class IV	0 (0%)
Epipharyngoscopy	
No adenoids	9 (90%)
Adenoids	1 (10%)
Nasoendoscopy preoperative	
Septum deviation right	5 (50%)
Septum deviation left	4 (40%)
Septum s-shaped	1 (10%)
Septum median	0 (0%)
Nasoendoscopy postoperative	
Septum deviation right	3 (30%)
Septum deviation left	0 (0%)
Septum s-shaped	2 (20%)
Septum median	5 (50%)
Diagnostic examination	
Olfactometry (sniffing sticks)	
Preoperative	12.9 (10–16)
Postoperative	12.7 (8–16)
Anterior rhinomanometry	
Both preoperative	402.73 (115–1091)
Both postoperative	493.13 (196–847)
Right preoperative	239.75 (61–650)
Right postoperative	272.82 (61–539)
Left preoperative	447.77 (50–3002)
Left postoperative	232.82 (9–554)
Volume-computertomography	
Preoperative	17022.50 (11,346–24,880)
Postoperative	19609.6 (14,405–26,284)

Discussion

The aim of this study was to determine if maxillary relocation influences the volume and functional aspects of the nasal airway after mono- or bimaxillary surgery in patients with mostly class III malformations. Both objective (CBCT combined with new segmentation software, anterior rhinomanometry) and subjective (disease-specific and generic questionnaires) parameters were used to assess this.

The results presented here show a significant increase in nasal airway volume after surgery, whereas the mean total nasal airflow, measured by anterior rhinomanometry, remains nearly unchanged with a non-significant increase of 22%. Anterior rhinomanometry is a simple method for evaluating nasal airflow, and allows objective quantification of nasal airway resistance. Rhinoscopically, we found fewer septal deviations, but no subjective improvement of breathing, after the operation. Although the perception of nasal patency is relevant from a clinical point of view, the subjective assessment of nasal patency is not reliable [1]. The findings, described in this study, are confirmed by Erbe et al., who report that the mean nasal airflow measured by anterior rhinomanometry does not change after Le Fort-I-osteotomy [1], although Galbati et al. found improved respiratory function after orthodontic surgery [3].

Regarding the impact of bimaxillary surgery on the pharyngeal or posterior airway space, [20] the use of 3D radiologic evaluation facilitates a more precise understanding of the anatomy [21]. Lateral cephalometry is generally perceived as the gold standard for assessing the volume of the pharyngeal or posterior airway space (PAS). However, the complexity of the oropharyngeal cavity, and its oval shape, do not allow precise measurements on a two-dimensional image. So far, no imaging gold standard has been established for measurement of the NAS. Schulze et al. recommend 3D imaging by means of MRI (magnetic resonance imaging), CT (computed tomography) or the CBCT scans for detailed analysis of the upper airway and definition of the anatomical structures [22]. CBCT is frequently used in the preoperative setting and as a post-operative control standard because of its low radiation exposure, as well as its wide availability in maxillofacial units. Furthermore, this method also enables

Fig. 4 Photo documentation: Intraoral situation before (**a**) and 16 months after completion of treatment (**b**)

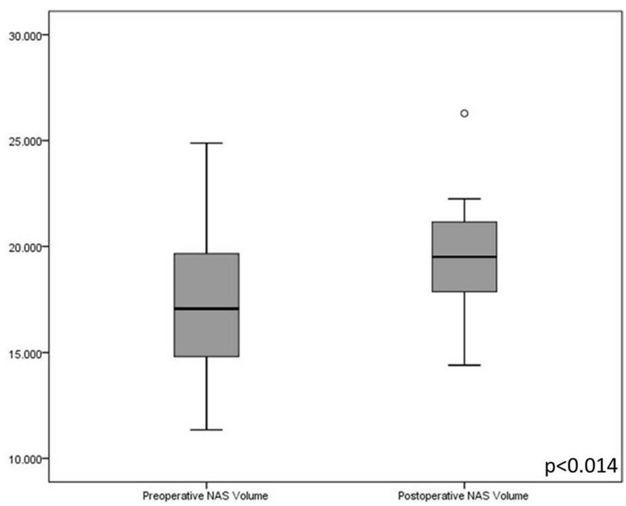

Fig. 5 NAS volume in cubic millimetres before and after the operation

Table 2 FROI-17, ROE, and SF-36 scales

	Preoperative cohort		Postoperative cohort		*p* value
	Mean	SD	Mean	SD	*p*
FROI-17					
Overall score	10.8	7.7	14.1	9.4	0.391
Nasal symptoms	12.7	8.3	17.7	13.3	0.327
General symptoms	9.3	7.2	11.8	8.9	0.498
Self-confidence	6	15.8	4	9.7	0.736
ROE	85.0	14.2	80.8	13.5	0.510
SF-36					
Physical functioning	96.0	8.1	97.0	5.4	0.749
Role-functioning physical	97.5	7.9	100.0	0.0	0.331
Bodily pain	92.2	11.8	96.7	5.4	0.292
General health	75.0	17.6	72.5	22.9	0.787
Vitality	62.0	16.2	61.5	18.9	0.950
Social functioning	52.5	7.9	46.3	6.0	0.062
Role-functioning emotional	96.7	10.5	100.0	0.0	0.331
Mental health	69.2	5.3	69.2	9.1	1.0

Higher scores of ROE and SF-36 indicate a more positive rating, whereas a lower score of FROI-17 indicates higher levels of satisfaction

precise display of bony structures, as well as clear determination of air compartments [20, 23]. Using volumetric pixels (Voxel) with a defined cubic size of 0.25 mm, results in reliable and consistent measurements. Accuracy of CBCT scans has been confirmed by Yamashina et al. (2008).

Use of the Sicat Air® software for the analysis of the PAS (posterior airway space) in orthognatic patients has already been demonstrated, and showed reliable measurements, in comparison to other segmentation programmes, such as iPlan ENT Brainlab [23]. The identification of air compartments in the CBCT scans was manually conducted, and the segmentation algorithms were able to identify most of the volumes. Small gaps localized in the cranial part of the nasal cavity or within the conchae, could not always be included in the analysis. This occurred with volumes with a voxel of size of approximately two. The authors find this occurrence negligible, due to its lack of influence on the relative changes before and after surgery. Given the currently available literature on CBCT and the use of the Sicat Air® software, the authors deem the method described above as a precise way for measuring air-filled compartments of the upper airway and especially the nasal airway space.

The measurement of HRQoL is increasingly gaining importance in assessing the outcome of surgery. Several questionnaires have been widely used to evaluate HRQoL after rhinoplastic interventions, commonly SF-36 as generic-, and FROI-17 and ROE as disease-specific questionnaires. The FROI-17 and ROE questionnaires are conclusive and valid for the specific evaluation of changes of QoL after septorhinoplasty [19, 24]. The Medical Outcomes Study short form 36 health survey (SF-36) is being increasingly used and recommended as a suitable measure of subjective health status. Despite existing weaknesses due to disregarded sleep variables and limited usability in comorbid patients over 65, the SF-36 is an excellent measure in our very young and apnea-free patients' cohort [25–29]. Several studies have shown improved post-operative FROI-17 and ROE scores after rhinoplasty [18, 19, 24, 30, 31]. In this study, patients who had undergone orthognathic surgery without simultaneous rhinosurgical treatment showed no significant increase in disease-specific QoL post-operatively as measured by FROI-17 and ROE. This could be due to differences in patient populations, since the patients in this study are a predominantly young and healthy collective with an average age of 23.6 ± 4.5 without symptomatic septal deviation and/or inferior turbinate enlargement. Regarding the generic SF-36 responses, the patients in this study showed significant improvement in "bodily pain" ($p = 0.023$) and "physical functioning" ($p = 0.053$) compared to the control population. Oral conditions (for example, severe malocclusion) can have a strong impact on patients' psychological, functional and social aspects which are referred to as oral health-related quality of life. Silvola and colleagues showed that treatment of severe malocclusion can improve oral health-related quality of life and reduce psychological discomfort and disability [31]. Dental aesthetics are firmly related to body image, self-esteem and self-concept [32, 33]. The significant decrease in social functioning 8 months after surgery in the findings reported here might be explained by patients being dissatisfied with the outcome after orthognathic surgery, resulting in social withdrawal. This is corroborated by Kiyak et al., who described a significant decline in self-concept values (for example, self-esteem, personal-, family- and social-self) 9 months after surgery [34]. MacGregor et al. reported that this psychological damage is created by cultural stereotyping by peers [35]. However, one can assume this to be only a temporary effect, as Flanary et al. found an improvement in patients' self-confidence by 72.1% and 77%, 1 and 2 years after orthognathic surgery respectively. Consequently, the results presented here support an influence of skeletal malformations on patient's quality of life.

Conclusion

This study evaluated form and function of the nasal airway before and after Le Fort I osteotomy, by use of CBCT, rhinoscopy, anterior rhinomanometry and disease-specific questionnaires. This is the first study to examine QoL using two disease-specific and one generic questionnaire in patients undergoing mono-/bimaxillary osteotomies in combination with objective pre- and post-surgical nasal airway measurements. To enhance comparability, accuracy and reliability of future studies, the authors highly recommend the combined use of standardized subjective evaluation methods, such as QoL questionnaires, and objective evaluation tools, such as volumetric CBCT and rhinomanometry.

Author contributions All authors made substantial contributions to the study and have approved the final article. MP: designed and coordinated the study, participated in data acquisition and analysis, interpreted the data and drafted the manuscript. RK: participated in data acquisition and analysis, coordinated the study and critically revised the manuscript for important intellectual content. IB: participated in data interpretation and revision of the manuscript. DLS: participated in data interpretation and revision of the manuscript. OR: participated in data interpretation and revision of the manuscript. KZ: designed and coordinated the study, participated in data acquisition and analysis, critically revised the manuscript for important intellectual content. CF: designed and coordinated the study, participated in data acquisition and analysis, interpreted the data, critically revised the manuscript for important intellectual content.

Funding No external/additional funding was received for this study.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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

Ethical approval The Ethics Committee of the Medical Faculty at the University of Heidelberg granted permission to conduct the study (project no S-533/2017).

References

1. Erbe M, Lehotay M, Gode U, Wigand ME, Neukam FW (2001) Nasal airway changes after Le Fort I—impaction and advancement: anatomical and functional findings. Int J Oral Maxillofac Surg 30(2):123–129
2. Guenthner TA, Sather AH, Kern EB (1984) The effect of Le Fort I maxillary impaction on nasal airway resistance. Am J Orthod 85(4):308–315

3. Galbiati G, Maspero C, Giannini L, Guenza GC, Zanoni F, Farronato G (2017) Orthodontic—surgical treatment and respiratory function: rhinomanometric assessment. Minerva Stomatol 66(3):91–97
4. Posnick JC, Agnihotri N (2010) Consequences and management of nasal airway obstruction in the dentofacial deformity patient. Curr Opin Otolaryngol Head Neck Surg 18(4):323–331
5. Haarmann S, Budihardja AS, Wolff KD, Wangerin K (2009) Changes in acoustic airway profiles and nasal airway resistance after Le Fort I osteotomy and functional rhinosurgery: a prospective study. Int J Oral Maxillofac Surg 38(4):321–325
6. Gokce SM, Gorgulu S, Karacayli U, Gokce HS, Battal B (2015) Three-dimensional evaluation of nasal and pharyngeal airway after Le Fort I maxillary distraction osteogenesis. Int J Oral Maxillofac Surg 44(4):455–461
7. Harada K, Ishii Y, Ishii M, Imaizumi H, Mibu M, Omura K (2002) Effect of maxillary distraction osteogenesis on velopharyngeal function: a pilot study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 93(5):538–543
8. Gokce SM, Gorgulu S, Gokce HS, Bengi O, Sabuncuoglu F, Ozgen F et al (2012) Changes in posterior airway space, pulmonary function and sleep quality, following bimaxillary orthognathic surgery. Int J Oral Maxillofac Surg 41(7):820–829
9. Rustemeyer J, Martin A, Gregersen J (2012) Changes in quality of life and their relation to cephalometric changes in orthognathic surgery patients. Angle Orthod 82(2):235–241
10. Becker M, Diamond R, Sainfort F (1993) A new patient focused index for measuring quality of life in persons with severe and persistent mental illness. Qual Life Res 2(4):239–251
11. Bulut OC, Plinkert PK, Wallner F, Baumann I (2016) Quality of life in functional rhinoplasty: rhinoplasty outcomes evaluation German version (ROE-D). Eur Arch Otorhinolaryngol 273(9):2569–2573
12. Bulut C, Wallner F, Plinkert PK, Baumann I (2014) Development and validation of the Functional Rhinoplasty Outcome Inventory 17 (FROI-17). Rhinology 52(4):315–319
13. Friedman M, Tanyeri H, La Rosa M, Landsberg R, Vaidyanathan K, Pieri S et al (1999) Clinical predictors of obstructive sleep apnea. Laryngoscope 109(12):1901–1907
14. Rodrigues MM, Dibbern RS, Goulart CW, Palma RA (2010) Correlation between the Friedman classification and the Apnea-Hypopnea Index in a population with OSAHS. Braz J Otorhinolaryngol 76(5):557–560
15. Clement PA (1984) Committee report on standardization of rhinomanometry. Rhinology 22(3):151–155
16. Vogt K, Sachse D, Wernecke KD, Kriesmer T (1990) [A computer-assisted system for diagnosing rhinologic function]. HNO 38(3):110–115
17. Bockmann R, Meyns J, Dik E, Kessler P (2014) The modifications of the sagittal ramus split osteotomy: a literature review. Plast Reconstr Surg Glob Open 2(12):e271
18. Bulut OC, Wallner F, Plinkert PK, Prochnow S, Kuhnt C, Baumann I (2015) Quality of life after septorhinoplasty measured with the Functional Rhinoplasty Outcome Inventory 17 (FROI-17). Rhinology 53(1):54–58
19. Bulut OC, Wallner F, Oladokun D, Kayser C, Plath M, Schulz E et al (2018) Long-term quality of life changes after primary septorhinoplasty. Qual Life Res 27(4):987–991
20. Kochel J, Meyer-Marcotty P, Sickel F, Lindorf H, Stellzig-Eisenhauer A (2013) Short-term pharyngeal airway changes after mandibular advancement surgery in adult Class II-Patients—a three-dimensional retrospective study. J Orofac Orthop 74(2):137–152
21. Lenza MG, Lenza MM, Dalstra M, Melsen B, Cattaneo PM (2010) An analysis of different approaches to the assessment of upper airway morphology: a CBCT study. Orthod Craniofac Res 13(2):96–105
22. Ghoneima A, Kula K (2013) Accuracy and reliability of cone-beam computed tomography for airway volume analysis. Eur J Orthod 35(2):256–261
23. Ristow O, Ruckschloss T, Berger M, Grotz T, Kargus S, Krisam J et al (2018) Short- and long-term changes of the pharyngeal airway after surgical mandibular advancement in Class II patients-a three-dimensional retrospective study. J Craniomaxillofac Surg 46(1):56–62
24. Bulut OC, Wallner F, Hohenberger R, Plinkert PK, Baumann I (2017) Quality of life after primary septorhinoplasty in deviated- and non-deviated nose measured with ROE, FROI-17 and SF-36. Rhinology 55(1):75–80
25. Hill S, Harries U, Popay J (1996) Is the short form 36 (SF-36) suitable for routine health outcomes assessment in health care for older people? Evidence from preliminary work in community based health services in England. J Epidemiol Community Health 50(1):94–98
26. Hayes V, Morris J, Wolfe C, Morgan M (1995) The SF-36 health survey questionnaire: is it suitable for use with older adults? Age Ageing 24(2):120–125
27. O'Mahony PG, Rodgers H, Thomson RG, Dobson R, James OF (1998) Is the SF-36 suitable for assessing health status of older stroke patients? Age Ageing 27(1):19–22
28. Smith IE, Shneerson JM (1995) Is the SF 36 sensitive to sleep disruption? A study in subjects with sleep apnoea. J Sleep Res 4(3):183–188
29. Ware JE Jr, Sherbourne CD (1992) The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med Care 30(6):473–483
30. Cingi C, Songu M, Bal C (2011) Outcomes research in rhinoplasty: body image and quality of life. Am J Rhinol Allergy 25(4):263–267
31. Silvola AS, Varimo M, Tolvanen M, Rusanen J, Lahti S, Pirttiniemi P (2014) Dental esthetics and quality of life in adults with severe malocclusion before and after treatment. Angle Orthod 84(4):594–599
32. Forssell H, Finne K, Forssell K, Panula K, Blinnikka LM (1998) Expectations and perceptions regarding treatment: a prospective study of patients undergoing orthognathic surgery. Int J Adult Orthodon Orthognath Surg 13(2):107–113
33. Zhou YH, Hagg U, Rabie AB (2001) Patient satisfaction following orthognathic surgical correction of skeletal Class III malocclusion. Int J Adult Orthodon Orthognath Surg 16(2):99–107
34. Kiyak HA, Hohl T, West RA, McNeill RW (1984) Psychologic changes in orthognathic surgery patients: a 24-month follow up. J Oral Maxillofac Surg 42(8):506–512
35. Macgregor FC (1970) Social and psychological implications of dentofacial disfigurement. Angle Orthod 40(3):231–233