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# Influence of different surgical concepts for moderate skeletal class II and III treatment on the nasopharyngeal airway space

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ABSTRACT

*Purpose:* This study aimed to compare the effects of different orthognathic and camouflage treatments for correcting moderate skeletal class II and III malocclusions on the pharyngeal airway space (PAS).
*Materials and methods:* Lateral cephalograms of 89 patients with moderate skeletal class II and III malocclusion (WITS up to 7 mm, −7 mm respectively) were evaluated before and after treatment. PAS was divided into 6 levels (P1: nasopharynx, P2-4: oropharynx, P5-6: laryngopharynx), and 7 groups were formed depending on the type of treatment: 1) class II, mandibular advancement; 2) class II, maxillary setback/mandibular advancement; 3) class II, upper premolar extraction; 4) class III, mandibular setback; 5) class III, maxillary advancement; 6) class III, maxillary advancement/mandibular setback; and 7) class III, lower premolar extraction.
*Results:* Significant changes occurred only in patients with class II malocclusion (groups 1 and 2) before and after surgery in the nasopharyngeal and oropharyngeal space. Furthermore, significant differences between the patients with class II malocclusion were found when compared to the premolar extraction group: group 1 vs. group 3 (P3: −1.31 mm (SD 1.74 mm) vs. 0.89 mm (SD 1.79 mm); P4: −0.72 mm (SD 2.82 mm) vs. 1.42 mm (SD 2.16 mm); $P \leq 0.05$), group 2 vs. group 3 (P2: 0.35 mm (SD 1.96 mm) vs. 2.28 mm (SD 1.88 mm), P3: −1.31 mm (SD 1.74 mm) vs. 0.35 mm (SD 1.96 mm), P4: −0.72 mm (SD 2.82 mm) vs. 2.84 mm (SD 2.16 mm), $P \leq 0.05$).
*Conclusions:* Orthognathic surgery in patients with moderate skeletal class II and III malocclusion seems to affect PAS only slightly. Premolar extractions for compensation (camouflage treatment) can result in a reduction of the oropharynx airway space in both types of skeletal malocclusions. Therefore, in borderline patients with presence of OSAS, orthognathic surgery should be considered.


## 1. Introduction

Severe dentofacial skeletal deformities usually require a combined orthodontic and surgical (orthognathic) treatment. Orthognathic surgery has the objective to correct malocclusion in the maxilla, mandible, or both in patients with severe skeletal class II or III discrepancy after completion of growth. Facial esthetic and functional deformities can be resolved with orthognathic surgery. This type of surgery often requires a sophisticated interdisciplinary approach, which can be divided into different phases (Wirthlin and Shetye, 2013). Patients start with a preoperative orthodontic preparation that can vary in length, followed by surgical planning, orthognathic surgery, and postsurgical orthodontic treatment to obtain the final occlusion (Luther et al., 2007). The presurgical orthodontic treatment aims to produce a dental decompensation that will enable a good surgical correction of the jaw discrepancy (Luther et al., 2007). The goals of the postsurgical orthodontic treatment are to settle the dental arches and ensure a precise tooth positioning (Vig and Ellis, 1990).

Obstructive sleep apnea syndrome (OSAS) represents a severe form of sleep-disordered breathing (SBD), in which repetitive episodes of apnea occur during sleep (Young et al., 1993; Bradley and Floras, 2009). OSAS is a heterogeneous disorder (Ryan and Bradley,

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2005). Anatomic factors that can predispose to OSAS are maxillary or mandibular retrognathism, as it occurs in patients with a severe class II or III malocclusion (Young et al., 1993; Lowe, 2006). In OSAS patients, the upper airway space is often compromised and reduced in dimensions. Therefore a decrease in the posterior airway space plays an essential role in OSAS (Riley et al., 1983). Orthognathic surgery and especially surgery with maxillary or mandibular setbacks are intensely discussed as a factor that decreases the pharyngeal airway space (PAS), thus promoting OSAS (Hochban et al., 1996; De Ponte et al., 1999; Tselnik and Pogrel, 2000). In contrast, an increase in PAS volume is shown in patients undergoing orthognathic surgery for mandibular advancement or bimaxillary advancement, which can improve the respiratory status of patients with OSAS (De Ponte et al., 1999). Therefore, changes in PAS due to orthognathic surgery must be taken into account during the presurgical planning, especially in patients who already experience OSAS but also to prevent new cases of OSAS.

Also, there are orthodontic treatment options that include extraction of the premolars for dental compensation in borderline cases of class II or III patients who do not want surgery (Jacobs et al., 2012). Dental extractions can cause dentofacial changes including incisor angulation, which in turn can influence the tongue position and PAS (Leonardi et al., 2010; Jacobs et al., 2012). Despite numerous studies that have investigated the effect of teeth extraction on the upper airway, conclusions drawn from these studies were contradictory (Valiathan et al., 2010; Germec-Cakan et al., 2011; Al Maaitah et al., 2012; Chen et al., 2012; Jacobs et al., 2012).

The influences of orthodontic treatment and orthognathic surgery on the cephalometric analysis of PAS have already been studied intensively (Table 1A,B). However, to date, there are no comparative studies on PAS changes during different orthognathic surgical methods and premolar extractions for compensation (camouflage therapy) in class II and III patients with moderate skeletal discrepancies. Therefore, the study aim was to determine the influence of these different treatments on PAS in these borderline patients. The first hypothesis of this investigation was that surgical treatment of moderate skeletal class II and III patients would lead to related changes in PAS. The second hypothesis was that camouflage treatment with premolar extraction would have more influence on PAS compared to orthognathic treatment.

## 2. Materials and methods

Ethical approval for the conduct of this retrospective study was obtained from the institutional review board at our home institution (Ethics Commission of University of the RWTH Aachen, Germany, No. 185/16). Relevant data including lateral cephalograms were collected from patients with moderate skeletal class II (Wits to 7 mm) and III (Wits to −7 mm).

All the lateral cephalograms were obtained by an experienced technician using a cephalometric imaging device (Galileos ComfortSirona, Germany) at the Department of Maxillofacial Surgery, University of Aachen, Germany. Routine calibration, system quality assurance, and imaging testing of the machine were performed regularly. The examined subjects were positioned in a standard sagittal plane perpendicular to the floor, which was parallel to the Frankfort plane.

Patients were allocated to seven groups depending on the type of skeletal malocclusion and performed therapy:

- Group 1 (skeletal class II malocclusion): monomaxillary surgery (mandibular advancement)
- Group 2 (skeletal class II malocclusion): bimaxillary surgery (mandibular advancement and maxillary setback)
- Group 3 (skeletal class II malocclusion): upper premolar extraction
- Group 4 (skeletal class III malocclusion): monomaxillary surgery (mandibular setback)
- Group 5 (skeletal class III): monomaxillary surgery (maxillary advancement)
- Group 6 (skeletal class III): bimaxillary surgery (mandibular setback and maxillary advancement)
- Group 7 (skeletal class III): lower premolar extraction.

Patients who were treated with orthognathic surgery received orthodontics both pre- and postsurgically. Depending on the presurgical planning of the maxillofacial surgeon and orthodontist, a Le Fort I osteotomy, a bilateral sagittal split osteotomy or both were performed. The evaluation time for these patients was carried out before (T1) and after (T2) orthognathic surgery. The evaluation time for the patients whose premolars were extracted was carried out was before (T1) and after (T2) orthodontic treatment.

A strict treatment concept, depending on the initial dental or skeletal findings, was not established. The decision was made considering the patient's preferences. Consideration was given to the skeletal and dental situation, the possibilities and risks of orthodontic compensation and orthognathic surgery, and the patient's subjective and objective feelings regarding facial aesthetics.

This study included a total of 89 patients (45 female, 44 male). The corresponding demographic treatment data of all the patients are presented in Table 2. A total of 178 lateral cephalograms were evaluated, two cephalograms from each patient at T1 and T2.

For the evaluation, the pharyngeal space was divided into six levels (P1–P6) according to Houfar et al (Hourfar et al., 2017).

The levels were defined as follows (Fig. 1):

- P1: pP-aP on PP: the distance between the posterior pharynx wall and the point PNS at the palatal plane level
- P2: pP-aP on OL: the distance between the posterior pharynx wall and the anterior pharynx wall/lingual root at the occlusal plane level
- P3: pP-aP on pC2-aC2: the distance between the posterior pharynx wall and the anterior pharynx wall/lingual root at the level of the second cervical vertebra (underside)
- P4: pP-aP on ML: the distance between the posterior pharynx wall and the anterior pharynx wall at the mandibular plane level
- P5: pP-aP on pC3-aC3: the distance between the posterior pharynx wall and the anterior pharynx wall at the level of the third cervical vertebra (underside)
- P6: pP-aP on pC4-aC4: the distance between the posterior pharynx wall and the anterior pharynx wall at the level of the fourth cervical vertebra (underside).

In addition to the usual cephalometric measurements, linear measurements (in mm) were performed to describe changes of pharyngeal depth and general treatment-related changes in all the groups (Figs. 2 and 3). The measurements were performed by one experienced operator using software support (OnyxCeph, Image Instruments GmbH, Chemnitz, Germany).

The statistical evaluation within or between the groups was carried out using paired or unpaired *t*-tests, and the level of significance was set at $P \leq .05$ using the statistical program Prism (version 7, GraphPad Software Inc., La Jolla, CA, USA). All the results are expressed as the mean ± standard deviation (SD).

## 3. Results

Treatment-related changes of PAS at T1, T2, and mean changes (ΔT2-T1) in skeletal class II (groups 1–3) and skeletal class III

**Table 1A**
Literature review of the orthognathic surgery influence on PAS investigated by cephalometric analysis.

| Author | Year | Class | Surgery | Findings |
|---|---|---|---|---|
| Do Vale et al. | 2019 | II | Monomaxillary | As an effect of mandibular advancement, an anteroposterior significant increase in PAS was perceived. |
| Jeong et al. | 2017 | II | Bimaxillary | Counterclockwise rotational orthognathic surgery without maxilla advancement for the correction of OSA can effectively increase the PAS. |
| Riepponen et al. | 2017 | II | Mono-, Bimaxillary | Patients with narrow PAS at the baseline, and those whose mandible moved in the counterclockwise direction with moderate advancement gained more retrolingual airway patency. |
| Dalla Torre et al. | 2017 | II | Monomaxillary | The effect of mandibular advancement on the PAS was significant. |
| Sahoo et al. | 2012 | II | Monomaxillary | An overall increase in airway dimension was found. The procedure may be considered beneficial in reducing upper airway collapsibility and preventing sleep disorders due to oropharyngeal airway deficiencies in skeletal class II malocclusion. |
| De Ponte et al. | 1999 | II | Mono-, Bimaxillary | An increase in PAS volume, especially at the hypopharynx and the lower part of the oropharynx was found, when the sagittal split osteotomy was performed and/or the maxilla was moved anteriorly and/or superiorly. A decrease of PAS was seen in downward and/or backward maxillary movements. |
| Farole et al. | 1990 | II | Monomaxillary | PAS usually increased after mandibular advancement, but the changes were varied. |
| Hourfar et al. | 2017 | II, III | Mono-, Bimaxillary | Bimaxillary surgery led to smaller changes of pharyngeal depth in Class II and III patients than monomaxillary surgery. |
| Keum et al. | 2017 | III | Monomaxillary, teeth extraction | Middle PAS decreased because of the posterior displacement of the mandibular incisors and/or the mandibular body. The inferior PAS decreased only in the mandibular setback group because of the posterior displacement of only the mandibular body. |
| On et al. | 2015 | III | Monomaxillary | The oropharynx significantly decreased after mandibular setback surgery, and changes in the surrounding structures were identified through posteroinferior movement of the hyoid bone during long-term follow-up. |
| Choi et al. | 2015 | III | Bimaxillary | Orthognathic surgery based on clockwise rotation of maxillomandibular complex did not cause severe PAS changes at 6 months postoperation |
| Uslu-Akcam and Gokalp, | 2015 | III | Bimaxillary | Two jaw surgery evoked an increase in the upper pharyngeal airway dimensions. |
| Santagata et al. | 2015 | III | Mono-, Bimaxillary | Bimaxillary surgery had less effect on reduction of the PAS than mandibular setback surgery only. |
| Cho et al. | 2015 | III | Monomaxillary | The PAS showed relatively high correlation with the amount of mandibular setback. |
| Choi et al. | 2014 | III | Monomaxillary | The amount of mandibular set back was significantly associated with postoperative reduction of PAS. |
| Burkhard et al. | 2014 | III | Bimaxillary | A significant increase in the upper airway dimensions before and after surgery occurred in all measured cases. |
| Gokce et al. | 2012 | III | Bimaxillary | The alterations indicated decreased airway resistance and better airflow. |
| Demetriades et al. | 2010 | III | Mono-, Bimaxillary | Postoperative polysomnography showed higher incidence of mild to moderate OSAS in patients who underwent mandibular retropositioning greater than or equal to 5 mm compared with patients who underwent mandibular retropositioning in combination with maxillary advancement. |
| Park et al. | 2010 | III | Monomaxillary | Although the structures around the mandible inevitably moved backward after mandibular setback surgery on linear analysis, physiologic deformation could occur to preserve the airway capacity after sagittal compression. |
| Jakobsone et al. | 2010 | III | Bimaxillary | Bimaxillary surgery for correction of Class III malocclusion did not cause decrease of the posterior airway space. Three-dimensional imaging techniques are preferable to 2-dimensional lateral cephalograms for evaluation of the upper airway after orthognathic procedures. |
| Foltan et al. | 2009 | III | Bimaxillary | The results indicate that bimaxillary surgery for class III malocclusion increased upper airway resistance. |
| Marsan et al. | 2009 | III | Bimaxillary | Bimaxillary surgery caused an increase in the upper retropalatal airway space, together with posterior and inferior movement of hyoid bone one week postoperatively. Some relapse was found in these changes over one year later. |
| Muto et al. | 2008 | III | Monomaxillary | These results show that mandibular setback surgery markedly decreases the PAS and changes the morphology of the soft palate. |
| Chen et al. | 2007 | III | Mono-, Bimaxillary | Bimaxillary surgery rather than only mandibular setback surgery is preferable to correct a Class III deformity to prevent narrowing of the pharyngeal airway space, a possible predisposing factor in the development of obstructive sleep apnea. |
| Kawakami et al. | 2005 | III | Monomaxillary | Mandibular setback caused airway narrowing late after surgery, while the early postoperative airway dimension was maintained. |
| Samman et al. | 2002 | III | Mono-, Bimaxillary | Minimal pharyngeal depth was reduced in both genders. After mandibular setback, the hypopharyngeal depth was reduced. The bimaxillary surgery group also demonstrated a more posterior tongue base but without reduction of the hypopharyngeal depth. The mandibular setback group should be most at risk of obstructive sleep apnea, but compensatory changes in soft palate morphology may explain the low occurrence in practice. |
| Tselnik and Pogrel | 2000 | III | Monomaxillary | Mandibular setback surgery causes a long-term decrease in PAS area. |
| Hochban et al. | 1996 | III | Monomaxillary | PAS decreased considerably in all patients.. The preoperative PAS was enlarged in all patients with mandibular hyperplasia compared to normal subjects. |

patients (groups 4–7) are shown in Tables 3–5 and illustrated in Figs. 4 and 5. The changes in WITS depending on the surgical technique are illustrated in Fig. 6.

No statistical differences were found regarding WITS before treatment, both in class II and class III patients. However, treatment in groups 1, 2, 4, and 5 resulted in statistically significant changes, but not in groups 3, 6, and 7. Regarding PAS, significant changes occurred only after monomaxillary and bimaxillary class II therapy (groups 1 and 2) in the nasopharyngeal and oropharyngeal space (monomaxillary: P1, 3, 4; bimaxillary: P2, 4). Furthermore, compared to the extraction treatment, significant differences between the different class II treatment were found: upper premolar extraction (group 3) vs. monomaxillary surgery (mandibular advancement) (group 1) (P3: −1.31 mm (SD 2.43 mm) vs. 0.89 mm (SD 1.79 mm); P4: −0.72 mm (SD 2.82 mm) vs. 1.42 mm (SD 2.61 mm); $P \leq 0.05$), upper premolar extraction (group 3) vs. bimaxillary surgery (maxillary setback/mandibular advancement) (P2: 0.35 mm (SD 1.96 mm) vs. 2.28 mm (SD 1.88 mm), P3: −1.31 mm (SD 2.43 mm) vs. 1.74 mm (SD 2.97 mm), P4: −0.72 mm (SD 2.82 mm) vs. 2.84 mm (SD 2.16 mm) $P \leq 0.05$).

**Table 1B**
Literature review of premolar extraction therapy in combination with orthodontic treatment influence on PAS by cephalometric analysis.

| Author (Year) | Year | Findings |
|---|---|---|
| Maurya et al. | 2019 | No significant change on airway after therapeutic orthodontic tooth movement with or without extraction treatment was found. |
| Bhatia et al. | 2016 | The size of the PAS (velopharyngeal and glossopharyngeal) reduced and hyoid bone position changed after retraction of the incisors in extraction space in bimaxillary protrusive adult patients. |
| Al Maahitah et al. | 2012 | Extraction of the first premolars for the treatment of bimaxillary proclination did not affect upper airway dimensions despite a significant reduction in tongue length. |
| Sharma et al. | 2014 | The nasopharyngeal dimension and total airway length were not found to be directly affected by the retraction of anterior teeth. |
| AlKawari et al. | 2018 | Extraction of premolars did not affect the pharyngeal dimensions except those of the nasopharynx, which showed a significant increase after extraction. |
| Wang et al. | 2012 | The PAS became narrower after treatment. Extraction of four premolars with retraction of incisors did affect velopharyngeal, glossopharyngeal, hypopharyngeal, and hyoid position in bimaxillary protrusive adult patients. |
| Valiathan et al. | 2010 | Extraction of four premolars with retraction of incisors did not affect the oropharyngeal airway volume |

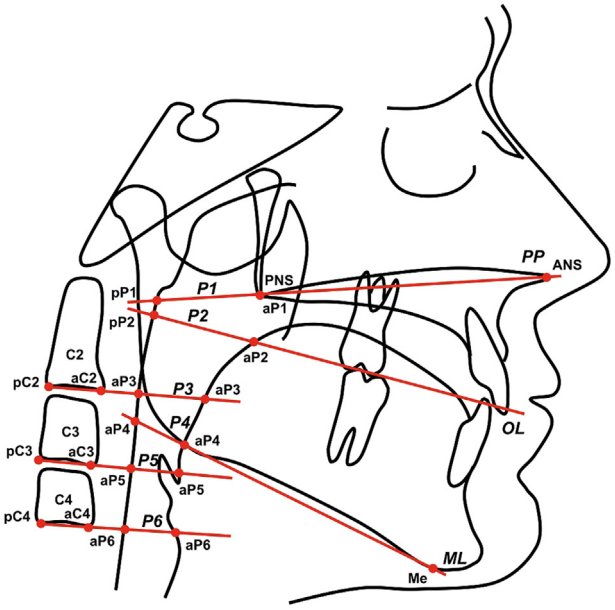


**Fig. 1.** Linear measurements of the nasopharyngeal airway space that were divided into six levels: P1 nasopharynx, P2–4 oropharynx, P5–6 laryngopharynx.

## 4. Discussion

The main study objective was to compare the influence of orthodontic treatment, different orthognathic surgical methods, and premolar extraction for compensation (camouflage therapy) for class II and III treatment on patients with PAS. The influence of a combined orthodontic–orthognathic surgical treatment and the division of mono- or bimaxillary surgery on PAS has been examined by Hourfar et al. (2017). However, until now, the influence of premolar extraction on PAS has not been investigated. Therefore, our study adds new data to the orthodontic literature.

For the analysis of PAS, lateral cephalograms were evaluated, which is an established method (Yu et al., 1994; De Ponte et al., 1999; Samman et al., 2002). Besides the evaluation of PAS using lateral cephalograms, the literature also describes the analysis of PAS using cone-beam computed tomography (CBCT) (Alves et al., 2012; Di Carlo et al., 2015) and computed tomography (CT) (Crosby et al., 2016). The differences between CT, CBCT, and lateral cephalograms are low (Vizzotto et al., 2012; Crosby et al., 2016). An advantage of the evaluation with lateral cephalograms in comparison to CBCT and CT is the reduced exposure to radiation in patients (Eastman, 2013).

In this study, PAS was evaluated at six different levels (P1–P6) (Hourfar et al., 2017). Significant changes occurred only after monomaxillary and bimaxillary class II therapy (group 1 and 2) in the nasopharyngeal and oropharyngeal space. PAS alterations were more accentuated in bimaxillary surgery in comparison to monomaxillary surgery. In contrast, the study of Houfar et al (Hourfar et al., 2017), observed a change in PAS in both bi-and monomaxillary osteotomy in class II and III patients, which was especially pronounced in monomaxillary surgery.

In individuals of Caucasian/white ethnicity, class II anomalies are more frequent than class III anomalies (33). However, in this study, the number of class III patients was tendentially larger than class II patients. One reason for this could be that patients with a class III anomaly experience more problems than class II patients due to the negative overjet.

Other studies have investigated the effect of orthognathic surgery on PAS in class III patients (Tselnik and Pogrel, 2000) with

**Table 2**
Patients demographic and treatment data, divided after malocclusion and appropriate treatment.

| Malocclusion | Group | Treatment | N | Gender | Mean/Range of age (years) | Mean/Range of time between T1 and T2 (years) | Mean/Range of time between surgery and T2 (years) |
|---|---|---|---|---|---|---|---|
| Class II | 1 | Mandibular advancement | 19 | 11 females | 27.4 (16.1–48.2) | 2.68 (2.07–3.47) | 0.96 (0.53–1.75) |
| | | | | 8 males | 24.8 (17.2–32.6) | 2.55 (2.01–3.40) | 1.76 (0.78–2.18) |
| | 2 | Mandibular advancement/maxillary setback | 11 | 5 females | 28.8 (17.2–46.3) | 3.27 (2.45–3.91) | 1.61 (0.84–2.19) |
| | | | | 6 males | 30.8 (18.2–49.8) | 3.01 (1.87–4.82) | 1.53 (1.87–3.03) |
| | 3 | Upper premolar extraction | 10 | 7 females | 22.7 (16.2–28.6) | 2.54 (2.05–3.68) | – |
| | | | | 3 males | 23.2 (17.6–27.2) | 2.84 (2.49–3.28) | – |
| Class III | 4 | Mandibular setback | 10 | 6 females | 27.2 (17.2–47.2) | 3.34 (2.63–4.01) | 1.38 (0.60–1.99) |
| | | | | 4 males | 22.2 (17.4–30.2) | 2.80 (2.19–3.51) | 1.35 (1.02–1.60) |
| | 5 | Maxillary advancement | 13 | 5 females | 31.3 (19.8–49.8) | 3.37 (2.28–5.42) | 1.59 (0.87–1.97) |
| | | | | 8 males | 23.8 (17.9–48.3) | 3.38 (1.70–5.18) | 1.64 (1.01–2.35) |
| | 6 | Mandibular setback/maxillary advancement | 13 | 7 females | 25.4 (17.2–39.8) | 2.99 (2.44–3.42) | 0.95 (0.42–1.32) |
| | | | | 6 males | 22.8 (18.2–34.6) | 3.19 (1.97–5.46) | 1.34 (0.77–1.79) |
| | 7 | Lower premolar extraction | 13 | 9 females | 29.3 (20.2–48.3) | 3.32 (2.24–4.62) | – |
| | | | | 4 males | 24.6 (18.2–52.8) | 2.78 (1.67–4.22) | – |

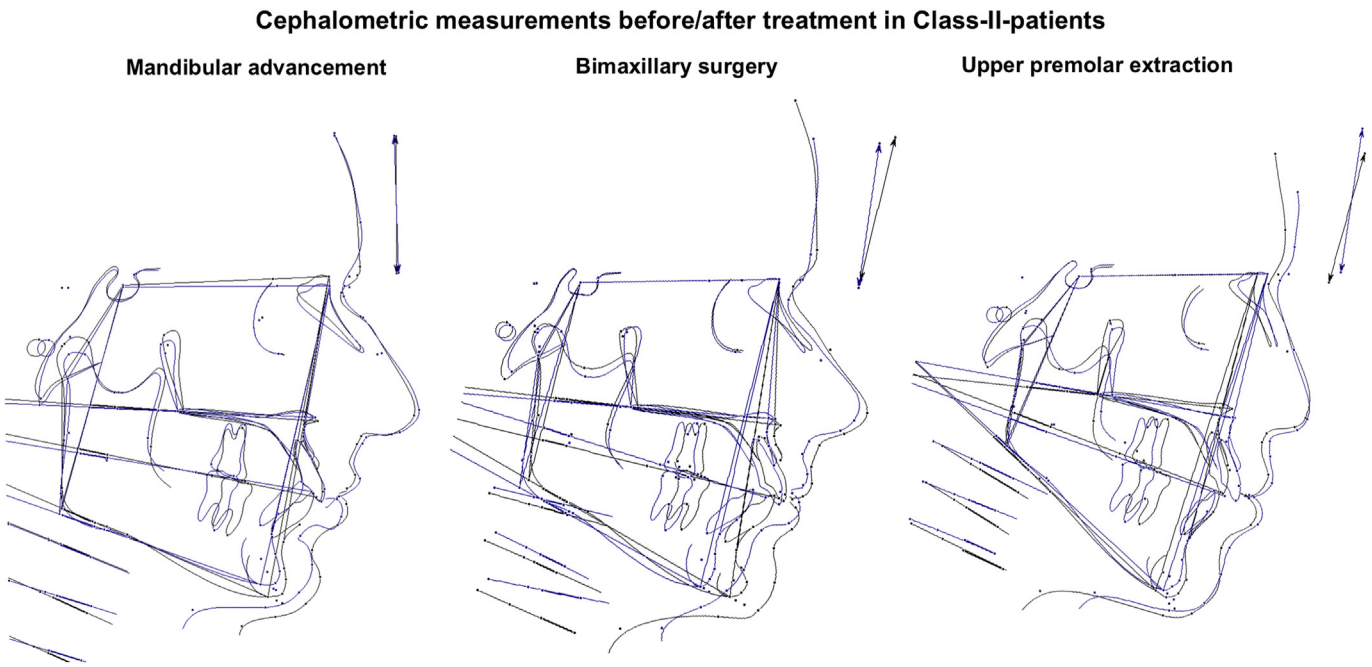


**Fig. 2.** An example of superimpositions of the cephalometric analysis before (T1, blue tracing) and after (T2, black tracing) the treatment in class II patients.

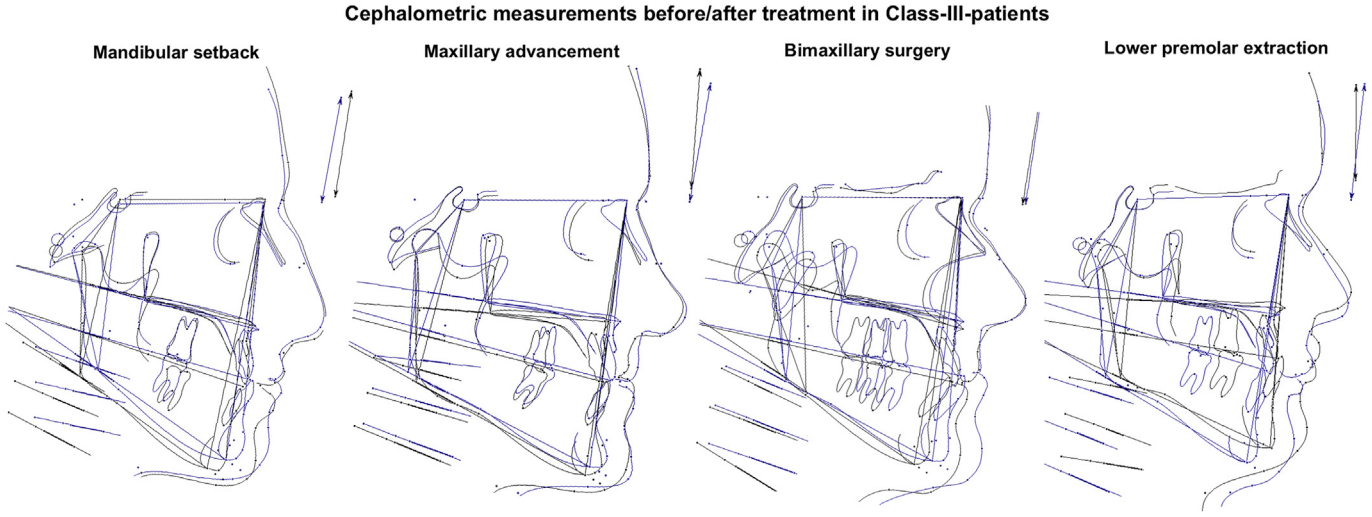


**Fig. 3.** An example of superimpositions of the cephalometric analysis before (T1, blue tracing) and after (T2, black tracing) the treatment in class III patients.

**Table 3**
Treatment-related changes of the pharyngeal airway space (PAS) in Class II patients after mono, bimaxillary surgery, and camouflage treatment.

| P | Class II Treatment | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mandibular advancement | | | | Maxillary setback/mandibular advancement | | | | Camouflage | | | |
| | T1 (mm) | T2 (mm) | Δ ST2-T1 (mm) | *p* value | T1 (mm) | T2 (mm) | Δ T2-T1 (mm) | *p* value | T1 (mm) | T2 (mm) | Δ T2-T1 (mm) | *p* value |
| 1 | 25.68 ± 4.16 | 24.17 ± 5.06 | −1.51 ± 2.62 | 0.022* | 26.62 ± 3.08 | 26.61 ± 1.64 | −0.01 ± 3.35 | 0.993 | 21.79 ± 5.37 | 22.77 ± 5.59 | 0.98 ± 4.51 | 0.509 |
| 2 | 10.39 ± 3.36 | 10.95 ± 2.50 | 0.56 ± 2.31 | 0.302 | 10.18 ± 1.79 | 12.46 ± 2.80 | 2.28 ± 1.88 | 0.002* | 11.08 ± 2.76 | 11.43 ± 2.73 | 0.35 ± 1.96 | 0.586 |
| 3 | 10.45 ± 3.22 | 11.35 ± 3.15 | 0.89 ± 1.79 | 0.043* | 9.58 ± 1.78 | 11.32 ± 2.87 | 1.74 ± 2.97 | 0.081 | 13.50 ± 2.04 | 12.19 ± 3.77 | −1.31 ± 2.43 | 0.122 |
| 4 | 9.55 ± 3.63 | 10.97 ± 3.60 | 1.42 ± 2.61 | 0.029* | 7.65 ± 2.18 | 10.48 ± 2.03 | 2.84 ± 2.16 | 0.001* | 12.87 ± 2.61 | 12.15 ± 4.11 | −0.72 ± 2.82 | 0.440 |
| 5 | 13.43 ± 4.79 | 12.14 ± 4.75 | −1.29 ± 3.97 | 0.174 | 11.15 ± 4.91 | 12.58 ± 3.09 | 1.44 ± 3.23 | 0.171 | 13.10 ± 3.85 | 12.90 ± 4.97 | −0.20 ± 3.90 | 0.875 |
| 6 | 16.42 ± 3.02 | 17.08 ± 2.95 | 0.66 ± 3.45 | 0.416 | 16.21 ± 2.97 | 16.47 ± 3.30 | 0.26 ± 2.78 | 0.759 | 16.38 ± 3.49 | 17.92 ± 1.87 | 1.54 ± 2.78 | 0.114 |

P: PAS Levels - P1: nasopharynx, P2-4: oropharynx, P5-6: laryngopharynx; T1: before treatment, T2: after treatment, Δ T2-T1: Change by treatment, positive measurements indicate increases and negative measurements indicate decreases of the PAS; *: statistically significant ($p \leq 0.05$).

**Table 4A**
Treatment-related changes of the pharyngeal airway space (PAS) in Class III patients after a surgical mandibular setback or maxillary advancement.

| P | Class III Treatment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mandibular setback | | | | Maxillary advancement | | | |
| | T1 (mm) | T2 (mm) | Δ T2-T1 (mm) | *p* value | T1 (mm) | T2 (mm) | Δ T2-T1 (mm) | *p* value |
| 1 | 25.95 ± 4.40 | 24.88 ± 4.27 | −1.07 ± 3.34 | 0.338 | 25.01 ± 3.85 | 23.81 ± 3.33 | −1.20 ± 2.10 | 0.061 |
| 2 | 11.49 ± 1.97 | 10.66 ± 1.97 | −0.83 ± 2.16 | 0.256 | 11.35 ± 2.54 | 12.02 ± 3.33 | 0.67 ± 1.84 | 0.214 |
| 3 | 11.99 ± 4.12 | 11.30 ± 6.13 | −0.69 ± 3.02 | 0.488 | 12.35 ± 4.09 | 11.85 ± 4.25 | −0.50 ± 3.37 | 0.602 |
| 4 | 9.74 ± 4.23 | 9.84 ± 3.07 | 0.10 ± 3.52 | 0.930 | 10.57 ± 3.11 | 10.26 ± 3.23 | −0.31 ± 2.75 | 0.694 |
| 5 | 14.33 ± 1.70 | 9.97 ± 2.98 | −4.36 ± 3.35 | 0.767 | 12.88 ± 5.00 | 12.88 ± 4.22 | 0.00 ± 4.12 | 0.999 |
| 6 | 16.23 ± 2.92 | 15.95 ± 5.67 | −0.28 ± 3.61 | 0.812 | 18.20 ± 3.90 | 16.52 ± 5.05 | −1.68 ± 3.23 | 0.084 |

P: PAS Levels - P1: nasopharynx, P2-4: oropharynx, P5-6: laryngopharynx; T1: before treatment, T2: after treatment, Δ T2-T1: Change by treatment, positive measurements indicate increases and negative measurements indicate decreases oft the PAS; *: statistically significant ($p \leq 0.05$).

**Table 4B**
Treatment-related changes of the pharyngeal airway space (PAS) in Class III patients after bimaxillary surgery or camouflage treatment.

| P | Class III Treatment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Maxillary advancement/mandibular setback | | | | Camouflage | | | |
| | T1 (mm) | T2 (mm) | Δ T2-T1 (mm) | *p* value | T1 (mm) | T2 (mm) | Δ T2-T1 (mm) | *p* value |
| 1 | 25.72 ± 3.91 | 25.52 ± 5.62 | −0.20 ± 3.42 | 0.837 | 24.65 ± 5.28 | 25.20 ± 5.74 | 0.55 ± 4.84 | 0.697 |
| 2 | 10.86 ± 2.24 | 11.50 ± 4.12 | 0.64 ± 2.70 | 0.411 | 9.99 ± 3.78 | 10.16 ± 3.26 | 0.17 ± 3.54 | 0.866 |
| 3 | 13.03 ± 3.77 | 12.84 ± 5.30 | −0.19 ± 3.24 | 0.834 | 12.38 ± 3.51 | 11.47 ± 4.34 | −0.91 ± 5.35 | 0.452 |
| 4 | 12.68 ± 4.85 | 11.87 ± 4.77 | −0.82 ± 4.44 | 0.521 | 11.03 ± 3.63 | 10.36 ± 3.18 | −0.67 ± 4.72 | 0.555 |
| 5 | 12.82 ± 5.02 | 10.81 ± 3.52 | −2.02 ± 5.21 | 0.188 | 13.06 ± 2.81 | 11.60 ± 3.50 | −1.46 ± 3.47 | 0.155 |
| 6 | 15.77 ± 5.84 | 15.32 ± 4.50 | −0.45 ± 3.21 | 0.619 | 16.98 ± 4.26 | 16.89 ± 3.21 | −0.08 ± 2.87 | 0.917 |

P: PAS Levels - P1: nasopharynx, P2-4: oropharynx, P5-6: laryngopharynx; T1: before treatment, T2: after treatment, Δ T2-T1: Change by treatment, positive measurements indicate increases and negative measurements indicate decreases oft the PAS; *: statistically significant ($p \leq 0.05$).

**Table 5**
*P* values of the comparisons between the mean changes of PAS levels after different surgical approaches or camouflage treatment after correcting moderate skeletal class II and III malocclusion.

| | | | *p* value | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | P1 | P2 | P3 | P4 | P5 | P6 |
| Class-II-Treatment | | | | | | | | |
| Monognathic (MnA) | vs. | Bignahtic (MxS/MnA) | 0.183 | 0.046[a] | 0.339 | 0.139 | 0.064 | 0.749 |
| | | Camouflage | 0.069 | 0.806 | 0.010[a] | 0.041[a] | 0.486 | 0.492 |
| Bignahtic (MxS/MnA) | vs. | Camouflage | 0.573 | 0.032[a] | 0.019[a] | 0.004[a] | 0.307 | 0.306 |
| Class-III-Treatment | | | | | | | | |
| Monognathic (MnS) | vs. | Monognathic (MxA) | 0.910 | 0.244 | 0.890 | 0.758 | 0.881 | 0.337 |
| | | Bignahtic (MxA/MnS) | 0.548 | 0.362 | 0.711 | 0.599 | 0.322 | 0.904 |
| | | Camouflage | 0.400 | 0.694 | 0.383 | 0.406 | 0.339 | 0.886 |
| Monognathic (MxA) | vs. | Bignahtic (MxA/MnS) | 0.378 | 0.973 | 0.814 | 0.729 | 0.285 | 0.339 |
| | | Camouflage | 0.265 | 0.655 | 0.295 | 0.472 | 0.338 | 0.194 |
| Bignahtic (MxA/MnS) | | Camouflage | 0.687 | 0.707 | 0.220 | 0.742 | 0.752 | 0.760 |

P: PAS Levels - P1: nasopharynx, P2-4: oropharynx, P5-6: laryngopharynx; MnA: Mandibular advancement; MnS: Mandibular setback; MxA: Maxillary advancement; MxS: Maxillary setback.
[a] Statistically significant.

controversial results. Azevedo et al. observed that the upper PAS increases after orthognathic surgery, although this was not statistically significant (Azevedo et al., 2016). In contrast, Park et al. observed no changes in PAS after bi- or monomaxillary surgery (Park et al., 2012). A decrease in PAS is often observed in class III patients treated with mandibular setback surgery (Muto et al., 2008; Hourfar et al., 2017). Chen et al. and Burkhard et al. pointed out that a decrease of PAS in class III patients can be reduced after a bimaxillary surgery with mandibular setback and maxillary advancement to prevent narrowing of PAS, possible development of breathing problems, and OSA/SBA (Chen et al., 2007; Burkhard et al., 2014).

Another aspect the study evaluated was the premolar extraction in patients with class II and III malocclusion. Extraction therapy is used to compensate for moderate skeletal anomalies. The study results showed that the combination of extraction and retrusion of the front could reduce the oropharynx airway space in skeletal class II and III malocclusion (groups 3 and 7), even if there were no significant changes. One explanation for this could be the reduction in tongue space. Some clinicians believe that by closing the extraction spaces, the maxilla and the mandible will retrude (McDougall et al., 1982), resulting in constriction of the oropharyngeal airway (Ozbek et al., 1998; Singh et al., 2007). A retruded mandibular position may be associated with airway constriction due to the lingual musculature. Particularly in class II patients, there is a significant difference between premolar extraction and mono- and bimaxillary osteotomy. In this study, camouflage therapy with premolar extraction and retrusion of the front significantly reduces the PAS more than surgical osteotomy. Practitioners must be aware of this phenomenon, especially in borderline cases and patients

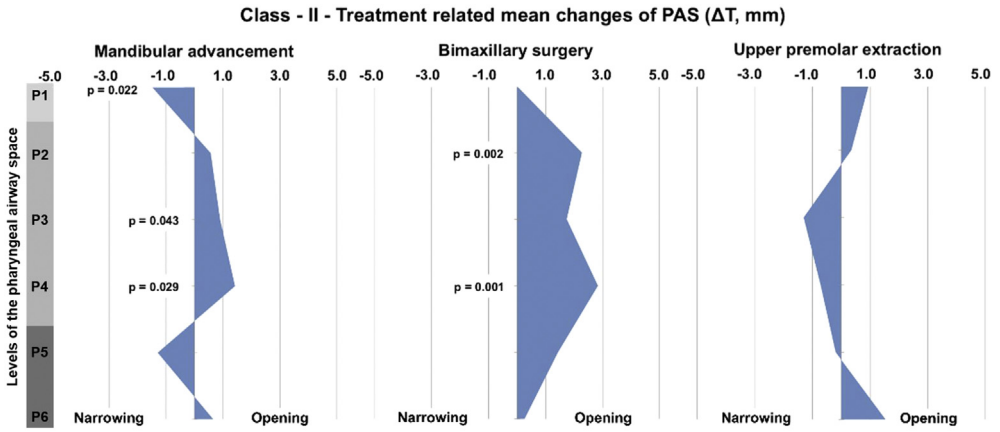


**Fig. 4.** Pharyngeal changes (mm) at different levels (P1–P6) after different surgical and camouflage treatments in class II patients. Changes (Δ T2 – T1) after mandibular advancement, bimaxillary surgery (mandibular advancement and maxillary setback), and upper premolar extractions. Negative values (shift to the left) represent narrowing, and positive values (shift to the right) represent the opening of the nasopharyngeal airway space. Statistical significance: $P \leq .05$.

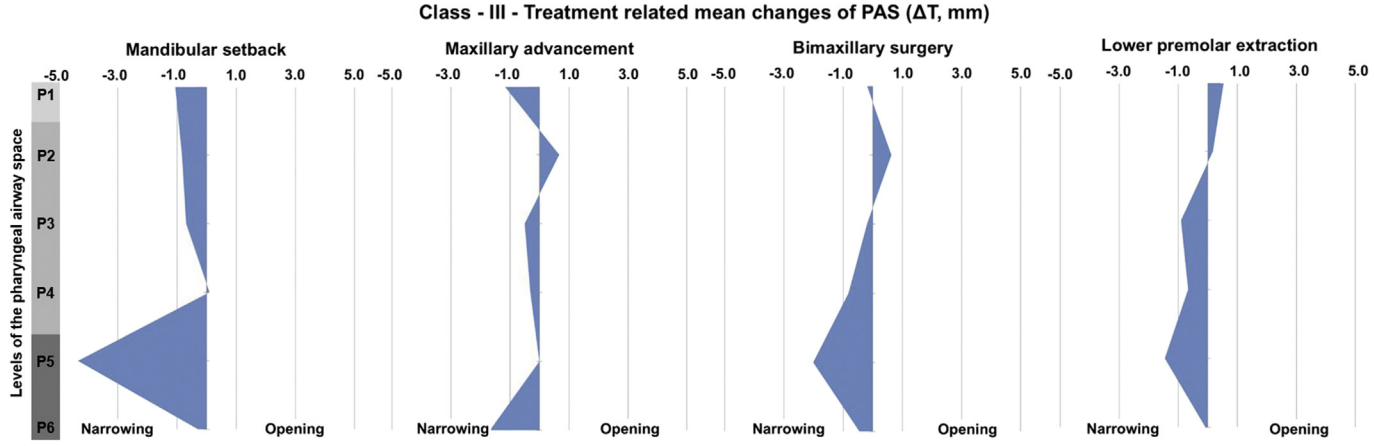


**Fig. 5.** Pharyngeal changes (mm) at different levels (P1–P6) after different surgical and camouflage treatments in class III patients. Changes (Δ T2 – T1) after mandibular setback, maxillary advancement, bimaxillary surgery (mandibular setback and maxillary advancement), and lower premolar extractions. Negative values (shift to the left) represent narrowing, and positive values (shift to the right) represent the opening of the nasopharyngeal airway space. Statistical significance: $P \leq .05$.

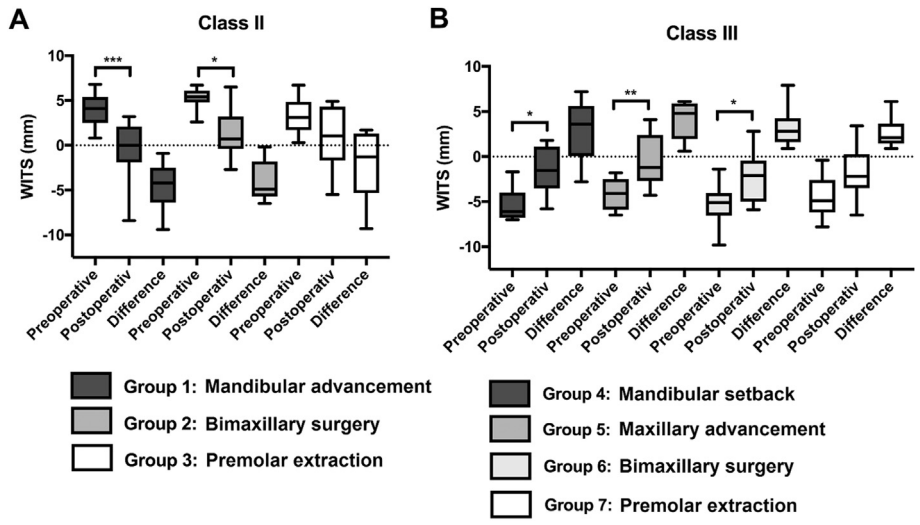


**Fig. 6.** Box plots of WITS changes (mm) at different levels (P1–P6) in class II patients (A) and class III patients (B) before and after monomaxillary surgery, bimaxillary surgery, and premolar extractions. Statistical significance: $P \leq .05$.

with potential breathing problems, in whom orthognathic surgery might be a better approach.

However, the results of this investigation must be viewed critically due to the small sample sizes as well as the lack of exact millimeter data for the respective displacements. Although the displacement distance can be suspected by the WITS values for monomaxillary surgery, it is limited in cases of bimaxillary treatment, because the actual movements in the sagittal plane were not apparent for the respective jaw. Nevertheless, in this case, the entire displacement of both jaws can be assumed.

PAS alterations after orthognathic surgery or premolar extraction are controversial topics in the literature. Previous studies have shown that after orthognathic surgery a physiological adjustment of the soft tissue occurs and the PAS goes back to its original form (Yu et al., 1994; Hochban et al., 1996; Samman et al., 2002; Chen et al., 2012). Yu et al. demonstrated that increases in PAS were unpredictable and are prone to decrease over time (Yu et al., 1994).

Even in the primary diagnostic workup, attention should be paid to possible breathing problems, since many patients have an undiagnosed OSAS and SBA (Armalaite and Lopatiene, 2016; Graf et al., 2016). When patients need orthodontic treatment or orthognathic surgery, a lateral cephalogram is usually performed for diagnosis. Several studies showed that the use of cephalometric analyses of lateral radiographs was suitable for diagnosing changes in PAS, which were directly related to OSAS/SBA. A hypoplastic mandible and/or maxilla, which are reflected by smaller SNB and SNA angles, has been mentioned as a factor contributing to the severity of OSAS/SBA (Battagel et al., 2002; Tsai et al., 2003; Sutherland et al., 2012). Therefore, the maxillofacial surgeon and orthodontist can be the first to discover possible anatomical changes of PAS and OSAS/SBA.

In contrast, according to Bacon et al., SNA, SNB, and ANB measurements did not show any influence when comparing patients with OSAS and the control group (Bacon et al., 1990). A meta-analysis by Armalaite and Lopatiene also pointed out that there were no statistically significant differences in the skeletal anteroposterior relationship between patients with OSAS and a control group (Armalaite and Lopatiene, 2016). Until now, literature of OSAS concerning skeletal craniofacial anomalies has been contradictory. OSAS or SBA probably cannot be diagnosed with certainty by a lateral cephalogram, but it may be a reference to an existing SBA/OSA and orthodontists can refer the patient to a specialist (Verbraecken et al., 2017).

## 5. Conclusions

Orthognathic surgery in moderate skeletal class II and III malocclusion seems to affect PAS only slightly. Slight PAS extension is possible after surgical class II treatment; however, PAS narrowing is not expected after class III treatment. Camouflage treatment can result in a reduction of the oropharynx airway space in both skeletal malocclusions. This may be due to a tongue shift to the dorsal. There is a statistically significant difference in the treatment of class II patients at the expense of camouflage treatment.

Taking into account the limitations of this study in terms of small sample sizes and missing information about displacement distances for orthognathic surgery–treated patients, it can be concluded that in these borderline patients, the presence of OSAS should be evaluated before treatment. In this case, orthognathic surgery seems to be a more effective treatment option due the possibility of additional OSAS therapy next to functional rehabilitation, while especially in class II borderline cases extraction therapy may increase the risk of narrowing the PAS.

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## References

Al Maaitah E, El Said N, Abu Alhaija ES: First premolar extraction effects on upper airway dimension in bimaxillary proclination patients. Angle Orthod 82: 853–859, 2012

AlKawari HM, AlBalbeesi HO, Alhendi AA, Alhuwaish HA, Al Jobair A, Baidas L: Pharyngeal airway dimensional changes after premolar extraction in skeletal class II and class III orthodontic patients. J Orthod Sci 7(10), 2018

Alves Jr M, Franzotti ES, Baratieri C, Nunes LK, Nojima LI, Ruellas AC: Evaluation of pharyngeal airway space amongst different skeletal patterns. Int J Oral Maxillofac Surg 41: 814–819, 2012

Armalaite J, Lopatiene K: Lateral teleradiography of the head as a diagnostic tool used to predict obstructive sleep apnea. Dentomaxillofac Radiol 45: 20150085, 2016

Azevedo MS, Machado AW, Barbosa Ida S, Esteves LS, Rocha VA, Bittencourt MA: Evaluation of upper airways after bimaxillary orthognathic surgery in patients with skeletal class III pattern using cone-beam computed tomography. Dental Press J Orthod 21: 34–41, 2016

Bacon WH, Turlot JC, Krieger J, Stierle JL: Cephalometric evaluation of pharyngeal obstructive factors in patients with sleep apneas syndrome. Angle Orthod 60: 115–122, 1990

Battagel JM, Johal A, Smith AM, Kotecha B: Postural variation in oropharyngeal dimensions in subjects with sleep disordered breathing: a cephalometric study. Eur J Orthod 24: 263–276, 2002

Bhatia S, Jayan B, Chopra SS: Effect of retraction of anterior teeth on pharyngeal airway and hyoid bone position in class I bimaxillary dentoalveolar protrusion. Med J Armed Forces India 72(Suppl. 1): 17–23, 2016

Bradley TD, Floras JS: Obstructive sleep apnoea and its cardiovascular consequences. Lancet 373: 82–93, 2009

Burkhard JP, Dietrich AD, Jacobsen C, Roos M, Lubbers HT, Obwegeser JA: Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery. J Craniomaxillofac Surg 42: 1428–1436, 2014

Chen F, Terada K, Hua Y, Saito I: Effects of bimaxillary surgery and mandibular setback surgery on pharyngeal airway measurements in patients with class III skeletal deformities. Am J Orthod Dentofacial Orthop 131: 372–377, 2007

Chen Y, Hong L, Wang CL, Zhang SJ, Cao C, Wei F, et al: Effect of large incisor retraction on upper airway morphology in adult bimaxillary protrusion patients. Angle Orthod 82: 964–970, 2012

Cho HW, Kim IK, Cho HY, Seo JH, Lee DH, Park SH: Retrospective study of changes in pharyngeal airway space and position of hyoid bone after mandibular setback surgery by cephalometric analysis. Maxillofac Plast Reconstr Surg 26: 38, 2015

Choi JW, Park YJ, Lee CY: Posterior pharyngeal airway in clockwise rotation of maxillomandibular complex using surgery-first orthognathic approach. Plast Reconstr Surg Glob Open 20: e485, 2015

Choi SK, Yoon JE, Cho JW, Kim JW, Kim SJ, Kim MR: Changes of the airway space and the position of hyoid bone after mandibular set back surgery using bilateral sagittal split ramus osteotomy technique. Maxillofac Plast Reconstr Surg 36: 185–191, 2014

Crosby T, Phillips J, Carbo A, Babcock K, Nathan CA: Use of modified barium swallow study to measure posterior airway space in obstructive sleep apnea. Acta Otolaryngol 136: 592–597, 2016

Dalla Torre D, Burtscher D, Widmann G, Rasse M, Puelacher T, Puelacher W: Long-term influence of mandibular advancement on the volume of the posterior airway in skeletal cla0ss II-patients: a retrospective analysis. Br J Oral Maxillofac Surg 55: 780–786, 2017

De Ponte FS, Brunelli A, Marchetti E, Bottini DJ: Cephalometric study of posterior airway space in patients affected by class II occlusion and treated with orthognathic surgery. J Craniofac Surg 10: 252–259, 1999

Di Carlo G, Polimeni A, Melsen B, Cattaneo PM: The relationship between upper airways and craniofacial morphology studied in 3D. A CBCT study. Orthod Craniofac Res 18: 1–11, 2015

Demetriades N, Chang DJ, Laskarides C, Papageorge M: Effects of mandibular retropositioning, with or without maxillary advancement, on the oro-naso-pharyngeal airway and development of sleep-related breathing disorders. J Oral Maxillofac Surg 68: 2431–2436, 2010

do Vale F, Rodrigues ML, Francisco I, Roseiro A, Santos I, Caramelo F, et al: Short-term pharyngeal airway space changes after mandibular advancement surgery in class II patients–a two-dimensional retrospective study. Orthod Craniofac Res 22: 81–86, 2019

Eastman TR: ALARA and digital imaging systems. Radiol Technol 84: 297–298, 2013

Farole A, Mundenar MJ, Braitman LE: Posterior airway changes associated with mandibular advancement surgery: implications for patients with obstructive sleep apnea. Int J Adult Orthodon Orthognath Surg 5: 255–258, 1990

Foltán R, Hoffmannová J, Donev F, Vlk M, Sedý J, Kufa R, et al: The impact of Le Fort I advancement and bilateral sagittal split osteotomy setback on ventilation during sleep. Int J Oral Maxillofac Surg 38: 1036–1040, 2009
Germec-Cakan D, Taner T, Akan S: Uvulo-glossopharyngeal dimensions in non-extraction, extraction with minimum anchorage, and extraction with maximum anchorage. Eur J Orthod 33: 515–520, 2011
Gokce SM, Gorgulu S, Gokce HS, Bengi O, Sabuncuoglu F, Ozgen F, et al: Changes in posterior airway space, pulmonary function and sleep quality, following bimaxillary orthognathic surgery. Int J Oral Maxillofac Surg 41: 820–829, 2012
Graf I, Schumann U, Neuschulz J, Hofer K, Ritter L, Braumann B: Sleep-disordered breathing in orthodontic practice: prevalence of snoring in children and morphological findings. J Orofac Orthop 77: 129–137, 2016
Hochban W, Schurmann R, Brandenburg U, Conradt R: Mandibular setback for surgical correction of mandibular hyperplasia–does it provoke sleep-related breathing disorders? Int J Oral Maxillofac Surg 25: 333–338, 1996
Hourfar J, Kinzinger GSM, Feifel H, Vehr VM, Lisson JA: Effects of combined orthodontic-orthognathic treatment for class II and III correction on posterior airway space: comparison of mono- and bignathic osteotomies. J Orofac Orthop 78: 455–465, 2017
Jacobs C, Jacobs-Muller C, Hoffmann V, Meila D, Erbe C, Krieger E, et al: Dental compensation for moderate class III with vertical growth pattern by extraction of the lower second molars. J Orofac Orthop 73: 41–48, 2012
Jakobsone G, Neimane L, Krumina G: Two- and three-dimensional evaluation of the upper airway after bimaxillary correction of class III malocclusion. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 110: 234–242, 2010
Jeong WS, Kim YC, Chung YS, Lee CY, Choi JW: Change in posterior pharyngeal space after counterclockwise rotational orthognathic surgery for class ii dentofacial deformity diagnosed with obstructive sleep apnea based on cephalometric analysis. J Craniofac Surg 28: e488–e491, 2017
Kawakami M, Yamamoto K, Fujimoto M, Ohgi K, Inoue M, Kirita T: Changes in tongue and hyoid positions, and posterior airway space following mandibular setback surgery. J Craniomaxillofac Surg 33: 107–110, 2005
Keum BT, Choi SH, Choi YJ, Baik HS, Lee KJ: Effects of bodily retraction of mandibular incisors versus mandibular setback surgery on pharyngeal airway space: a comparative study. Korean J Orthod 47: 344–352, 2017
Leonardi R, Annunziata A, Licciardello V, Barbato E: Soft tissue changes following the extraction of premolars in nongrowing patients with bimaxillary protrusion. A systematic review. Angle Orthod 80: 211–216, 2010
Lowe AA: Orthodontists and sleep-disordered breathing. Am J Orthod Dentofacial Orthop 129: 194, 2006
Luther F, Morris DO, Karnezi K: Orthodontic treatment following orthognathic surgery: how long does it take and why? A retrospective study. J Oral Maxillofac Surg 65: 1969–1976, 2007
Marşan G, Vasfi Kuvat S, Oztaş E, Cura N, Süsal Z, Emekli U: Oropharyngeal airway changes following bimaxillary surgery in class III female adults. J Craniomaxillofac Surg 37: 69–73, 2009
Maurya MRK, Kumar CP, Sharma LCM, Nehra LCK, Singh H, Chaudhari PK: Cephalometric appraisal of the effects of orthodontic treatment on total airway dimensions in adolescents. J Oral Biol Craniofac Res 9: 51–56, 2019
McDougall PD, McNamara Jr JA, Dierkes JM: Arch width development in class II patients treated with the Frankel appliance. Am J Orthod 82: 10–22, 1982
Muto T, Yamazaki A, Takeda S, Sato Y: Effect of bilateral sagittal split ramus osteotomy setback on the soft palate and pharyngeal airway space. Int J Oral Maxillofac Surg 37: 419–423, 2008
On SW, Han MW, Hwang DY, Song SI: Retrospective study on change in pharyngeal airway space and hyoid bone position after mandibular setback surgery. J Korean Assoc Oral Maxillofac Surg 41: 224–231, 2015
Ozbek MM, Memikoglu TU, Gogen H, Lowe AA, Baspinar E: Oropharyngeal airway dimensions and functional-orthopedic treatment in skeletal class II cases. Angle Orthod 68: 327–336, 1998
Park JW, Kim NK, Kim JW, Kim MJ, Chang YI: Volumetric, planar, and linear analyses of pharyngeal airway change on computed tomography and cephalometry after mandibular setback surgery. Am J Orthod Dentofacial Orthop 138: 292–299, 2010
Park SB, Kim YI, Son WS, Hwang DS, Cho BH: Cone-beam computed tomography evaluation of short- and long-term airway change and stability after orthognathic surgery in patients with class III skeletal deformities: bimaxillary surgery and mandibular setback surgery. Int J Oral Maxillofac Surg 41: 87–93, 2012
Riley R, Guilleminault C, Herran J, Powell N: Cephalometric analyses and flow-volume loops in obstructive sleep apnea patients. Sleep 6: 303–311, 1983
Riepponen A, Myllykangas R, Savolainen J, Kilpeläinen P, Kellokoski J, Pahkala R: Changes in posterior airway space and hyoid bone position after surgical mandibular advancement. Acta Odontol Scand 75: 73–78, 2017
Ryan CM, Bradley TD: Pathogenesis of obstructive sleep apnea. J Appl Physiol (1985) 99: 2440–2450, 2005
Sahoo NK, Jayan B, Ramakrishna N, Chopra SS, Kochar G: Evaluation of upper airway dimensional changes and hyoid position following mandibular advancement in patients with skeletal class II malocclusion. J Craniofac Surg 23: e623–e627, 2012
Samman N, Tang SS, Xia J: Cephalometric study of the upper airway in surgically corrected class III skeletal deformity. Int J Adult Orthodon Orthognath Surg 17: 180–190, 2002
Santagata M, Tozzi U, Lamart E, Tartaro G: Effect of orthognathic surgery on the posterior airway space in patients affected by skeletal class III malocclusion. J Maxillofac Oral Surg 14: 682–686, 2015
Sharma K, Shrivastav S, Sharma N, Hotwani K, Murrell MD: Effects of first premolar extraction on airway dimensions in young adolescents: a retrospective cephalometric appraisal. Contemp Clin Dent 5: 190–194, 2014
Singh GD, Garcia-Motta AV, Hang WM: Evaluation of the posterior airway space following Biobloc therapy: geometric morphometrics. Cranio 25: 84–89, 2007
Sutherland K, Lee RW, Cistulli PA: Obesity and craniofacial structure as risk factors for obstructive sleep apnoea: impact of ethnicity. Respirology 17: 213–222, 2012
Tsai WH, Remmers JE, Brant R, Flemons WW, Davies J, Macarthur C: A decision rule for diagnostic testing in obstructive sleep apnea. Am J Respir Crit Care Med 167: 1427–1432, 2003
Tselnik M, Pogrel MA: Assessment of the pharyngeal airway space after mandibular setback surgery. J Oral Maxillofac Surg 58: 282–285, 2000 Discussion 285–287
Uslu-Akcam O, Gokalp H: Tongue size and posterior airway space changes in class III malocclusion after maxillomandibular surgery: a retrospective study. Int J Orthod Milwaukee 26: 37–43, 2015
Valiathan M, El H, Hans MG, Palomo MJ: Effects of extraction versus non-extraction treatment on oropharyngeal airway volume. Angle Orthod 80: 1068–1074, 2010
Verbraecken J, Hedner J, Penzel T: Pre-operative screening for obstructive sleep apnoea. Eur Respir Rev 26, 2017
Vig KD, Ellis 3rd E: Diagnosis and treatment planning for the surgical-orthodontic patient. Dent Clin North Am 34: 361–384, 1990
Vizzotto MB, Liedke GS, Delamare EL, Silveira HD, Dutra V, Silveira HE: A comparative study of lateral cephalograms and cone-beam computed tomographic images in upper airway assessment. Eur J Orthod 34: 390–393, 2012
Wang Q, Jia P, Anderson NK, Wang L, Lin J: Changes of pharyngeal airway size and hyoid bone position following orthodontic treatment of class I bimaxillary protrusion. Angle Orthod 82: 115–121, 2012
Wirthlin JO, Shetye PR: Orthodontist's role in orthognathic surgery. Semin Plast Surg 27: 137–144, 2013
Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S: The occurrence of sleep-disordered breathing among middle-aged adults. N Engl J Med 328: 1230–1235, 1993
Yu LF, Pogrel MA, Ajayi M: Pharyngeal airway changes associated with mandibular advancement. J Oral Maxillofac Surg 52: 40–43, 1994 Discussion 44