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Predictability of pharyngeal airway space dimension changes after orthognathic surgery in class II patients: A mathematical approach

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ABSTRACT

Introduction: Angle Class II malocclusion due to mandibular retrognathia is a common dentofacial deformity. It is well known that mandibular advancement increases pharyngeal airway dimensions. The aim of this study was to evolve a mathematical method for predicting posterior pharyngeal airway space (PAS) changes based on 2D lateral cephalographic radiographs (LCRs) and expected extent of mandibular advancement prior to BSSO.

Materials and methods: Linear regression analyses were performed in order to investigate the relation between the posterior airway space and mandibular advancement. LCRs were carried out to assess skeletal landmarks and pharyngeal airway space pre- (T0) and postoperatively (T1). To detect changes postoperatively, the posterior airway space was divided into three units: nasopharyngeal airway space (superior airway space — SPAS), oropharyngeal airway space (mid airway space — MAS) and hypopharyngeal airway space (inferior airway space — IAS). The differences between the distances of distinct measurement points (DIFF) were measured pre- and postoperatively. DOA referred to the distance of mandibular advancement and DP to the distance between the measurement points preoperatively. The parameters a , b_1 and b_2 were the regression coefficients that were determined separately for each unit (SPAS, MAS, and IAS).

Results: 49 patients (16 male and 33 female) with a mean age of 27.2 years (SD: 10.09), ranging from 18 to 51 years, who underwent mandibular advancement surgery (BSSO) were enrolled in this study. The mean distance of mandibular advancement was 5.05 mm (SD: 1.63). Regarding SPAS and IAS, mandibular advancement did not affect dimensions significantly: SPAS DIFF, $0.33 \text{ mm} \pm 1.13 \text{ mm}$ ($b_1, p = 0.0881$; $b_2, p = 0.087$); IAS DIFF, $0.66 \text{ mm} \pm 2.45 \text{ mm}$ ($b_1, p = 0.342$; $b_2, p = 0.765$). DOA and DP did not influence DIFF significantly in both sections. Regarding MAS, the mean effect of mandibular advancement was an expansion of $2.47 \text{ mm} \pm 2.24$. The linear regression model showed a statistically significant ($b_1, p = 0.0064$; $b_2, p = 0.0240$) influence of DOA and DP on DIFF in posterior airway dimensions pre- and postoperatively.

Discussion: Based on preoperative LCR imaging data, a linear regression model was developed as a mathematical approach to allow prediction of PAS development in patients with Angle Class II malocclusions of different degrees. Increasing mandibular advancement was shown to be linked to increasing PAS, while a greater distance between the measuring points preoperatively led to smaller predicted PAS increases postoperatively.

Conclusion: Predicting pharyngeal airway space (PAS) development after mandibular advancement by analysing lateral cephalometric radiographs (LCR) may be useful in the screening and treatment of obstructive sleep apnea syndrome (OSAS) patients. Our mathematical approach is a simple and sustainable prediction tool based on LTR data for patients with Class II malocclusions.

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1. Introduction

Angle Class II malocclusion is a common dentofacial deformity with a prevalence of 15% in Caucasians. In one third of those patients the distal occlusion is caused by a micrognathic or retrognathic mandible (McLain and Proffit, 1985). In these cases, bone discrepancies can be corrected by bilateral sagittal split ramus osteotomy (Lye, 2008). Initially orthognathic surgery is intended to restore dental occlusion and soft tissue irregularities (Rustemeyer and Gregersen, 2012). In addition, it is known that maxillomandibular hypoplasia has the potential to decrease the size of the pharyngeal airway space (Gonçales et al., 2014). Against this backdrop, corrections to deformities of the maxillomandibular complex may lead to an increased pharyngeal airway space volume in cases of forward displacement of the mandible, or a decreased airway space in cases of mandibular setback (Mehra et al., 2001; Liukkonen et al., 2002). However, some authors assert that mandibular setback has no significant effect on pharyngeal airway space (Kawakami et al., 2005). The assumption that mandibular setback narrows the pharyngeal airway space suggests that mandibular advancement would improve the sleep quality of patients suffering from obstructive sleep apnea syndrome (OSAS). In these cases an operative intervention could be justified for the treatment of existing symptoms of the sleep disorder complex (Turnbull and Battagel, 2000).

Recent studies have emphasized the use of three-dimensional (3D) scans for pharyngeal airway space investigations, maintaining that anatomical characteristics can be depicted more accurately (Lenza et al., 2010) and that 2D (lateral cephalometric radiographic – LCR) analysis may even be inadequate for 3D structure evaluations (Schulze et al., 2013). By contrast, the more complex analysis of 3D based approaches tend to be vulnerable to certain potential pitfalls (Sutthiprapaporn et al., 2008; Kim et al., 2014). However, 2D measurement using cephalometric data is a widespread method for craniofacial evaluation (Tourné, 1990), and results in radiation exposure that is several times lower than that associated with 3D imaging techniques (Wrzesien and Olzewski, 2017).

Although advancements in the maxillomandibular complex seem to have measurable effects on the dimensions of the posterior pharyngeal airway space, and some studies already state the extent

to which 2D advancement dimensions affect cephalometric measurements (Proffit et al., 2007), the prediction of changes to the posterior airway space after a planned advancement of the mandible has not been established mathematically.

The aim of this study was to develop a mathematical method for predicting changes to the posterior pharyngeal airway space on the basis of 2D (LCR) cephalometric data and knowledge of the extent of mandibular advancement prior to BSSO.

2. Materials and methods

2.1. Patients

Data were collected from 49 Caucasian patients (16 male and 33 female) aged between 18 and 51 years (mean 27.19; SD 10.09) who underwent mandibular advancement surgery between 2013 and 2015. We did not expect any gender-dependent differences in measurements, so the subjects were combined for subsequent analyses. The study included patients with Class II malocclusion who underwent mandibular advancement. The surgical treatment in all included cases consisted of bilateral sagittal split osteotomy (BSSO). Osteosynthesis was performed with titanium miniplates (Mini 2000, 2.0; Mondeal, Mühlheim a.d., Donau, Germany) The overall mean mandibular advancement distance was 5.05 mm (SD 1.63). Postoperative X-ray imaging was performed 8–12 (mean 9) months after BSSO. Exclusion criteria were previous orthognathic surgery, congenital craniofacial anomalies, presence of OSAS, and additional genioplasty.

2.2. Imaging

All lateral cephalometric radiographs (LCRs) in this study were obtained with an Orthophos XG (Sirona, Bensheim, Germany), and used to assess skeletal landmarks and pharyngeal airway dimensions before surgery (T0) and postoperatively (T1). During the scanning procedure patients were standing in an upright position with the head positioned along the Frankfurt horizontal plane, stabilized by a forehead and chin support. Each patient was instructed to hold still and not to swallow or move their tongue.

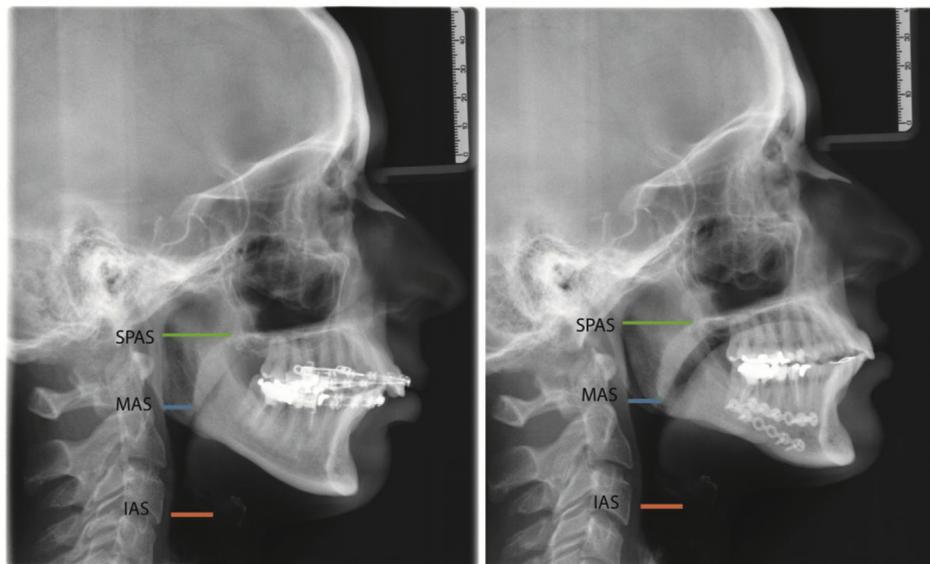


Fig. 1. Changes in development of PAS in LCR: (left) before surgery; (right) after surgery (mandibular advancement).

2.3. Measurement of PAS

All LCR scans were analyzed using ONYX CEPH software (Version 3.2.4.0, Image instruments, Chemnitz, Germany) operated on a Hewlett Packard® PC running Windows® XP. The following cephalometric landmarks were used for analysis (Fig. 1):

The posterior nasal spine (PNS), the most posteroinferior point of the uvula (U) and the epiglottic vallecula (V); the upper posterior pharyngeal wall (SPA_{post} — intersection of a perpendicular line from PNS with the posterior pharyngeal wall); the middle posterior pharyngeal wall (MAS_{post} — intersection of a perpendicular line from U with the posterior pharyngeal wall); and the inferior posterior pharyngeal wall (IAS_{post} — intersection of a perpendicular line from V with the posterior pharyngeal wall).

The posterior airway space was measured using the following distances, in millimetres (mm):

- PNS — SPA_{post}, representing the superior, nasopharyngeal airway space (SPAS)
- U — MA_{post}, representing middle, oropharyngeal airway space (MAS)
- V — IA_{post}, representing the inferior, hypopharyngeal posterior airway space (IAS)

Thus, the posterior airway space was divided into three units.

2.4. Statistics

Data were coded in Microsoft® Excel® (Version 2011 for Macintosh) and statistically evaluated using R (Version 3.4.3, R Core Team, Vienna, Austria). Regression analyses were performed in order to investigate the relationship between the posterior airway space and mandibular advancement. For each of the three units (SPAS, MAS, and IAS) a multiple linear regression model was applied to the difference between the posterior airway space distances measured pre- and postoperatively as the outcome variable. The distance of mandibular advancement and airway space measurement before surgery were considered as explanatory variables. The corresponding model equation was:

$$DIFF = a + b_1 \times DOA + b_2 \times DP + \epsilon$$

where DIFF is the difference between the distances (e.g. U minus posterior pharyngeal wall) pre- and postoperatively, DOA is the distance of mandibular advancement, and DP is the distance between the measurement points (e.g. U minus posterior pharyngeal wall) preoperatively. The parameters *a*, *b*₁, and *b*₂ are the regression

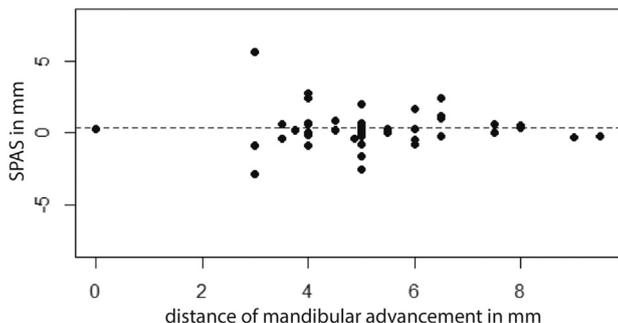


Fig. 2. Distribution of measurement points for SPAS: (x-axis) distance of advancement in mm; (y-axis) differences in PAS in SPAS; dotted line = mean value.

coefficients, which were determined separately for each unit (SPAS, MAS, and IAS), and ϵ is the error term.

Wald tests were used for determining the significance of the regression coefficients. *p*-values ≤ 0.05 were regarded as statistically significant.

3. Results

3.1. Patient data

Of 49 patients enrolled, 16 (32.65%) were males and 33 (67.35%) were females. The mean age was 27.19 ± 10.09 years, ranging from 18 to 51. The mean distance of mandibular advancement was $5.09 \text{ mm} \pm 1.67$.

3.2. Posterior airway space

3.2.1. Nasopharyngeal airway space (SPAS)

The mean effect (DIFF) of mandibular advancement surgery on the nasopharyngeal airway space was an expansion of $0.33 \text{ mm} \pm 1.13$. According to *b*₁ (*p* = 0.881) and *b*₂ (*p* = 0.087), DOA and DP do not influence DIFF significantly (Fig. 2, Table 1).

3.2.2. Oropharyngeal airway space (MAS)

The mean effect (DIFF) of mandibular advancement surgery on the oropharyngeal airway space was an expansion of $2.47 \text{ mm} \pm 2.24$.

The linear regression model showed a statistically significant (*b*₁, *p* = 0.0064; *b*₂, *p* = 0.0240) influence of DOA and DP on the difference (DIFF) in posterior airway dimension pre- and postoperatively (Fig. 3, Table 2). According to Table 2, in this case the regression coefficients *b*₁ and *b*₂ can be interpreted as follows:

*b*₁: If the distance of advancement (DOA) decreases/increases by 1 mm, surgery leads to a postoperative decrease/increase in distance between the MAS measuring points of, on average, 0.5 mm (at constant DP).

*b*₂: If the DP decreases/increases by 1 mm, the distance between the measuring points of MAS will increase/decrease by, on average, 0.23 mm (at constant DOA).

Hence one can say:

- The greater the distance of advancement (DOA), the larger is the predicted difference between the pre/post measuring points (DIFF).
- The greater the distance between the measuring points preoperatively (DP), the smaller is the predicted DIFF postoperatively.

Sample calculations:

Sample 1: (Assuming that the hypothetical DOA would be 5 mm in a patient with a DP of 5 mm, the predicted DIFF would be):

$$2.2 \text{ mm} + 0.5 \times 5 \text{ mm} - 0.23 \times 5 \text{ mm} = 3.55 \text{ mm}$$

In this example, PAS at MAS will increase by 3.55 mm due to mandibular advancement of 5 mm.

Sample 2: (Assuming that the hypothetical DOA would be 7 mm in a patient with a DP of 2 mm, the predicted DIFF would be):

Table 1
Regression coefficients and corresponding *p*-values for SPAS.

Coefficient	Estimated value	<i>p</i> -value
<i>a</i>	2.19184	0.0561
<i>b</i> ₁	0.01759	0.8808
<i>b</i> ₂	-0.08236	0.0872

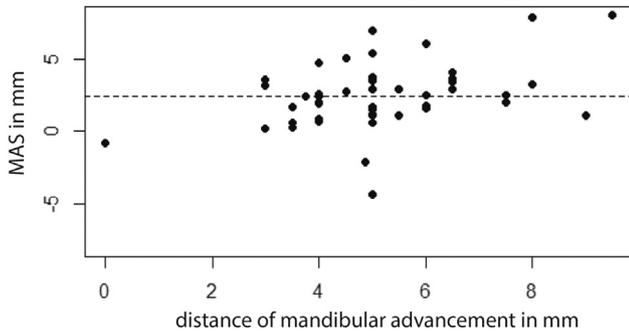


Fig. 3. Distribution of measurement points for MAS: (x-axis) distance of advancement in mm; (y-axis) differences in PAS in MAS; dotted line = mean value.

Table 2
Regression coefficients and corresponding p-values for MAS.

Coefficient	Estimated value	p-value
a	2.19284	0.1211
b_1	0.49388	0.0064
b_2	-0.23094	0.0240

$$2.2 \text{ mm} + 0.5 \times 7 \text{ mm} - 0.23 \times 2 \text{ mm} = 5.24 \text{ mm}$$

Here the increase in PAS is caused by the larger DOA and smaller DP.

3.2.3. Hypopharyngeal airway space (IAS)

The mean effect of mandibular advancement surgery on the hypopharyngeal airway space was an expansion of $0.66 \text{ mm} \pm 2.45$. According to b_1 ($p = 0.342$) and b_2 ($p = 0.765$), DOA and DP did not influence DIFF significantly (Fig. 4, Table 3).

4. Discussion

This study assessed the effect of mandibular advancement for Class II malocclusions on the pharyngeal airway space (PAS). Further, we developed an easy mathematical approach for the prediction of changes in the airway space after surgical procedure, based on cephalometric measurements. When attempting to develop a statistical model that is capable of predicting surgery outcomes, possible sources of error should be eradicated. Therefore, we selected solely patients with Angle Class II diagnosis and mandibular advancement only. Well aware of the fact that

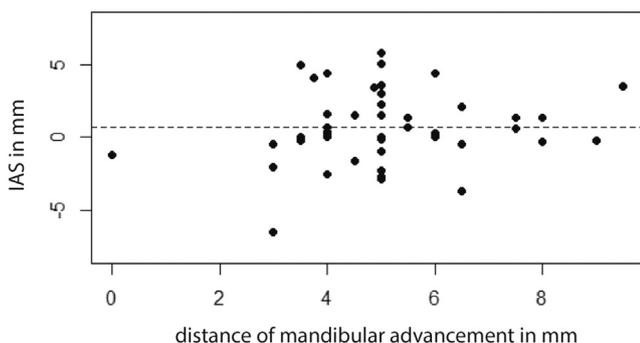


Fig. 4. Distribution of measurement points for IAS: (x-axis) distance of advancement in mm; (y-axis) differences in PAS in IAS; dotted line = mean value.

Table 3
Regression coefficients and corresponding p-values for IAS.

Coefficient	Estimated value	p-value
a	0.16375	0.942
b_1	0.20605	0.342
b_2	-0.03696	0.765

bimaxillary advancement has a greater effect on PAS, we decided to focus on BSSO outcomes to obtain a comparable and reliable study group.

We enrolled a total of 49 patients (16 male, 33 female) with a mean age of 27.2 years (SD: 10.09), ranging from 18 to 51 years.

The mean distance of mandibular advancement was 5.05 mm (SD: 1.63). As already expected, mandibular advancement increased the PAS of patients treated with BSSO, according to 2D cephalometric analysis. Nevertheless, significant increases were measured solely in the oropharyngeal airway space (MAS). The most likely explanation of our findings may be the anatomical changes engendered by BSSO. By performing this procedure, the predominant impact on anatomical structures is the elevation and superior–anterior movement of the hyoid bone (Riepponen et al., 2016). However, the adaptive changes to the soft tissues, muscles, and fascias are complex, and show interindividual differences. The two layers of muscle wall of the pharynx must be taken into consideration. While the external circular muscle layer consists of three constrictor muscles, the internal layer of muscles is arranged longitudinally (Moore and Agur, 1995). Further, baseline skeletal morphology, respiration, head posture, and craniofacial anatomy are all known to affect BSSO surgery outcome (Mobarak et al., 2001). Some authors purport that clinically significant dimensional changes, involving measured increases of 2 mm and more, are observed in lateral cephalograms (Dolce et al., 2002; Joss et al., 2010). In bimaxillary osteotomy rotation, clockwise as well as counterclockwise movements were observed to have additional and diverse effects on PAS increase (Goncalves et al., 2006; Zinser et al., 2013), which may also apply to some extent to BSSO. While it is generally accepted that postoperative stability is the major contributing factor to long-term orthognathic results, effects on hyoid-bone position and PAS are contentious issues (Eggensperger, 2006; Goncalves et al., 2006).

While aiming to establish a simple mathematical approach that is possibly utilizable as a screening tool for PAS development in Angle Class II patients, a cost-effective, easily implemented, and reasonable method, with low radiation exposure, is required. Lateral cephalometric radiographs meet these criteria most adequately. Widely available and inexpensive, LCR appears to be the most suitable technique for evaluating skeletal and soft-tissue abnormalities, as well as PAS.

The degree of accuracy of LCR-based measurement of PAS in comparison with 3D techniques is an area of debate. Some authors suggest that the accuracy of LCR-based PAS measurements correlates strongly with that of 3D CT (Kochel and Meyer-Marcotty, 2013). In contrast, 3D scans can provide accurate information on changes in the PAS in terms of volume, depth, and length. LCR is based on a superimposition of osseous and soft-tissue craniofacial structures, and provides two-dimensional measurements only (Muto et al., 2008). Consequently, the axial plane cannot be assessed (Abramson et al., 2010). Hence, the visualization of two-dimensional PAS dilatation allows no definitive statement about changes to the PAS in the axial plane (Fig. 5).

3D reconstructions of MRI and CT data, or CBCT scans, are generally able to provide more precise data on soft tissue boundaries, empty spaces, and visualization along all three axes (Achilleos

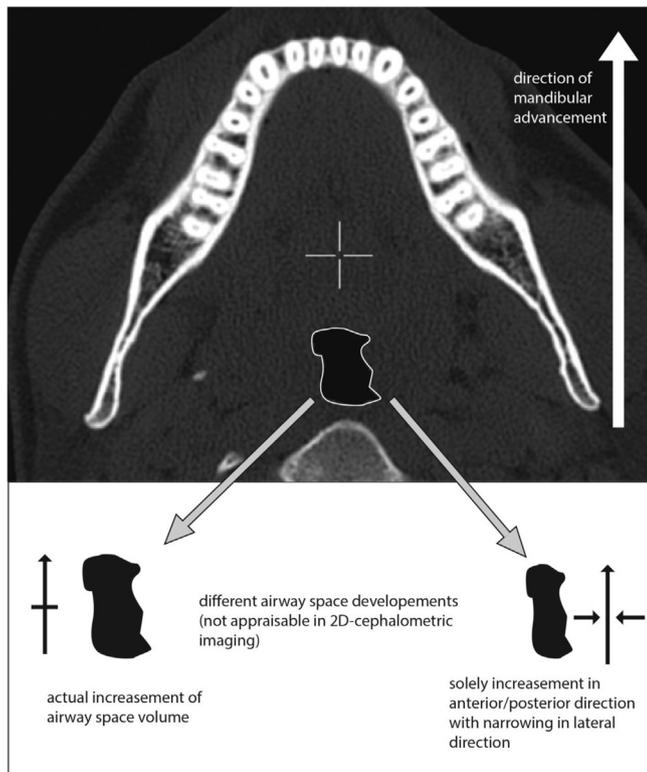


Fig. 5. Possible changes in airway space development after mandibular advancement; example shown in axial CT scan.

et al., 2000; Saitoh, 2004; Stratemann et al., 2010; Sears et al., 2011). Nevertheless, the high radiation exposure of up to 2000 μSv associated with spiral CT (Chang et al., 2015) undermines this as a technique for assessing PAS. CBCT's lower radiation exposure of 200–400 μSv (Mah and Hatcher, 2004) makes it more suitable for operation planning. LCR exhibits by far the lowest radiation exposure (1.1–2.3 μSv), and is therefore most suitable as a standard routine technique for delineating the PAS and planning orthognathic surgery (Visser et al., 2001).

Our formula is based on a multiple linear regression model. The sample calculations determine to what extent the PAS increases. By knowing the distance between the measuring points before and after surgical treatment (DIFF). As expected, the higher the DOA, the larger was the predicted DIFF. Furthermore, the formula showed that a larger distance between the measuring points preoperatively (DP) led to a smaller predicted DIFF postoperatively. This meant that patients with a narrow baseline PAS benefited most from mandibular advancement. These findings are in accordance with results of other studies (Yu et al., 1994; Riepponen et al., 2016).

It is well known that oropharyngeal and craniofacial structures, including mandibular retrognathia, short mandibular length, and low hyoid position, are associated with a narrow PAS and consequently higher risk of developing OSAS (Hoekema et al., 2003). Nonetheless, a number of important issues should be taken into account when considering orthognathic surgery as a treatment option for OSAS. Possible multifactorial skeletal relapse after mandibular advancement is a crucial issue, with no reliable or predictable outcome. Previous studies have shown that achieved sagittal PAS increases might relapse over time (Joss et al., 2010; Sahoo et al., 2012). Additionally, weight gain, ageing, and proliferation of pharyngeal fat tissue tend to change PAS structure over a longer period of time (El and Palomo, 2008).

Furthermore, PAS and craniofacial angle seem to be closely related (Muto et al., 2002). Hyoid bone position is influenced by the position of the head (Winnberg et al., 1988), and positioning of the head in pre- and postoperative imaging is not precisely reproducible (Solow and Siersbaek-Nielsen, 1992), while orthognathic surgery can change the position of the head, due to its effects on anatomical structures in the craniofacial system (Kim et al., 2014).

LCR and CBCT are the most widely used imaging techniques for dysgnathia and for correlating measurements of the PAS. Both imaging protocols are based on an upright position of the patient. However, in patients suffering from OSAS, the narrowing of PAS is most crucial during sleep in a horizontal position.

An additional weakness of this study is the rather low number of subjects. Future studies on OSAS with comparable protocols, long-term follow-up examinations, larger numbers of patients, and a special focus on head positioning during imaging should be performed.

5. Conclusion

Our mathematical approach allows the prediction of PAS development by using measurements on preoperative LCR imaging of patients with Angle Class II malocclusions of different degrees. Our study showed that increasing mandibular advancement was linked with increasing PAS, while greater distances between the measuring points preoperatively led to smaller predicted PAS increases postoperatively.

However, in order to develop this formula as a screening instrument for OSAS patients and PAS evaluation, larger studies with reliable protocols are required.

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Conflicts of interest

We declare that we have no conflicts of interest. We received no funding.

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