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Assessment of the impact of fixed functional appliances on airway in patients receiving orthodontic treatment: A systematic review

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Abstract
Introduction: Mandibular deficiency-related Class II malocclusion is widely recognized as a potential risk factor for upper airway sleep disorders such as Obstructive Sleep Apnea (OSA), as it can compromise the oropharyngeal airway. Several studies have indicated that functional appliances, commonly used to correct Class II malocclusions, may help to increase airway dimensions, thereby reducing the risk of respiratory issues. This systematic review aims to evaluate the effectiveness of fixed functional appliances on airway dimensions in patients undergoing orthodontic treatment.
Material and Methods: A total of 19,400 articles were identified through four search engines (PubMed, Medline, Cochrane Library, Google Scholar, and clinicaltrials.gov). After applying the inclusion criteria, 10 studies were selected for analysis. The studies included were human clinical trials, covering randomized controlled trials (RCTs), controlled clinical trials (CCTs), observational studies, and both prospective and retrospective studies. Studies were included if they provided clinical data on the effectiveness of fixed functional appliances on airway dimensions in orthodontic patients. Only studies published between January 2000 and March 30, 2023, were considered.
Results: The analysis revealed that fixed functional appliances have a positive impact on airway dimensions in patients undergoing orthodontic treatment, particularly those with retrognathic mandibles. Significant enlargement of the airway was observed, predominantly in the oropharyngeal and hypopharyngeal regions, while the nasopharyngeal region showed comparatively smaller changes.

Keywords: Elastic modulus, flexural strength, provisional restorative materials

Introduction
Orthodontists struggle to change facial profiles, particularly in Skeletal Class II malocclusion with a convex profile. This condition involves dental misalignment due to factors like mandibular retrusion [3-5]. Growth modification is the preferred solution to address jaw imbalances and profile issues [6].

Recent studies indicate that beyond craniofacial growth, the sagittal skeletal pattern influences airway size changes. Specific craniofacial traits are linked to respiratory problems alongside neuro-muscular tone and inflammation [8]. Notably, individuals with Class II skeletal imbalance and mandibular retrusion are more likely to have narrower airways and potential respiratory issues [9-12], particularly for conditions like Obstructive Sleep Apnea (OSA). The forward movement of the mandible influences the position of the hyoid bone and enlarges the pharyngeal airway space [14-16]. Functional appliances used for correcting Class II malocclusions can increase airway dimensions, thereby alleviating respiratory problems [18, 19]. Advancing the mandible with these appliances not only improves the position of the hyoid bone but also enhances the morphology of the upper airway. For adolescents with mandibular hypoplasia who face issues with appliance compliance, surgical options are often considered [20].

The research highlights how mandibular position influences airway size, impacting potential respiratory issues, including sleep disorders. dimensions [22].

Functional appliances, like the Herbst appliance, are used to treat Class II malocclusions 21 and have shown promise in improving airway. The objective of this study is to assess the impact of fixed functional appliances on airway dimensions in patients undergoing orthodontic treatment.

Materials and Methods

Protocol and Registration: The protocol for this systematic review was prospectively registered on PROSPERO (www.crd.york.ac.uk/PROSPERO; Registration number: CRD42023413411).

Eligibility Criteria

1. Participants included both children and adults with malocclusion who required orthodontic treatment.
2. Eligible studies were clinical trials involving humans, including Randomized Controlled Trials (RCTs), Controlled Clinical Trials (CCTs), as well as observational, prospective, and retrospective studies.
3. Only studies that reported clinical outcomes evaluating the effectiveness of fixed functional appliances on the airway in patients undergoing orthodontic treatment were included.
4. Studies published between January 2000 and March 30, 2023, were considered.

Exclusion Criteria

1. Studies based on In vitro or animal studies and questionnaire surveys,
2. Studies published in languages other than English are excluded.

Information Strategy

The following search strategy was used for the identification of studies. Two authors searched electronic databases on PubMed, Medline, and Cochrane Library. Additional sources (Google Scholar, clinicaltrials.gov) were manually searched for additional trials or protocols till 30th March 2023 with the keywords or combination: Fixed functional appliances, Randomized Controlled Trials, Clinical Controlled Trials, Airway, and Orthodontics.

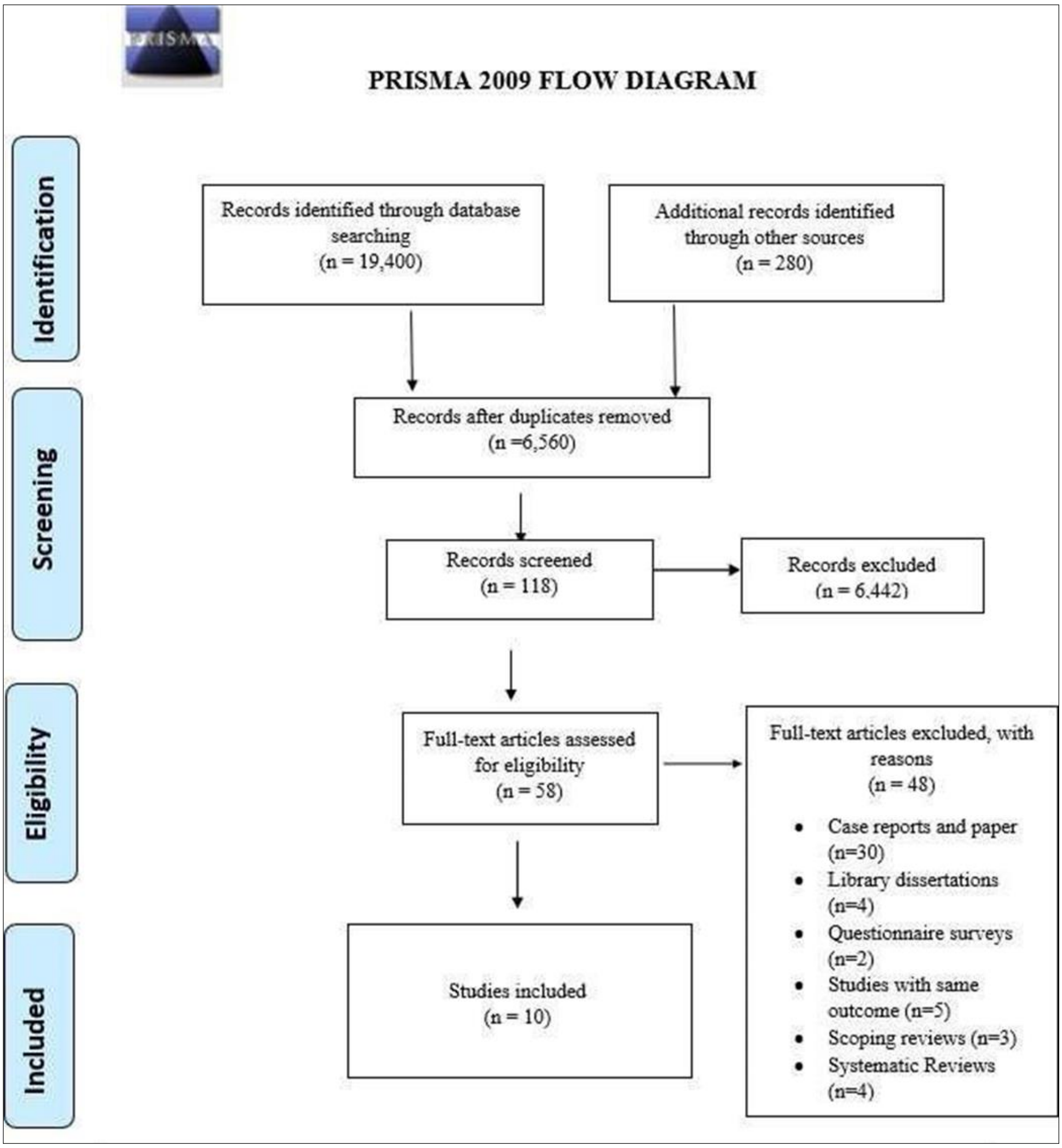

Fig 1: PRISMA Flow Diagram showing the literature search protocol.

Table 1: Study design and patient of included study

	Author	Year	Study design	Age range	Sample size
1	Maria Denisa Statie *et al.* [23]	2022	RCT	13.8±2 years	24
2	Varun Govindraj *et al.* [24]	2021	Prospective Clinical Study	16-24 years	15
3	Yousef Abdalla *et al.* [25]	2020	Restrospective study	Avg 12 years	73
4	Paula Moreira Oliveira *et al.* [26]	2020	Prospective Clinical study	12.0 to 16.9 years	42
5	Woei Li Koay *et al.* [27]	2016	Retrospective Comparative study	12.8 ± 1.3 years	27
6	Mevlut Celikoglu *et al.* [28]	2016	Retrospective Study	13.11 ± 1.29 years and 12.84 ± 1.27 years)	30
7	Nehir Canigur Bavbek *et al.* [29]	2015	Retrospective study	13.62 ± 1.92 years	18
8	Amjad Al Tak *et al.* [30]	2015	Prospective Study	11 years 4 months	25
9	Fulya Ozdemir *et al.* [31]	2014	Retrospective study	17.3±4.2 years	46
10	Ashok Kumar Jena *et al.* [32]	2013	Retrospective study	8 to 14 years	83

Table 2: Risk of bias evaluation for the studies

Checklist	Abdalla *et al.* 2019	Al Taki *et al.* 2015	Bavbek *et al.* 2015	Celikoglu *et al.* 2016	Govindraj *et al.* 2021	Jena *et al.* 2013	Koay *et al.* 2016	Oliveira *et al.* 2020	Ozdemir *et al.* 2014	Statie *et al.* 2022
The study clearly identifies the cause (use of fixed functional appliances) and the effect (changes in airway dimensions), establishing a direct cause-and-effect relationship.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Were the participants in the comparisons comparable?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Did participants receive uniform treatment or care apart from the intervention?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Was a control group included?	Y	Y	Y	Y	N	Y	N	Y	N	Y
Were multiple outcome measurements taken before and after the intervention?	N	N	N	N	N	N	N	N	N	N
Was the follow-up thorough, and were group differences analyzed?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Were the outcomes assessed uniformly among participants?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Were the measurements of outcomes dependable?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Was suitable statistical analysis employed?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Yes (%)	88.9	88.9	88.9	88.9	77.8	88.9	77.8	88.9	77.8	88.9
Risk of Bias	L	L	L	L	L	L	L	L	L	L

H: High risk of bias; M: Moderate risk of bias; L: Low risk of bias

The study quality and bias were assessed using the Joanna Briggs Institute Critical Appraisal Checklist for Quasi-Experimental Studies. This tool consists of nine questions related to study design, with responses of 'yes' (indicating higher quality), 'no' (indicating lower quality), or 'unclear.' The bias risk percentage was calculated based on the number of 'yes' responses. Any question marked as 'NA' was excluded from the calculation, following Joanna Briggs Institute guidelines. A score below 49% was categorized as high risk of bias, 50% to 70% as moderate risk, and above 70% as low risk. All ten studies assessed showed a low risk of bias.

Statistical Analysis

Meta-analyses were conducted using the random effects model via RevMan 5.4 (RevMan 5.4, The Nordic Cochrane Centre, and Copenhagen). Heterogeneity was evaluated using the Q test and quantified by I^2 statistics. Pre-treatment and post-treatment airway dimensions from the selected studies were compared. If substantial heterogeneity was detected ($I^2 > 50\%$), a random effects model was used; otherwise ($I^2 < 50\%$), a fixed effects model was applied.

Comparison of Pre-treatment and Post-treatment Airway Dimensions: A meta-analysis was carried out on nine studies with 18 comparisons that met the criteria for quantitative analysis. The overall results are displayed in a forest plot. As heterogeneity was low ($I^2 = 0\%$), a fixed effects model was used. Post-treatment airway dimensions showed an increase, with a standardized mean difference of -0.33 (95% CI: -0.48 to -0.17; Z = 4.16). The difference between pre-treatment and post-treatment dimensions was statistically significant ($p<0.0001$).

Results

Out of the 19,400 articles screened, 19,390 were excluded, leaving only 10 studies included in this systematic review. These studies primarily focused on the effectiveness of fixed functional appliances on the airway, with 18 comparisons analyzed. There was strong agreement between the two reviewers, indicated by a high kappa coefficient (k > 0.91). The selection process for studies is illustrated in Figure 1, and Table 2 presents the study designs and sample data of the included studies. Across all 10 studies, the effectiveness of fixed functional appliances was evaluated over various time spans, comparing pre-treatment and post-treatment records using different methods (2D and 3D imaging).

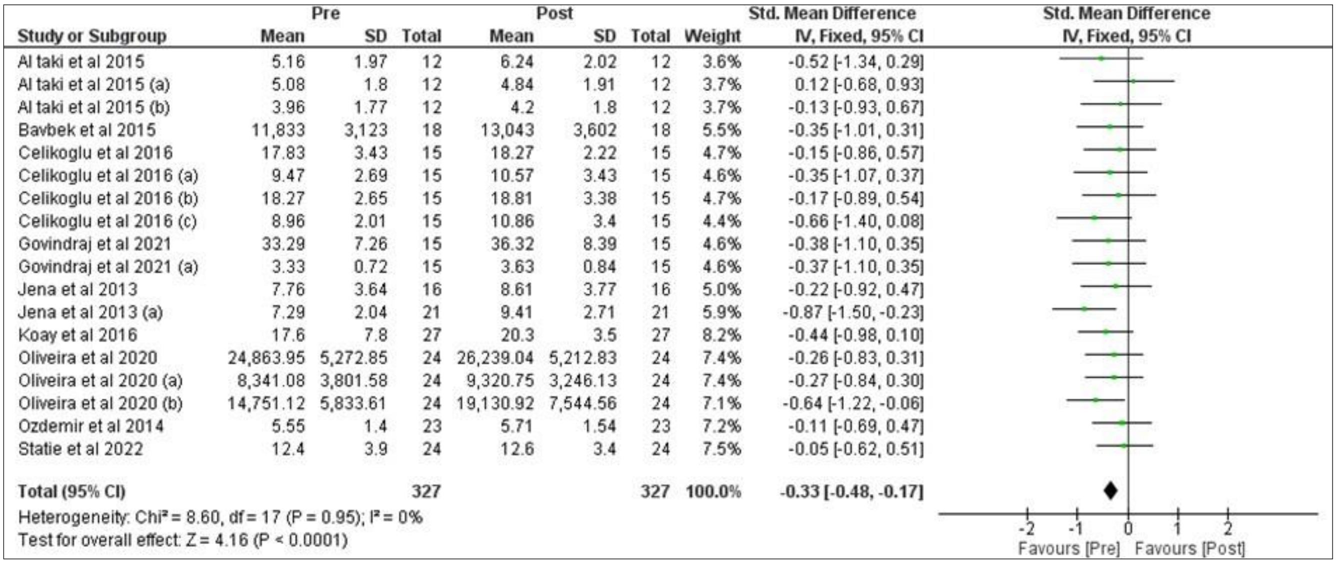

Fig 2: Comparison of pre and post treatment

Table 3: The Effectiveness of fixed functional appliances on airway

Author	Year	Study design	Assesment method	Sample size	Appliance	Part of airway studied	Effectiveness on airway	Time of FFA therapy
Maria Denisa Statie *et al.* [23]	2022	RCT	Lateral cephalogram	24	Mandibular Anterior Repositioning Appliance	Saggital Airway	No significant favourable changes	2 yrs
Varun Govindraj *et al.* [24]	2021	Prospectiv e clinical study	Lateral cephalogram ,Acoustic Pharyngometr y	15	Forsus Fatigue Resistant Device attachments	Upper Airway	Significant changes were observed in the mean upper airway volume and area after treatment.	NR
Yousef Abdalla *et al.* [25]	2020	Retrospect ive study	Cone Beam Computed Tomography	73	Fixed Functional Appliances	Upper Airway	A significant increase was noted in airway volume and the minimum cross-sectional area following treatment.	NR
Paula Moreira Oliveira *et al.* [26]	2020	Prospectiv e clinical study	Cone Beam Computed Tomography	42	Herbst appliance	Upper Airway	Significant increase in oropharynx, but not significant volumetric modifications in	1 yrs
Woei Li Koay *et al.* [27].	2016	Retrospect ive comparativ e study	Lateral cephalogram	27	Herbst appliance	Upper airway	Significant increase in oropharyngeal and hypopharyngea l airway dimensions	3±1.1 yrs
Mevlut Celikoglu *et al.* [28].	2016	Retrospect ive study	Lateral cephalogram	30	Herbst appliance skeletal anchored Forsus FRD EZ appliance	Upper and lower pharynge al airway	Both upper and lower pharyngeal airway dimensions increased in both groups, with a significant increase observed in the lower pharyngeal dimension, particularly in the skeletal anchored group.	NR
Nehir Canigur Bavbek *et al.* [29]	2015	Retrospect ive study	Lateral cephalogram	18	Forsus fatigue resistant device	Orophar yngeal airway	Positive effects in oropharyngeal airway dimensions	1 year
Amjad Al Tak *et al.* [30]	2015	Prospectiv e study	Lateral cephalograms	25	Forsus fatigue resistant device	Pharynge al airway	UPAD: No effect MPAD: No effect LPAD significantly increased	3months- 1 year
Fulya Ozdemir *et al.* [31]	2014	Retrospect ive Study	Lateral cephalogram	46	Forsus fatigue resistant device	Posterior airway	No significant posterior airway changes	5 months 13 days ±1 month 4 days
Ashok Kumar Jena *et al.* [32]	2013	Retrospect ive study	Lateral cephalogram	83	Mandibular Protraction Appliance -IV	Pharynge al airway passage	A significant decrease in soft palate length was observed. Improvement in soft palate inclination was noted. There was a significant increase in oropharynx depth.	NR

Discussion

Functional appliances have been in use since the 1930s. Skeletal Class II malocclusion, accounting for 19-20% of all malocclusions globally, is the most prevalent form [33, 34]. The most common cause is a hypoplastic mandible in relation to cranial base structures [35], which often results in restricted airway patency. Orofacial structural development is genetically driven and continues until around 13-15 years of age. In adolescents with growing skeletal Class II malocclusion and mandibular retrognathism, the soft palate and tongue are positioned posteriorly, contributing to the narrowing of the oropharyngeal airway space [24]. This review includes patients in their late pubertal stages or after pubertal growth spurts because fixed functional appliances are typically used after such growth spurts, while conventional appliances are employed during active growth [35].

The depth of the nasopharyngeal airway did not exhibit significant changes between pre- and post-treatment stages with fixed functional appliances30. However, some studies reported increased upper airway dimensions during the use of the Herbst and Skeletal Anchored Forsus FRD EZ appliances [25-28].

In certain studies, the middle pharyngeal airway depth (MPW) remained unchanged, even after mandibular advancement. This suggested that the forward positioning of the mandible did not alter MPW due to the lack of soft palate thickening or length reduction30. However, several studies refuted this, demonstrating that fixed functional appliances significantly increased oropharyngeal airway dimensions26-30.

The lower pharyngeal airway depth (LPAD) or the depth of the hypopharyngeal/laryngopharyngeal airway, which is maintained by both the tongue root and hyoid bone, showed significant changes in different studies [27, 28, 30, 32].

This review included a variety of fixed functional appliances such as the Herbst appliance, FFR, Skeletal Anchored Forsus FRD EZ appliance, and the Mandibular Protraction Appliance-IV. It is not solely based on cephalometric studies but also includes 3D techniques like CBCT and acoustic pharyngometry [25-27], which enhances the reliability of the findings.

Limitations

1. This review involved a limited number of Randomized Controlled Trials (RCTs).
2. Many of the included studies relied on lateral cephalograms, which produce 2D images, making airway changes less precise and only approximate.
3. Due to the limited availability of data on the effects of all fixed functional appliances on the airway, not all appliances were covered. Thus, the findings of this review primarily focus on commonly used appliances like the Herbst and Forsus Fatigue Resistant devices.

Conclusion

The systematic review led to the following conclusions:

1. Fixed functional appliances positively impact airway dimensions in patients undergoing orthodontic treatment.
2. This effect is most prominent in patients with a retrognathic mandible.
3. The increase in airway dimensions affects all three parts of the pharyngeal airway.

Fixed functional appliances notably expand the oropharyngeal and hypopharyngeal regions, with less impact on the nasopharyngeal region.

Conflict of Interest

Not available

Financial Support

Not available

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