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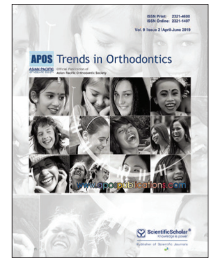

Systematic Review

Effects of functional appliance treatment on pharyngeal airway passage dimensions in Class II malocclusion subjects with retrognathic mandibles: A systematic review

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ABSTRACT

Objective: The objective of this study was to assess the pharyngeal airway passage (PAP) dimension changes following functional appliance treatment in Class II malocclusion subjects with retrognathic mandibles.

Materials and Methods: Two authors independently searched various electronic databases such as PubMed, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Scopus, NCBI, and Google Scholar for the available literature within the period from January 1, 2001, to December 31, 2018. On the basis of population, intervention, comparison, and outcome, "changes in PAP dimensions following functional appliance therapy in skeletal Class II malocclusion subjects associated with mandibular retrusion" was considered as search question of the study. After the selection and removal of duplicate articles, assessment for risk of bias was calculated and the data from the included articles were extracted by two authors independently.

Results: From six databases and additional hand searching, a total of 5784 articles were extracted. Of 5784 articles, 3754 articles were screened after removal of 2030 duplicates. After going through the title and abstract, 3197 articles were excluded and 40 articles were assessed for full text. From these 40 articles, eight articles fulfilled our inclusion and exclusion criteria for the qualitative synthesis review.

Conclusions: The correction of mandibular deficiency by functional appliances has minimum effect on the nasopharynx. Functional appliance treatment has a significant effect on the improvement of the oropharyngeal airway. Changes of hypopharyngeal airway passage need to be studied further among Class II malocclusion subjects with retrognathic mandibles.

Keywords: Pharyngeal airway passage, Upper airway changes, Functional appliances, Removable functional appliance, Fixed functional appliance, Class II malocclusion

INTRODUCTION

Short and deficiency in the anteroposterior position of the mandible is very common in Class II malocclusion subjects.[1] As the mandible is more retrognathic in relation to the anterior cranial base, it decreases the space between cervical column and mandibular corpus and leading to posteriorly positioned tongue and soft palate.[2,3] As a result, there is an increase chance of impaired respiratory functions during the day and various sleep-related breathing problems during night.[2,3] A small airway dimension during childhood may increase the risk of sleep-related breathing problems during adulthood secondary to fat deposition in the posterior pharyngeal region. Katyal *et al*.[4] concluded that the children with increased ANB angle have smaller airway dimensions and increased the risk of sleep-disordered breathing (SDB) problems compared with normal children.

Advancing the mandible forward brings the associated soft tissue, tongue, and hyoid bone along with it, thus indirectly increases the pharyngeal airway space.[5] Increase in pharyngeal airway space by mandibular advancement may prevent SDB problems in adulthood. Furthermore, the changes in the pharyngeal airway passage (PAP) dimensions following mandibular advancement are maintained in the long term.[6,7]

Functional appliances are commonly used for the correction of retrognathic mandible in growing children.[8,9] Most of the studies have given their result as increase in the PAP dimensions,[10-19] but few of them also showed no significant changes in PAP dimensions after the use of functional appliances.[20-22] Although studies have given positive impact of the functional appliances on PAP dimensions, many studies lack proper protocol, some studies with improper controls[23-25] and some without control.[26-28] Thus, it is difficult in deriving conclusive results to use in clinical scenario. Although there are two systematic reviews that have been done in this area with same population, intervention, comparison, and outcome (PICO) question, both the systematic reviews have included low-quality retrospective studies in their review which makes the conclusions less reliable.[29,30] Thus, the present review has been conducted to address the currently available best possible evidence regarding the changes in PAP dimensions following the functional appliance therapy in skeletal Class II malocclusion due to mandibular deficiency.

MATERIALS AND METHODS

Protocol and registration

The present review was conducted on the basis of Primary Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. The study protocol was registered in the International Prospective Register of Systematic Reviews, having registration no CRD42018086241.

Search question

On the basis of PICO, search question of the study was "changes in PAP dimensions following functional appliance therapy in skeletal Class II malocclusion subject associated with mandibular retrusion."

Selection criteria

The study protocol was designed with the inclusion and exclusion criteria based on the PICOS strategy, i.e. PICO and study designs. The details of the study protocol are described in Table 1.

Table 1: The details of the study protocol with various inclusion and exclusion criteria as per the PICOS format.

Category	Inclusion criteria	Exclusion criteria
Population	Study conducted on human beings with Class II malocclusion due to mandibular retrusion of any age and gender	Subjects with craniofacial syndromes, cleft lip, and palate anomaly
Intervention	Correction of mandibular retrusion with the use of removable functional appliance or fixed functional appliance	Class II malocclusions treated only by comprehensive orthodontic treatment, extractions of premolars, Class II elastics, orthognathic surgeries
Comparison	Same individuals before and after functional appliance therapy and with Class II control subjects	Without Class II control subjects
Outcome	Studies with linear, angular measurements using lateral cephalometric analysis and studies with volumetric measurements using 3D imaging techniques.	Studies providing linear, angular measurements from 3D imaging techniques and studies with volumetric measurements using lateral cephalometric analysis.
Study design	Systematic reviews Randomized double-blinded clinical controlled trials Prospective controlled clinical trials Retrospective studies with matched controls	Cohort studies Clinical trials without control Case series Case reports Observational studies Descriptive studies without intervention Narrative reviews Unpublished thesis Books Expert opinions

Information resources and search strategy

Two authors (AV and JS) independently searched various electronic databases for the available literature within the period from January 1, 2001, to December 31, 2018. Databases included were PubMed, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Scopus, NCBI, and Google Scholar. Key words used for searching were "pharyngeal airway," "upper airway," "functional appliances," "Class II malocclusion," and "airway changes." According to the database, the search strategy was created using Boolean operators as mentioned in Table 2.

Study selection

From the above-mentioned databases and also through the hand searching, articles were obtained independently by two authors (AV and JS). After removal of duplicates, articles were screened for the titles and abstracts followed by full text in selected articles. Based on selection criteria, articles which do not fulfill the inclusion criteria were excluded from the study. Whenever conflict arose, the consensus was reached by discussing with the third author (AKJ).

Data collection

Various facts such as authors, publication year, study design, study set-up, demographic data, interventions done, treatment duration, type of tool used for the assessment of PAP, variables compared, and outcome were extracted from each included article. As different articles used different terminologies to describe the parameters, for the convenience of interpretation, equivalent terms pertaining to the variables from the studies were grouped and the same was followed throughout the review.

Quality assessment of individual studies

Two authors (AV and JS) independently assessed the risk of bias of included articles using ROBINS-I non-randomized case control studies as recommended.[31]

ROBINS-I tool uses seven domains at three periods, i.e., pre-intervention, at intervention, and post-intervention. Every domain is assessed to assign a score either as low, moderate, serious, critical risk of bias, and no information. Based on this, again overall risk of bias judgment is taken. The quality of each study included in the present review is described in Table 3.

RESULTS

From six databases and additional hand searching, a total of 5784 articles were extracted. Of 5784 articles, 3754 articles were screened after removal of 2030 duplicates. After going through the title and abstract, 3714 articles were excluded as they were not relevant to our research question and 40 articles were assessed for full text. From these 40 articles, one systematic review[30] and one meta-analysis[29] included studies that were not having properly matched controls, 21 studies were without control and improper control subjects, four studies had Class I subjects as control,[10,24,32,33] one article did not record post follow-up variables for their control subjects,[34] three articles had not proper definition for case and included OSA patients as subjects,[15,35,36] and one article assessed CO-CR discrepancy.[37] Hence, all these 32 articles were excluded from present review, and finally, eight studies were included in the qualitative synthesis. The PRISMA flow diagram is described in Figure 1.

Table 2: Search strategy used for different databases.

Database	Search strategy used
PubMed	((Upper airway changes [MeSH Terms]) OR (upper airway changes [Title/Abstract]) OR (pharyngeal airway changes [MeSH Terms]) OR (pharyngeal airway changes [Title/Abstract]) AND (removable functional appliance [Title/Abstract]) OR (twin block [MeSH Terms]) OR (activator appliance [MeSH Terms]) OR (Bionator appliance [MeSH Terms]) OR (Frankel appliance [Other Term]) OR (Bimler appliance) OR (Teuscher appliance) OR bite-jumping appliance) OR (bite jumper))
Cochrane library and CENTRAL	Upper airway changes OR pharyngeal airway changes AND removable functional appliance treatment OR activator appliance OR Bionator OR Bimler appliance OR twin block OR bite-jumping appliance
NCBI	((upper airway changes [MeSH Terms]) OR (upper airway changes [Title/Abstract]) OR (pharyngeal airway changes [MeSH Terms]) OR (pharyngeal airway changes [Title/Abstract]) AND (removable functional appliance [Title/Abstract]) OR (twin block [MeSH Terms]) OR (activator appliance [MeSH Terms]) OR (Bionator appliance [MeSH Terms]) OR (Frankel appliance [Other Term]) OR (Bimler appliance) OR (Teuscher appliance) OR bite-jumping appliance) OR (bite jumper))
Google Scholar	Changes of airway dimensions after functional appliance therapy in skeletal Class II malocclusion
Scopus	Pharyngeal airway and Class II malocclusion, pharyngeal airway and Bionator, pharyngeal airway and twin block, pharyngeal airway and activator, upper airway and activator, upper airway and Bionator, upper airway and twin block, upper airway and class ii malocclusion, upper airway and bite-jumping appliance.

Table 3: Risk of bias assessment of the included studies according to the ROBINS-I tool.

Domains	Jena *et al.*, 2013[16]	Ghodke *et al.*, 2014[17]	Elfkey 2015[18]	Ulusoy *et al.*, 2014[13]	Bavbek *et al.*, 2016[5]	Atik *et al.*, 2017[19]	Aksu *et al.*, 2017[23]	Ozbek *et al.*, 1998[3]
Pre-intervention								
Bias due to confounding	Low	Low	Low	Low	Low	Low	Low	Low
Bias in selecting participants in the study	Low	Low	Low	Low	Low	Low	Low	Low
At intervention								
Bias in classification of intervention	Low	Low	Low	Low	Low	Low	Low	Low
Post-intervention								
Bias due to deviations from intended interventions	Low	Low	Low	Low	Low	Low	Low	Mod
Bias due to missing data	Low	Low	Low	Low	Low	Low	Low	Low
Bias in measurement of outcomes	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate
Bias in selection of the reported result	Low	Low	Low	Low	Low	Low	Low	Low
Overall risk of bias judgment	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate

Risk of bias assessment

Among the eight articles that included in this review, seven articles had low-to-moderate risk of bias and one article was having low risk of bias [Table 3]. All the data except the variables extracted from the included articles are listed in Table 4 and all the variables related PAP analysis are listed along with their description in Table 5.

Results of the individual studies

The results of the individual studies with respect to the changes in the nasopharynx, oropharynx, hypopharynx, and hyoid bone position are presented in Table 6. The first three studies were prospective controlled clinical trials. The remaining studies in the review were designed retrospectively.

The first study[16] in this systematic review was a case–controlled clinical trial. This study compared the effectiveness of twin block and mandibular protraction appliance-IV (MPA-IV) in the improvement of PAP. Lateral cephalograms were used for the evaluation of upper airway dimension. The change in the dimension of nasopharynx was marginal during the study period in control and treatment subjects ($P = 0.437$). The improvement of oropharynx dimension by twin-block appliance was significantly more compared to untreated Class II control subjects ($P < 0.01$). The change in the dimension of hypopharynx was comparable, but the intergroup comparison was not statistically significant ($P = 0.479$). The second study[17] was a case–controlled clinical trial which used lateral cephalograms to evaluate the effects of twin-block appliance on PAP dimensions and posterior pharyngeal wall thickness. The changes in the dimensions of nasopharynx were comparable in Class II control and twin-block subjects. The change in the dimension of oropharynx was significantly more in the twin-block subjects compared to Class II controls ($P < 0.05$). The dimension of hypopharynx was increased significantly following twin-block treatment (1.77 mm, $P < 0.01$). The third study[18] evaluated the three-dimensional effects of twin-block therapy on pharyngeal airway parameters in Class II malocclusion patients. Cone-beam computed tomography (CBCT) was used for the volumetric evaluation of upper airway. The mean nasopharyngeal and oropharyngeal airway volumes were increased significantly in both groups. The improvement in airway volume was significantly more in twin-block subjects compared to untreated Class II control subjects.

Ulusoy *et al.*[12] evaluated the effect of activator on the airway dimensions and changes in hyoid bone position. They compared the linear and angular cephalometric parameters of upper airway. The mean nasopharyngeal area improved significantly in the activator group ($P < 0.05$) by 558 ± 763 mm^2, but the mean oropharyngeal area did not improve significantly. Compared with controls, the improvement of nasopharyngeal and oropharyngeal area was nearly the same in both groups. The C3-H distance increased significantly in both the groups, and improvement

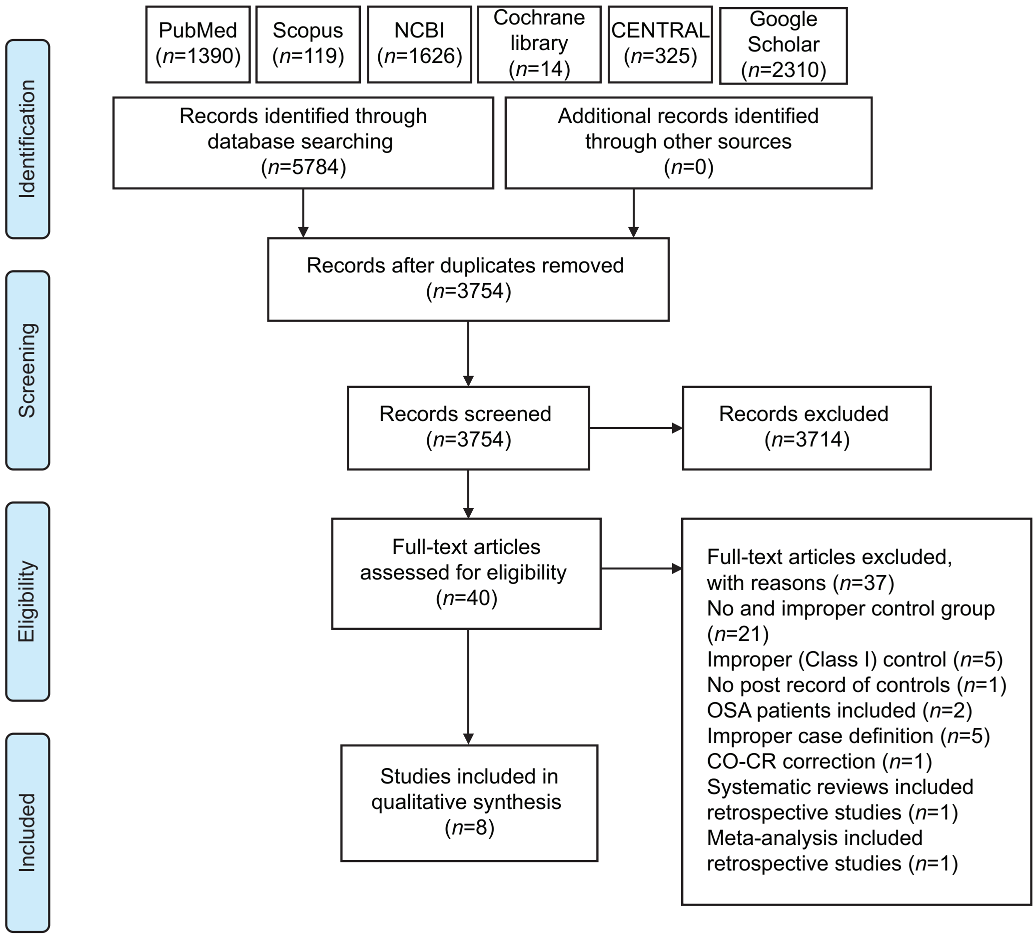

Figure 1: Primary Reporting Items for Systematic Reviews and Meta-Analysis flow diagram used in the present review.

was significantly more in the activator group. Aksu *et al*.[23] retrospectively assessed the upper airway size after activator treatment with lateral cephalometric parameters and compared with Class II control. Compared to control group, only the middle airway space increased significantly in the activator group by 1.6 ± 2.5 mm ($P < 0.05$). Bavbek *et al*.[5] evaluated changes in airway dimensions and hyoid bone position two dimensionally after Class II correction with FFRD. Oropharyngeal dimension evaluated was MPS and C3-H for hyoid position. After treatment, the mean value of MPS was increased significantly by 1.28 mm in the Forsus Fatigue Resistance Device (FFRD) group. The C3-H distance was increased by 1.68 mm after FFRD treatment. Both were significantly more in FFRD compared to control group.

Atik *et al*.[19] compared the airway effects of X-Bow and Frankel-2 appliance with untreated control. Lateral cephalometric parameters Superior pharyngeal airway space (SPAS), Middle airway space (MAS), Inferior airway space (IAS) were evaluated as airway dimensions of oropharyngeal airway. PNS-AD1, PNS-AD2, and Ba-PNS were evaluated as airway dimensions of nasopharyngeal airway. After treatment, there is a significant improvement only in the PNS-AD2 and MPS values of Frankel-2 group, $P = 0.043$ and $P = 0.019$, respectively. There are no significant changes in the intergroup comparison, compared to control group both the treatment groups had non-significant changes. Ozbek *et al*.[38] studied the changes of oropharyngeal airway dimensions after functional-orthopedic treatment. Lateral cephalometric measurements of (oropharyngeal measurements) SPAS, MAS, IAS, and ORO were taken. Compared with control, a significant improvement was seen in the treatment group with $P < 0.001$ in SPAS and ORO, $P < 0.01$ in MPAS, and $P < 0.05$ in IAS.

DISCUSSION

Summary of evidence

The present review addressed the PAP dimension changes following the application of functional appliances. A total of 313 subjects were studied in this review with 179 treatment subjects and 134 controls. To interpret easily, available evidence was summarized in the following headings.

Table 4: Various data included from the studies in the present review.

Author, publish year	Study design	Demographic data				Interventions done	Treatment duration and observation period (Mean±SD)	Type of image analyzed	Variables compared and outcome
		Groups	Age (Years)	Sex (Male, Female)	Number of subjects				
Jena *et al*., 2013[16]	CCT	CG TG-1 TG-2	10.56 12.81 11.38	9, 7 9, 7 11, 10	16 16 21	No MPA-IV. Twin-block therapy	9.86±1.79 6.18±1.20 9.38±1.68 months	Cephalogram	Linear dimensions of pharyngeal airway. Soft palate dimensions. Significant increase in the oropharynx and hypopharynx dimensions in both MPA-IV and twin-block subjects.
Ghodke *et al*., 2014[17]	CCT	CG TG	10.94 10.90	9, 9 11, 9	18 20	No twin block	222±32 244±35 days	Cephalogram	Linear dimensions of pharyngeal airway and thickness of posterior pharyngeal wall. Significant improvement in the oropharynx and hypopharynx was found.
Elfeky *et al*., 2015[18]	CCT	CG TG	11.27 11.89	Only female	18 18	No twin block	8 months	CBCT	Nasopharyngeal and oropharyngeal airway volumes. Significant increase in the nasopharyngeal and oropharyngeal volume after twin-block treatment.
Ulusoy *et al*., 2014[13]	Retrospective	CG TG	12.14 11.36	8, 11 8, 8	19 16	No activator	11±34 11.37±1.2 months	Cephalogram	Linear dimensions of pharyngeal airway. Hyoid bone distance and head posture. Significant increase in nasopharyngeal area and height along with increased hyoid bone distance.
Bavbek *et al*., 2016[5]	Retrospective	CG TG	12.74 13.62	8, 11 8, 8	19 16	No FFRD	11.89±1.37 8.74±3.46 months	Cephalogram	Linear dimensions of pharyngeal airway. Significant increase in superior and middle pharyngeal space. Increased hyoid bone – SN distance.
Atik *et al*., 2017[19]	Retrospective	CG TG-1 TG-2	9.27 8.94 10.58	6, 4 4, 11 6, 9	10 15 15	No FR-2 X-bow	1.23±0.16 years 1.19±0.20 years 0.72±0.19 years	Cephalogram	Linear measurements of pharyngeal airway. Significant increase in nasopharyngeal and oropharyngeal airway dimensions was found only in FR-2 group.
Aksu *et al*., 2017[23]	Retrospective	CG TG	10.2 10.3	9, 10 4, 12	19 16	No activator	1.0±0.0 years 1.3±0.8 years	Cephalogram	Linear measurements of pharyngeal airway. Only the middle airway space significantly increased in the treatment group.
Ozbek *et al*., 1998[3]	Retrospective	CG TG	11.29 11.63	7, 8 11, 15	15 26	No HA with/without occipital pull headgear.	1.92±0.05 1.45±0.10	Cephalogram	Linear measurements of pharyngeal airway. When compared to controls oropharyngeal airway dimensions were significantly increased.

CBCT: Cone-beam computed tomography, CCT: Case controlled trial, CG: Control group, TG: Treatment group, MPA: Mandibular protraction appliance, FFRD: Forsus fatique resistant device, FR: Functional regulator, HA: Headgear-Activator

Table 5: Various variables analyzed in the present review and their descriptions.

Variable	Description
DNP – depth of the nasopharynx	Ptm-UPW: Pterygomaxillary fissure to the intersection of line Ptm-Ba and posterior pharyngeal wall
HNP – height of the nasopharynx	The shortest linear distance from PNS to Ba-N plane and height between points S and PNS
SPS – superoposterior pharyngeal space	The distance of the midpoint of line from the PNS to the tip of soft palate to the horizontal counterpart on the posterior pharyngeal wall along the parallel line to the Frankfurt horizontal line
DOP – depth of the oropharynx and MPS – middle pharyngeal space	U–MPW: Tip of soft palate to the intersection of perpendicular line on Ptm perpendicular from "U" with posterior pharyngeal wall & the distance of tip of the soft palate to the horizontal counterpart on the posterior pharyngeal wall along the parallel line to the Frankfurt horizontal line
DHP – depth of the hypopharynx	V-LPW: Vallecula to the intersection of perpendicular line on Ptm perpendicular from "V" with posterior pharyngeal wall
Nasopharyngeal airway volume	Volume calculated between the anterior border that is a line connecting PTM and PNS, inferior border that is a plane parallel to the Frankfort through the PNS and the posterior border that is the posterior wall of the pharynx
Oropharyngeal airway volume	Volume calculated between the superior border, i.e., a plane parallel the Frankfort through the PNS and the inferior border that is a plane passing through inferior anterior point of third cervical vertebra parallels the Frankfort horizontal
Minimal constricted axial area	Soft determined area of pharyngeal airway relative to posterior nasal spine
H-SN	The perpendicular distance from hyoid bone to SN plane
SPL – soft palate length	U–PNS: Tip of soft palate to posterior nasal spine
SPT – soft palate thickness	The maximum thickness of the soft palate
SPI – soft palate inclination	The angle between Ptm perpendicular and the soft palate
PPWT 1 – posterior pharyngeal wall thickness 1	The distance from the intersection point of palatal plane and posterior pharyngeal wall to the intersection point of palatal plane and anterior tangent of C2 vertebra
PPWT 2 – posterior pharyngeal wall thickness 2	The distance from the intersection point of line parallel to the palatal plane passing through "MSP" and the posterior pharyngeal wall to the intersection point of same line extended posteriorly and anterior tangent of C2 vertebra
PPWT 3 – posterior pharyngeal wall thickness 3	The distance from the intersection point of line parallel to palatal plane passing through the "U" and the posterior pharyngeal wall to the intersection point of same line extended posteriorly and anterior tangent of C2 vertebra
PPWT 4 – posterior pharyngeal wall thickness 4	The distance from the intersection point of the mandibular plane and posterior pharyngeal wall to the intersection point of the mandibular plane and anterior tangent of C2 cervical vertebra
PPWT 5 – posterior pharyngeal wall thickness 5	The distance from the intersection point of line parallel to the mandibular plane passing through the superior-anterior point of C3 vertebra and the posterior pharyngeal wall to superior-anterior point of C3 vertebra
PPWT 6 – posterior pharyngeal wall thickness 6	The distance from the intersection point of line parallel to mandibular plane passing through the inferior-anterior point of C3 vertebra and the posterior pharyngeal wall to inferior-anterior point of C3 cervical vertebra

PPWT: Posterior pharyngeal wall thickness, PTM: Pterygomaxillary point, PNS: Posterior nasal spine

Changes in nasopharynx

The first clinical trial[16] compared the changes in pharyngeal airway dimensions produced by two different appliances and revealed that the depth as well as height of nasopharynx was not affected in treatment groups as well as in control group. Literature revealed that from the age of 8 years till 14 years, changes in nasopharyngeal dimensions are minimal and the effects of growth as well as the effects of mandibular advancement through functional appliances have no role in altering the nasopharyngeal dimensions.[16,38,39] Ghodke *et al*.[17] also observed that the depth of nasopharynx did not change significantly in the treatment group as well as in untreated control subjects; however, they found a significant increase in the height of nasopharynx in control group subjects ($P < 0.05$). The third clinical trial by Elfeky and Fayed[18] was based on CBCT which revealed a significant increase in the nasopharyngeal airway volume in control group as well as treatment subjects. It also showed that the change was significantly more after functional appliance treatment compared to untreated subjects. The change in the volume of nasopharynx could be due to

Table 6: Results of the individual studies included in the present review.

Study	Nasopharynx	Oropharynx	Hypopharynx	Hyoid position
Jena *et al.*, 2013[16]	CG (0.63±2.70 mm) TG1 (0.63±3.03 mm) TG2 (−0.49±2.89 mm)	CG (0.01±1.48 mm) TG1 (2.12±1.81 mm)*** TG2 (0.85±1.56 mm)*	CG (0.65±1.66 mm) TG1 (1.19±1.70 mm)** TG2 (0.55±1.83 mm)	-
Ghodke *et al.*, 2014[17]	-	CG (0.089 mm)* TG (1.54 mm)***	CG (0.37 mm) TG (1.77 mm)**	-
Elfkey, 2015[18]	CG (151.26±104.98 mm^3)*** TG (501.33±282.34 mm^3)***	CG (738.18±507.11 mm^3)*** TG (3052.45±1281.20 mm^3)***	-	-
Ulusoy *et al.*, 2014[13]	CG (398±841 mm^2) TG (558±763 mm^2)*	CG (607±1766 mm^2) TG (1079±2257 mm^2)	-	CG (1.68±1.60 mm) TG (1.81±2.50 mm)
Aksu *et al.*, 2017[23]	CG (−0.3±2.6 mm) TG (1.1±4.7 mm)	CG (−1.5±2.3 mm) TG (1.6±2.5 mm)*	CG (−0.7±1.8 mm) TG (0.2±2.7 mm)	-
Bavbek *et al.*, 2016[5]	CG (0.89±1.33 mm) TG (1.01±1.61 mm)	CG (−0.21±1.32 mm) TG (1.28±1.49 mm)*	CG (0.42±1.22 mm) TG (1.33±1.33 mm)	CG (0.84±1.60 mm) TG (1.68±1.56 mm)*
Atik *et al.*, 2017[19]	CG (−0.09±2.89 mm) TG1 (2.09±4.78 mm) TG2 (0.27±4.48 mm)	CG (0.58±1.22 mm) TG1 (0.69±1.00 mm) TG2 (0.41±3.46 mm)	-	-
Ozbek *et al.*, 1998[3]	-	CG (−0.76±0.57 mm) TG (2.28±0.59 mm)**	-	-

*<0.05, **<0.01, ***<0.001, CG: control group, TG: Treatment group

transverse growth of nasopharynx which was not detected in conventional lateral cephalograms.

Ulusoy *et al.*[12] and Aksu *et al.*[23] retrospectively studied the effects of activator on nasopharynx. Earlier study found that the nasopharyngeal area of the treatment group improved significantly compared to pre-treatment value.[12] However, when compared with control, the improvement was not significant. They have calculated the area from lateral cephalogram which may not be the appropriate tool to see the changes. Later, the study found that the nasopharynx did not increase significantly. Both studies used lateral cephalometric parameters which may be the reason as it could not find the transverse changes. Atik *et al.*[19] compared the changes of pharyngeal airway after treatment with Frankel-2 and X-bow and compared with untreated the control. Among the nasopharyngeal measurements, the PNS-AD2 had increased significantly in the Frankel-2 group after treatment ($P < 0.05$). However, compared with X-bow and control group, there was non-significant improvement in the mean value.

Bavbek *et al.*[5] found no significant improvement at PP level after the use of FFRD. Although he measured only at one level, the changes observed were more contributed by growth. Fixed functional appliance did not help in improving the nasopharyngeal dimensions. In comparison with fixed functional appliance, removable functional appliance showed significant difference in nasopharyngeal dimension. Except the third study (prospective trial), all studies used lateral cephalometric parameters for representing the nasopharyngeal dimensions. The main limitation of lateral cephalogram is two-dimensional representations of three-dimensional structures. However, the use of lateral cephalogram for the airway analysis is very frequent and an established tool.[40]

Thus, from the present review, it could be concluded that correction of mandibular deficiency by functional appliances has minimum effect on the nasopharynx.

Changes in oropharynx

Of the first three studies,[16-18] two studies[17,18] revealed a significant effect of growth on the oropharyngeal dimension. However, all three studies showed significant improvement in the oropharyngeal airway passage following functional appliance treatment.[16-18] The improvement in the dimension of oropharynx was more with removable functional appliance (twin block) compared to fixed functional appliance (MPA-IV).[16] Although the growth itself had a mild benefit in the improvement of oropharyngeal dimension, the advancement of mandible by functional appliance was more beneficial in the improvement. The anterior relocation of mandible by the functional appliances positioned the tongue more forward and thus increased the dimension of oropharynx.[1]

Aksu *et al.*[23] found significant improvement of oropharyngeal airway after activator treatment. However, the contribution to oropharyngeal airway improvement was seen only at the level of MPS. Middle pharyngeal space increased by 1.6 ± 2.5 mm. SPAS and IAS measurements did not increase markedly. However, Ozbek *et al.*[38] found significant improvement in all the parameters of oropharyngeal airway. Mean value of SPAS, MAS, and IAS as well as ORO increased significantly after treatment with Harvold-type activator compared to control group. Maximum contribution in oropharyngeal airway improvement was by MPS with increase of 2.28 ± 0.59 mm. Analyzing the changes produced by fixed functional appliance, effects of FFRD have been studied. FFRD improved the oropharyngeal airway significantly when compared the untreated subjects. After treatment, the mean values of SPS and MPS were increased by 1.06 mm and 1.28 mm respectively in the FFRD group. In this study also, the maximum contribution to the oropharyngeal airway was by MPS.

In contrast to above findings, Ulusoy *et al*.,[12] in a retrospective case–control study, evaluated the effect of activator found no significant improvement of oropharyngeal area before and after activator treatment. It was also noticed that mean oropharyngeal area did not differ from control group. Supporting this, another study[19] compared the effects of Frankel-2 and X-bow appliance with untreated control found no significant improvement of oropharyngeal airway in all three groups.

The present review concludes the fact that correction of mandibular deficiency by functional appliances has a prominent effect on the oropharynx.

Changes in hypopharynx

The results of the two cephalometric studies[16,17] showed significant increase in the depth of hypopharynx following mandibular advancement by twin-block appliance. It was also noted that fixed functional appliance was not efficient in the improvement of hypopharyngeal airway passage. Furthermore, we found that the growth itself had no effect in the improvement of hypopharyngeal airway dimension among Class II control subjects. The improvement in the dimension of hypopharynx following advancement of mandible was due to forward position of tongue and repositioning of the mandible.[16,41]

Among the retrospective studies, Aksu *et al*.[23] measured the EAS equivalent to the depth of hypopharynx, and observed no significant improvement in hypopharynx. Bavbek *et al*.[5] measured the CV3 projection in FFRD and control group found that FFRD did not increase the hypopharyngeal dimension. Other three studies did not measure the hypopharyngeal airway dimension.

The present review has given mixed results regarding the hypopharyngeal dimensions. Prospective controlled clinical trials with removable appliance treatment improved the dimension of hypopharyngeal airway, whereas the retrospective studies concluded no significant effect on hypopharyngeal dimension. Thus, from the present review, it could be concluded that twin-block appliance significantly improves the dimension of hypopharynx in Class II malocclusion subjects with retrognathic mandibles.

Analyzing the type of functional appliance to produce significant effects on pharyngeal airway, existing evidence showed that removable functional appliance, i.e., twin block produced the maximum improvement in the upper airway dimension (i.e., on oropharynx and hypopharynx). Fixed functional appliance (MPA-IV) used for the correction of mandibular retrusion has minimal effect on the upper airway. Changes in nasopharynx are attributed more to growth than functional appliance.

Changes in hyoid bone

Activator appliance increased C3-H distance by 1.81 ± 2.50 mm.[12] The C3-H distance was increased by 1.68 mm after FFRD treatment.[5] Both removable and fixed functional appliances produced a significant increase in the hyoid bone distance compared with untreated control. Removable functional appliance produced more improvement than fixed appliance.

Changes in craniocervical angulation

Craniocervical angulation at the time of lateral cephalometry is important variable which influences the dimensions of pharyngeal airway. Although only two studies[3,12] in the review had measured the craniocervical angulation, it can be observed that changes in the craniocervical angulation before and after treatment in the treatment and untreated control group did not differ significantly. Thus, the variables taken into analysis were reliable to draw the conclusion.

CONCLUSIONS

The following conclusions were derived from the present systematic review:

1. There was a significant improvement in the PAP dimensions following functional appliance treatment in Class II malocclusion subjects with retrognathic mandibles.
2. Functional appliances had minimum effect on nasopharyngeal airway passage and the minor improvement was mainly due to growth.
3. Improvements of oropharyngeal airway passage dimensions were very prominent effects of functional appliance treatment.
4. Improvements of hypopharyngeal airway passage dimensions were need to be analyzed further.
5. Removable functional appliance was more efficient than fixed functional appliance in the improvement of PAP dimension among Class II malocclusion subjects with retrognathic mandible.
6. Changes observed in hyoid bone distance were more prominent in horizontal than vertical direction.

Limitations of the present review

A randomized double-blinded controlled clinical trial is the gold standard, but this review lacks such studies. Many aspects of the research question such as which appliance is better in increasing the airway volume, which dimension of pharyngeal airway is most improved, what is the expected increase in respect to dimensions and long-term post-treatment stability, etc., are yet to be answered.

Declaration of patient consent

Patient's consent not required as there are no patients in the study.

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Conflicts of interest

There are no conflicts of interest.

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