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The upper airway dimensions in different sagittal craniofacial patterns: a systematic review

Iveta Indriksone, Gundega Jakobsone

SUMMARY

Objective. Upper airway changes caused by orthognathic surgery operations have been a topic of a concern in the orthodontic literature because of a possible development of obstructive sleep apnea. Diverse response of the airway patency could be expected if the dimensions of the airway differ among various malocclusions already before orthognathic treatment. However the associations between facial morphology and the upper airway dimensions have not been clarified. The purpose of this systematic review was to elucidate whether the upper airway dimensions differ among various sagittal craniofacial patterns.

Material and methods. MEDLINE and the Cochrane Library were searched up to November 2012. Reference lists of relevant articles were checked for further possible studies. Strict inclusion and exclusion criteria were applied when considering the studies to be included. Screening of eligible studies and data extraction were conducted independently by two reviewers.

Results. 758 studies were identified and 11 of these were recognized as suitable for further analysis. 75% of studies did not find differences in the nasopharyngeal dimensions among craniofacial patterns. The findings for the oropharyngeal dimensions were controversial as 5 of 11 investigations found these to be smaller in Class II subjects, and 6 of 11 concluded that oropharynx size is larger in Class III pattern. The vertical growth type of the subjects was not considered in five investigations, and 45% of the included studies used lateral cephalometry as only tool for airway assessment.

Conclusions. Currently there is insufficient evidence that the upper airway dimensions differ in various sagittal skeletal patterns.

Key words: airway, skeletal pattern, systematic review.

INTRODUCTION

The upper airway is the first component of the significant structure, which provides respiration – one of the vital functions of the human body. Disturbed breathing function could lead to life threatening situations. One of the conditions associated with breathing disturbances is obstructive sleep apnea (OSA), which is characterized by recurrent episodes of upper airway obstruction during sleep resulting in reduced oxygen saturation and is associated with increased morbidity and mortality (1). Several studies have shown distinct differences between the upper airway dimensions of OSA patients and normal subjects (2, 3). The posterior airway space (PAS) (space behind the base of the tongue) of patients with OSA is smaller than that of normal individuals (4, 5), and their craniofacial morphology is characterized by: short cranial base (6, 7), posteriorly positioned maxilla and mandible (3, 6), retrognathia or micrognathia (8, 9) and increased upper and lower face heights (6, 8).

Since a close relationship between the upper airway patency and craniofacial structures has been shown in OSA patients (10, 11), an association could be expected to exist between the airway dimensions and the craniofacial pattern. Orthodontists deal with various kinds of malocclusions, including severe skeletal Class II and III deformities, and advancement and setback operations are standard procedures for correction of the jaw discrepancies. Orthognathic procedures are designed to correct dentofacial deformities, but they also inevitably affect the size and the position of the surrounding soft tissues. Although

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there are a lot of studies reporting changes in the dimensions of the upper airway following surgical repositioning of the mandible and the maxilla, the estimations about the changes in the posterior airway space (PAS) after mandibular setback and advancement surgeries remain controversial (12). Despite a few case reports of mandibular setback surgery in skeletal Class III patients inducing OSA associated with airway narrowing (13-15), prospective studies (16, 17) failed to demonstrate disturbances of respiration during sleep after mandibular setback even though retropalatal airway size was reduced. These findings might be explained by the observation that preoperative airway size in patients with Class III deformity was larger than values in normal population (17, 18).

In order to predict possible changes of the upper airway after diverse orthognathic procedures, with regard of possible development of OSA, it would be advantageous to have the data about the upper airway dimensions in untreated population. Therefore this review was undertaken to answer the question: "Are there any differences in the upper airway dimensions of patients with different sagittal skeletal patterns?"

MATERIAL AND METHODS

To identify all studies that have examined the upper airway dimensions in different anterioposterior skeletal patterns a computerized literature survey was carried out and abstracts were gathered by searching the following electronic databases: MEDLINE (Entrez PubMed, *www.ncbi.nlm.nih.gov*) and the Cochrane Library (*www.cochrane.org*). The survey covered the period from January 1960 to November 2012. The primary search terms used were "airway" AND "skeletal".

The initial eligibility of the studies was determined by reading the titles and the abstracts of the articles. Full articles were retrieved and examined when their title and abstract did not provide enough information for a definite decision. The following criteria were formulated to select articles for inclusion in this review: articles on the airway dimensions of skeletal Class I and/or Class II and/or Class III patients, randomized controlled trials (RCTs), cohort studies (included if there were at least 30 patients in study group) and case-control studies, language in English. Exclusion criteria were case reports and case series, articles that did not follow the objective of this review, articles reporting airway dimensions of syndromic, medically compromised or cleft patients, articles reporting airway dimensions, but not strictly determining sagittal skeletal pattern, and articles in a language other than English.

A thorough examination was performed of full-text articles that appeared eligible for the selection. Additionally, relevant references in these articles were examined to make sure that all investigations which could answer the question of the review were inspected. Eligibility of the studies was determined and data were extracted by two reviewers (I.I., G.J.) independently. Any disagreements were resolved by discussion and mutual agreement between two reviewers.

It is important to have a well-defined evaluation system in order to describe airway differences in various skeletal subtypes in a number of studies. The upper airway can be assessed by multiple imaging techniques, including lateral cephalometric radiography (LCR), computed tomography (CT), cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI). Various authors offer different measurements for evaluating the upper airway dimensions in LCR and different 3D imagining techniques, which make studies and obtained results difficult to compare. Probably, the most informative and widely used pharynx classification is the one described in Gray`s anatomy (19), where the pharynx is divided into nasopharynx (from the nasal turbinates to the superior surface of the soft palate), oropharynx (from the superior surface of the soft palate to the upper border of the epiglottis), and hypopharynx or laryngopharynx (from the tip of the epiglottis to the inferior border of cricoid cartilage). This is the classification we use in this review.

A quality evaluation of the methodological soundness of each article was performed, and the following characteristics were used: sample size and prior estimate of sample size, method error analysis, adequate statistics, possible influence of confounding factors and method (imagining technique) used. The quality of the retrieved studies was categorized as low, medium or high.

RESULTS

Search results

The total number of articles found through Medline was 757. Searching the Cochrane library produced 1 additional source. After application of the inclusion and exclusion criteria the vast majority of studies were found irrelevant, leaving 15 studies. Full-texts of all the relevant articles were collected and reviewed. Additionally 11 titles were selected for article retrieval using hand search of the

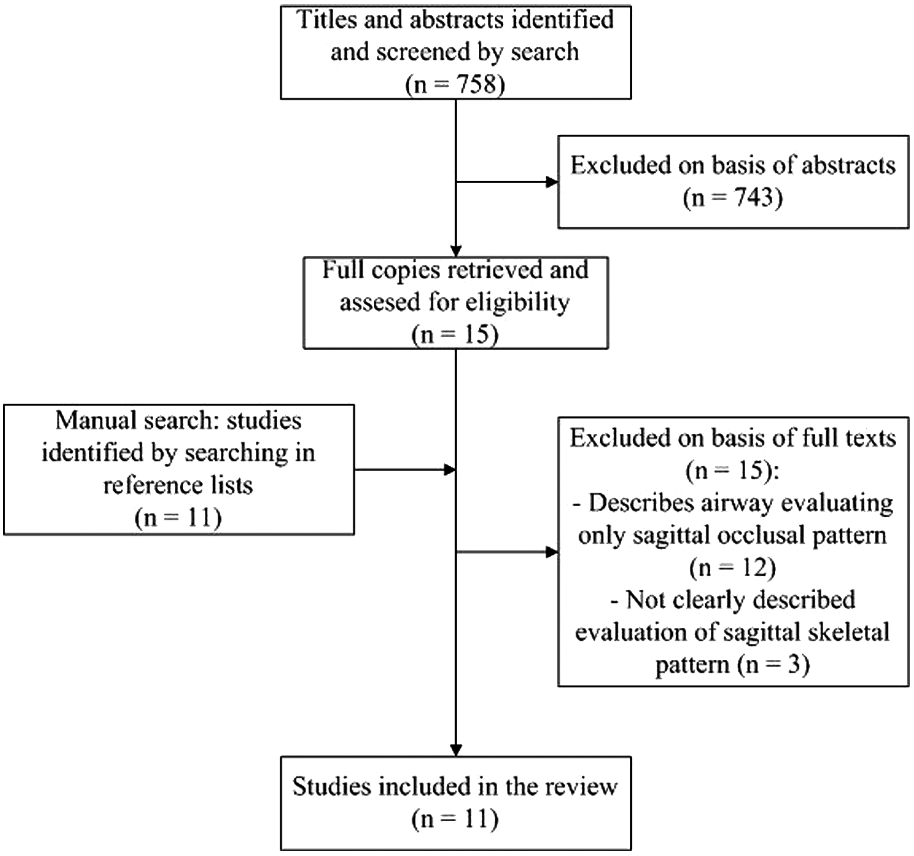

Fig. A flow diagram of literature search

references of these 15 investigations. Finally after assessment of these 26 full-text articles, only 11 that met all the inclusion criteria remained (20-30). These 11 were used for data extraction and subsequent review. A flow diagram of literature search is shown in the Figure.

Imagining methods

In 5 studies lateral cephalometry was used as the only diagnostic tool of airway dimensions (20, 25, 27, 29, 30). One study was done by CT (28), and other 5 were CBCT investigations (21-24, 26).

Outcomes of the included studies

Study characteristics and results of the 11 eligible articles are summarized in Table 1.

The nasopharynx was described in 8 articles, of which six found that there were no significant differences at the nasopharyngeal level neither in the sagittal linear measurements nor in the nasopharyngeal volume among skeletal Class I, Class II and Class III groups (21, 24-26, 28, 30). However one of these studies acknowledged that the transversal dimension of the nasopharynx tended to be larger in Class III compared to Class II (28). Differences in nasopharyngeal airway volume were found in two of studies included in this review. El *et al.* concluded that Class I individuals had larger volume than Class II subjects (22), and Hong et al. found that volume was larger in Class III compared to Class I (23).

Out of the 11 investigations that focused on the dimensions of the oropharynx region, five found no significant differences in sagittal linear or in volume measurements among Class I, Class II and Class III skeletal patterns (20, 24, 28-30). However six articles found differences between various skeletal sagittal patterns, and three of those six concluded that Class II had smaller oropharyngeal volume compared to Class I (21, 22, 26) and Class III (22, 26). Also sagittal measurements of the oropharynx were found to be smaller in Class II when compared to Class I (21, 27) and Class III (25, 27). Results of three investigations showed that Class III individuals when comparing to Class I subjects had larger oropharyngeal cross sectional area (23) and sagittal (25, 27) measurements.

Only three of the eleven articles described the hypopharynx in different skeletal subtypes. Two of those three found no differences in sagittal or volume measurements among various sagittal craniofacial patterns (28, 30), and one investigation showed that the sagittal dimension of the hypopharynx was larger in Class III than in Class II (25).

It was not possible to compare the absolute values of the upper airway measurements because of the different borders, measurements and imagining methods used in various articles (Table 1).

Quality analysis

The analysis showed that the research quality and methodological soundness was low in 1 study, low/medium in 6 studies, medium in 3 studies, and high in 1 study (Table 2).

DISCUSSION

This review with a thorough search strategy was performed to review the available literature on the differences in the airway dimensions in different sagittal skeletal patterns. The articles were selected according to the strict inclusion and exclusion cri-

Table 1. Summarized data of included studies *(continued on next page)*

Study	Design	N	Sex (male/ female)	Age range (mean) years	Method	Head position	Skeletal pattern selection	Vertical pattern determination (Yes/No)	Airway measurements*	Airway dimensions in different sagittal skeletal patterns (study conclusions)
Memon et al., 2012	RS	360	172/188	14-20 (15.3±1.3)	LC	?	ANB angle (I, II classes)	Yes (HA, NA, LA)	Sagittal measurements at oropharyngeal levels.	Sagittal malocclusion type did not influence upper airway size.
Alves Jr et al., 2012	RS	50	27/23	8-10 (9.2±0.64)	CBCT	FH parallel to floor	ANB angle (I, II classes)	Yes (NA)	Sagittal measurements at nasopharyngeal and oropharyngeal levels. Oropharyngeal volume, area and minimal CSA** measurements within borders: superior – the edge of the hard palate to the posterior of the pharynx; inferior – the tip of the epiglottis; lateral, anterior and posterior – walls of the pharynx.	Oropharyngeal airway volume, area, minimal CSA and sagittal dimension at soft palate level were statistically significantly smaller in Class II compared to Class I.
El et al., 2011	RS	140	70/70	14-18	CBCT	NHP	ANB angle (I, II, III classes)	Yes (NA)	Volumes within borders: (1)Oropharyngeal (OP): superior – palatal plane extending to the posterior wall of the pharynx; inferior – the plane through the most anteroinferior point of the 2nd cervical vertebrae; lateral, anterior and posterior – walls of the pharynx. (2)Nasopharyngeal (NP): inferior – the superior limit of the OP; superior – the last slice before the nasal septum fused with the posterior wall of the pharynx; posterior and lateral – walls of the pharynx; anterior – NP volume rendered as a whole structure and included the nasopharynx, turbinates, and nares.	Oropharyngeal airway volume in Class II was smaller than in Class I and Class III. Nasopharyngeal airway volume was smaller in Class II than in Class I.
Hong et al., 2011	RS	60	30/30	18-30 (26.0±4.5)	CBCT	FH parallel to floor	ANB angle (I, III classes)	No	Total volume within borders: anterior - posterior border of the vomer, soft palate, base of tongue and anterior wall of the pharynx; posterior and lateral – walls of the pharynx; inferior – horizontal plane through the base of the epiglottis; superior – the highest point of the nasopharynx. Airway divided into nasopharyngeal and oropharyngeal compartments by a horizontal plane through the PNS and volumes measured. CSA measurements at various nasopharyngeal and oropharyngeal levels.	The nasopharyngeal volume and CSA measurements at soft palate plane and the epiglottis plane were significantly greater in the Class III than in Class I.
Oh et al., 2011	RS	60	25/35	10-13 (11.8±1.1)	CBCT	NHP	ANB angle (I, II, III classes)	No	Volumes within borders: (1)Nasopharyngeal (NP): anterior – a vertical plane through the PNS; inferior – a plane perpendicular to the sagittal plane through the PNS and lower medial border of the 1st cervical vertebra; posterior and lateral – walls of the pharynx. (2)Oropharyngeal: superior – inferior border of NP; inferior – a plane tangent to the most caudal medial projection of the 3rd cervical vertebra perpendicular to the sagittal plane; posterior, anterior and lateral – walls of the pharynx.	No statistically significant differences in airway volumes between Class I, II and III.

Table 1. Summarized data of included studies *(continued from previous page)*

Study	Design	N	Sex (male/ female)	Age range (mean) years	Method	Head position	Skeletal pattern selection	Vertical pattern determination (Yes/No)	Airway measurements*	Airway dimensions in different sagittal skeletal patterns (study conclusions)
Zhong et al, 2010	RS	190	91/99	11-16 (?)	LC	FH parallel to floor	ANB angle (I, II, III classes)	Yes (HA, NA, LA)	Sagittal measurements at nasopharyngeal, oropharyngeal and hypopharyngeal levels.	Sagittal dimension at oropharyngeal (both soft palate and base of tongue) and hypopharyngeal levels was larger in Class III compared to Class I and Class II. No differences at nasopharyngeal level.
Grauer et al, 2009	RS	62	25/37	17-46 (24.7)	CBCT	Head stabilized with strap, chin on the platform	ANB angle, Md length (I, II, III classes) + photos	Yes (HA, NA, LA), but not considered in evaluation	Total volume within borders: anterior – vertical plane through PNS; posterior and lateral – walls of the pharynx; upper – highest point of nasopharynx; lower – plane tangent to most caudal medial projection of third cervical vertebra perpendicular to sagittal plane. Total volume divided into nasopharynx and oropharynx volumes by plane perpendicular to sagittal plane through PNS and lower medial border of 1st cervical vertebra.	Oropharyngeal airway volume in Class II was smaller than in Class I and Class III. No significant differences at nasopharyngeal airway volume.
Muto et al, 2008	RS	99	0/99	17-32 (?)	LC	FH parallel to floor	SNB angle (Md retrognathism, prognathism, normal)	No	Sagittal measurements at oropharyngeal levels.	Oropharyngeal sagittal measurements decrease from mandibular prognathism to normal mandible to mandibular retrognathism group.
Alves et al, 2008	?	60	30/30	? (18.0±1.8)	CT	NHP	ANB, SNA, SNB angle (II, III classes)	Yes (NA)	Sagittal, transversal and CSA measurements at nasopharyngeal, oropharyngeal and hypopharyngeal levels. Airway divided into 3 parts and volumes measured: (1) nasopharynx – till cross-sectional plane of AwRP1-AwRP2; (2) upper oropharynx – between cross sectional planes of AwRP1-AwRP2 and SoftPal-AwRP3 (3) lower oropharynx – between cross sectional planes of SoftPal-AwRP3 and Epg-AwRG1.	No statistically significant difference in most airway measurements between Class II and Class III except transversal width of nasopharynx was larger in Class III than Class II.
Allhaija et al, 2005	RS	90	45/45	14-17	LC	NHP	ANB (I, II, III classes)	Yes (NA)	Sagittal measurements at oropharyngeal levels.	No statistically significant difference at any of oropharyngeal measurements.
Ceylan et al, 1995	?	90	45/45	13-15 (?)	LC	NHP	ANB (I, II, III classes)	Yes , but only vertical occlusal relationship	Sagittal measurements at nasopharyngeal, oropharyngeal and hypopharyngeal levels. Sagittal nasopharyngeal and oropharyngeal area measurements.	Oropharyngeal area in sagittal dimension decreases from Class III to Class I to Class II, but results were not statistically significant between Class I and Class III. No differences in linear measurements or nasopharyngeal area.

Study design: RS – retrospective. Methods: CBCT – cone beam computed tomography, CT – computed tomography, LC – lateral cephalometry. Head position: FH – Frankfort horizontal, NHP – natural head position. Vertical pattern: HA – high angle/vertical growth type, NA – normal angle/normal growth type, LA – low angle/ horizontal growth type. *Abbreviations used as in original study; **CSA – cross sectional area.

teria to ensure that valid and reliable results were obtained.

Only studies which stated the exact criteria they used to assess the skeletal relationships were included in this review. Most often the studies were excluded because the malocclusion was determined only by the occlusal relationships and the skeletal pattern was assessed afterwards or not at all. The studies evaluating merely the occlusal pattern (Angle molar and/or canine relationships or overjet) were excluded, because it has been shown that the dental anterioposterior relationships were not reliable predictors of the underlying skeletal pattern (31, 32). Almost all of the included investigations used ANB angle to establish the anterioposterior jaw relationships, and it should be recognized that it has well known limitations as it is influenced by many variables such as morphology of the nasion area, the vertical dimensions of the face, the inclination of the anterior cranial base and the inclination

Table 2. Quality description of the included studies

Article sample size	Previous estimate of sample size	Method error analysis	Adequate statistics provided	Possible influence of confounding factors**	Method***	Judged quality standard
Memon et al. 180 Class I 180 Class II	Yes	Yes	No*	No	2D	Medium
Alves Jr et al. 25 Class I 25 Class II	No	Yes	Yes	No	3D	Medium
El et al. 46 Class I 50 Class II 44 Class III	Yes	Yes	Yes	No	3D	High
Hong et al. 29 Class I 31 Class III	No/unknown	Yes	Yes	Yes	3D	Low/Medium
Oh et al. 19 Class I 27 Class II 14 Class III	No/unknown	Yes	Yes	Yes	3D	Low/Medium
Zhong et al. 82 Class I 54 Class II 54 Class III	No/unknown	Yes	No*	No	2D	Low/Medium
Grauer et al. 21 Class I 22 Class II 19 Class III	No/unknown	Yes	Yes	Yes	3D	Low/Medium
Muto el al. 31 ClassI 30 Class II 38 Class III	No/unknown	Yes	No*	Yes	2D	Low/Medium
Alves et al. 30 Class II 30 Class III	No/unknown	Yes	Yes	No	3D	Medium
Allhaija et al. 30 Class I 30 Class II 30 Class III	No/unknown	Yes	No*	No	2D	Low/Medium
Ceylan et al. 30 Class I 30 Class II 30 Class III	No/unknown	Yes	No*	Yes	2D	Low

*Use of parametric tests in samples that were not tested for normality; ** Not taking into account vertical growth type, head position, age (promptly described in the discussion); ***2D – 2-dimensional (lateral cephalometry), 3D – 3-dimensional (computed tomography, cone beam computed tomography).

of the jaws (33). If only the ANB angle is used to measure the relative position of the maxilla and the mandible to each other, the location of points A and B in the vertical plane will have an influence on the size of the angle and not the actual sagittal relation of the jaws (34). However it is still acknowledged as a traditional way of determining the anteroposterior skeletal pattern, and was accepted also in this review.

Only 6 of 11 included studies took into account the vertical skeletal pattern of the individuals included in the investigation (20-22, 25, 28, 29). Previously described influence of vertical pattern on ANB angle and studies, which have shown distinct differences in the airway dimensions between brachifacial, normal and dolichofacial subjects (20, 25, 35) suggest that misleading conclusions could be made without incorporating vertical growth type in the evaluation of the upper airways.

Most of the studies used natural head position (NHP) or Frankfurt horizontal (FH) during image taking procedures, but one of the included studies reported using head stabilization with head strap and chin put on the platform (26). The authors (26) discussed that a more prominent chin could lead to changes in the extension of the head and sequent increase of the upper airways. Several studies have found a significant correlation between the posterior airway space (PAS) and head extension or craniocervical angulation (36, 37). Muto et al. stated that 10 degrees of head extension increases PAS by 4mm (36). Therefore the imagining of the airway should be recorded with the head in natural position.

The age of individuals included in the investigations varied from 8 to 46 years. Sheng et al. found a significant increase of airway dimensions between age ten to twenty-two (38). Martin et al. investigated individuals aged 16 to 74 years and concluded that almost all upper airway dimensions decreased with increasing age in both men and women (39). In long-term follow-up studies, it has been established that between 20 and 50 years of age there is progressive decrease of the oropharyngeal sagittal dimension both behind the soft palate and behind the tongue (40). All of these studies suggested that the samples should be selected with subjects of approximate ages to avoid the effect of different ages on the airway measures. This aspect was not taken into account in one investigation (26).

The upper airway can be assessed by multiple imagining techniques, including cephalometry, computed tomography, cone beam computed tomography and magnetic resonance. Lateral cephalometry (LCR) was used in 5 of 11 included studies as only imagining tool for the upper airway dimensions (20, 25, 27, 29, 30). LCR has been the basic imagining technique for orthodontic investigations from year 1931 when was first described by Broadbent and was proven to provide valuable information of the upper airway morphology (33). However it offers only a 2-dimensional illustration of a 3-dimensional structure and provides no information about the lateral structures, volume and cross sectional area of the upper airway. A study comparing airway dimensions on the lateral cephalometric radiographs and CT reported a significant correlation between the PAS measured on LCR and the volume of the upper airway on CT (41). On the contrary, others have claimed that accurate determination of the airway size from LCR may give doubtful results (42) and sagittal linear measurements used in LCR are weakly correlated with cross sectional area measurements in CBCT, which are more important to describe airway patency (43, 44).

The findings of the most of the studies (75%) included in this review (21, 24-26, 28, 30) suggested that the dimensions of the nasopharynx do not differ among sagittal skeletal patterns. However one (22), which was judged as having high quality standard, suggested that individuals with Class II pattern had smaller nasopharyngeal dimensions compared to Class I. The nasal volume was rendered as whole structure including nasopharynx, turbinates and nares in this study (22), which could be a reason for notably diverse results.

Reported findings for the differences in the oropharyngeal dimensions among the 11 articles were significantly controversial. The quality analysis showed 7 of 11 studies (23-27, 29, 30) describing the oropharyngeal dimensions being of low or low/medium quality. Not considering the possible influence of previously described significant confounding factors or not using adequate statistical analysis could have a considerable impact on the results. Since opposing views exist regarding accuracy of upper airway assessment in LCR, also results of 2-dimensional studies (20, 25, 27, 29, 30) must be evaluated with care. Probably the best insight could be given by 3-dimensional investigations with good methodological soundness (21, 22, 28). Alves Jr *et al.* (21) and El and Palomo (22) found significant evidence that subjects with retruded mandibular positions are prone to smaller oropharyngeal dimensions, which however was not supported by findings of Alves *et al.* (28) and Memon *et al.* (20). Inconsistencies of the findings suggest that clear differences in the upper airway dimensions among sagittal craniofacial patterns could not be established.

CONCLUSIONS

This study was undertaken to answer the question "Is there any difference in the upper airway dimensions in patients with different skeletal pattern?"

On the basis of the analysis of 11 included articles, the following conclusions could be made:

75% of the studies did not find any differences in the nasopharyngeal airway dimensions among different skeletal anterioposterior patterns;

Almost half of the investigations found no differences in oropharyngeal airway volume and/or sagittal linear measurements among various skeletal sagittal patterns;

However 5 of 11 articles concluded that the oropharyngeal airway dimensions were smaller in Class II compared to Class I and/or Class III subjects. 6 of 11 studies found evidence that Class III sample had larger oropharyngeal dimensions than Class I and/or Class II groups;

The vertical growth type of the subjects was not considered in five investigations, and 45% of the included studies used lateral cephalometry as only tool for airway assessment.

Currently there is insufficient evidence that the upper airway dimensions differ in various sagittal skeletal patterns. There is a need for high quality research with well-defined methodology; and the use of 3D imaging techniques should be preferred for evaluation of the upper airway.

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