Sleep Breath (2015) 19:441–451
DOI 10.1007/s11325-015-1122-1

REVIEW

The effect of teeth extraction for orthodontic treatment on the upper airway: a systematic review

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Received: 19 April 2014 / Revised: 21 November 2014 / Accepted: 13 January 2015 / Published online: 28 January 2015

Abstract
Purpose The purpose of this study was to evaluate the effect of teeth extraction for orthodontic treatment on the upper airway.
Methods Relevant trials assessing the effect of orthodontic extractions on the upper airway were retrieved electronically through PubMed, Embase, Medline, Web of Knowledge, and the Cochrane Library. The processes of literature search, selection, quality assessment, and data extraction were performed by two authors independently.
Results Seven articles were included in this systematic review. They were categorized into three groups according to their indications for extractions, namely anteroposterior discrepancy (group 1), crowding (group 2), and unspecified indications (group 3). In group 1, enrolled patients were diagnosed with class I bimaxillary protrusion and had four first premolars extracted, with a significant decrease in upper airway dimension. In group 2, increase in the upper airway dimension was reported in patients who were diagnosed with class I crowding and four first premolars extracted. In group 3, all patients were adolescents and no significant change in the upper airway dimension was observed.
Conclusions Currently, it is difficult to draw evidence-based conclusions because of the exceeding heterogeneity among included studies, and more qualified trials are required to provide reliable evidence. Extractions followed by large retraction of the anterior teeth in adult bimaxillary protrusion cases could possibly lead to narrowing of the upper airway. Mesial movement of the molars appeared to increase the posterior space for the tongue and enlarge the upper airway dimensions. Although the effect of teeth extraction on upper airway dimension seems to be related to indications for extraction, accepted scientific evidence is still insufficient owing to the limited number of included studies. The relationship between the upper airway size and the respiratory function has not been demonstrated. While there may be a decrease in the upper airway volume, there is no evidence that this would turn an airway more collapsible. None of the studies assessed in this review had actual functional assessment of breathing. Additional qualified trials are necessary to verify reliability.

Keywords Orthodontics · Tooth extraction · Upper airway · Systematic review

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Introduction

The upper airway is composed of the nasopharynx, oropharynx, and laryngopharynx, among which the oropharynx is the narrowest and potentially the most susceptible to adverse effects following orthodontic treatment [1]. Constriction of the upper airway may lead to respiratory disorders, such as snoring and obstructive sleep apnea (OSA), which may degrade quality of life and or even be life-threatening. OSA, which is a chronic sleep-related respiratory dysfunction, is defined as cessation of airflow with persistent respiratory effort because of collapsed upper airways [2, 3]. Recently, increasing evidence has demonstrated that patients with OSA have dentofacial morphologic characteristics associated with a narrowed upper airway, such as a retrusive mandible, steep mandibular plane, dorsally positioned tongue, and long soft palate [4–6]. The effects of oral appliances on the upper airway, involving altered dentofacial morphology, have been extensively investigated [7–11]. For example, mandibular advancement devices have been widely used to cure mild-tomoderate snoring and OSA by enlarging the upper airway [7–9]. However, the effect of orthodontic extraction on the upper airway has received little attention until recently.

Teeth extraction is required extensively in orthodontic treatment. Significant dentofacial changes can exist after orthodontic extractions, including changes in skeletal structure, soft profile, and incisor angulation [12]. An alteration of incisors and soft tissue position could potentially affect tongue position and pharyngeal airway. The main concern involving the altered pharyngeal dimension caused by orthodontic extraction is the sleep quality of patients. To date, several studies evaluating the effect of orthodontic extraction on the upper airway have been published [13–19]. However, the conclusions were inconsistent.

A full recognition of the consequences of teeth extraction would definitely promote the development of the most suitable orthodontic treatment for each patient. Therefore, the aim of this systematic review was to evaluate the effect of teeth extraction for orthodontic treatment on the upper airway.

Materials and methods

This systematic review was performed in accordance with the guidelines recommended by the PRISMA statement [20]. Study designs included comparative studies or case series evaluating the association between teeth extractions and upper airway dimensions in orthodontic treatment. Participants (intervention and control groups) included subjects with extraction or non-extraction orthodontic treatment. Eligible studies were intended to assess upper airway dimension as an outcome measure.

Search strategy

Relevant publications were retrieved from the following electronic databases without restriction: PubMed (from 1950), Embase (from 1946), Medline (from 1946), Web of Knowledge (from 1986), and the Cochrane Library (to January 2014). The titles of included articles were input into Google Scholar for relevant articles, and the references of included articles were also screened for possible relevant citations. The final electronic searches were conducted on January 25, 2014. The search strategy is presented in Table 1.

All the studies were reviewed by two authors independently. Titles and abstracts were first screened to exclude irrelevant articles. Full texts of the remaining studies were further evaluated according to pre-set selection criteria. Discrepancies between the two reviewers were addressed by discussion with a third author. Final decisions were made after consensus was reached.

Selection criteria

The inclusion criteria are as follows:

(1) Human studies
(2) Prospective or retrospective clinical trials, case series
(3) Patients who received fixed orthodontic treatment with four premolars extracted
(4) Lateral cephalogram measurements, three-dimensional digitizer analysis, or dental cast measurements used to evaluate the dental and skeletal changes.

The exclusion criteria are as follows:

(1) Animal studies
(2) Case reports, reviews, and letters
(3) Studies concerning other treatments, such as maxillary expansion, maxillary protraction, and mandibular advancement
(4) Patients with a history of previous orthodontic/orthopedic treatment
(5) Patients with medical histories of craniofacial deformities, pharyngeal pathology and/or nasal obstruction, chronic mouth breathing, snoring, obstructive sleep apnea, adenoidectomy, or tonsillectomy.

Data extraction and analysis

Data extraction

Data were extracted independently by two reviewers, using a specially designed data extraction form. The following data were extracted: author, year of publication, study design, image examination, participant information, malocclusion, extraction indication, teeth extraction, anchorage design, outcomes, and conclusions.

Quality assessment

Quality assessment of included articles was performed according to the predetermined criteria in Table 2. The articles were mainly graded by their control group, sample size, selection criteria, baseline characteristics, outcome measurements, method error analysis, and blinding in measurements. The highest score for each article was 14. Quality was categorized as low (score 1–6), medium (score 7–11), and high (score 12–14). Quality assessment was done by two reviewers independently, and any disagreement was resolved through discussion with a third author before the final decision was made.

Table 1 Search strategies for each database

Step	PubMed	Embase, Medline, Web of Knowledge and Cochrane Library
1	"Orthodontics"[Mesh] OR orthodontic*	orthodontics OR orthodontic*
2	("Tooth Extraction"[Mesh]) OR ((tooth OR teeth OR premolar*) AND extract*)	(extraction*) OR ((tooth OR teeth OR premolar*) AND extract*)
3	airway	airway
4	1 AND 2 AND 3	1 AND 2 AND 3

Results

The article selection process is described in Fig. 1. The initial number of retrieved citations was 70, among which 69 were derived from electronic databases and one from relevant articles of Google Scholar [18]. A total of 45 duplicates were removed. The titles and abstracts of the remaining 25 articles were evaluated for relevance. After removing 17 irrelevant citations, eight articles were screened for eligibility. Full texts of the eight articles were assessed according to the pre-set criteria. One article was excluded because the patients included were diagnosed with OSA [21]. Finally, seven eligible articles were included in this systematic review.

The general information of the included studies and their main outcomes and conclusions are presented in Tables 3 and 4, respectively. Quality assessment of the included articles is shown in Table 5.

According to the indications for extraction, the included articles were categorized into three groups, as shown in Table 6. One article divided patients into three groups: extraction with minimum anchorage, non-extraction, and extraction with maximum anchorage, with the non-extraction group as the control [16]. The indication for extraction in the minimum anchorage group was crowding, whereas the indication for extraction in the maximum anchorage group was anteroposterior discrepancy. Therefore, this article [16] was categorized into both groups 1 and 2.

Group 1: anteroposterior discrepancy

Four articles were categorized into this group [13–16]. All patients were diagnosed with class I bimaxillary protrusion and treated with extraction of four first premolars. In this group, significant retraction of the incisors and decreased incisor inclination were observed after orthodontic treatment, without significant bony changes. Three among the four articles showed consistent results that the dimension of the upper airway was reduced after extraction of four first premolars with large retraction of the anterior teeth [13, 15, 16]. The other article reported no significant upper airway change after extraction [14].

Table 2 Criteria for quality assessment of the included articles

Component	Points	Definition
Control group	2	Presence of control group
	0	Absence of control group
Sample size	2	Adequate sample size
	0	Inadequate sample size
Selection criteria	2	Clearly described and appropriate defined inclusion/exclusion criteria
	1	Unclearly described or inappropriate defined inclusion/exclusion criteria
	0	No description
Baseline characteristics	2	Adequately described and comparable baseline characteristics
	1	Inadequately described or incomparable baseline characteristics
	0	No description
Outcome measurements	2	Reliable outcome measurements
	1	Relatively reliable outcome measurements
	0	Unreliable outcome measurements
Method error analysis	2	Method error analysis applied
	0	No method error analysis applied
Blinding in measurements	2	Yes
	0	No

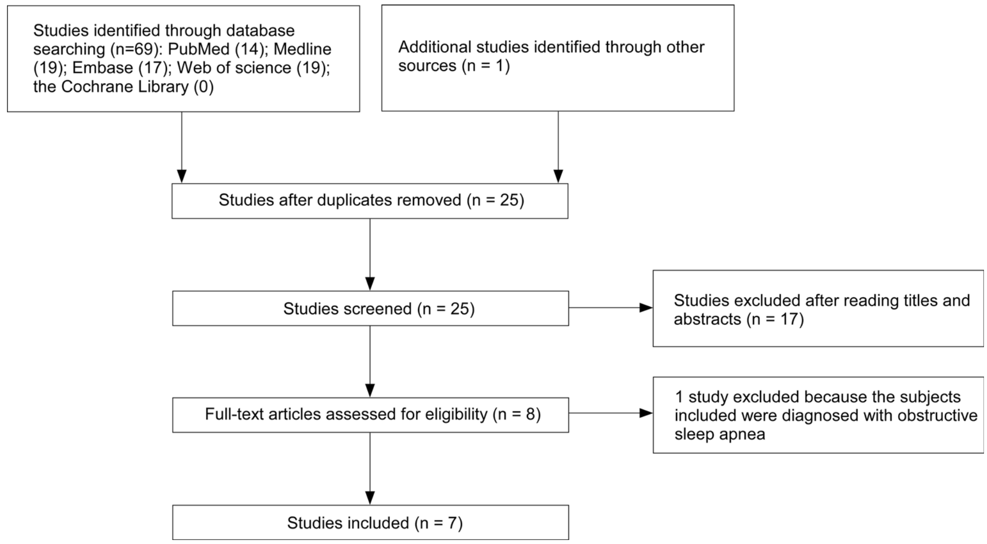

Fig. 1 Flow diagram for systematic search and selection strategy

Additionally, the relationship between the sagittal position of the anterior teeth and the position of the hyoid was assessed in all four articles. Al Maaitah et al. [14] and Germec-Cakan et al. [16] stated that the position of the hyoid seemed to be unaffected by retraction of the anterior teeth. However, the other two articles reported that the retraction of anterior teeth led to backward and downward movement of the hyoid [13, 15].

Group 2: crowding

One article was categorized into this group [16]. The patients in this study were diagnosed with class I crowding and treated with extraction of four first premolars. After alleviation of crowding, the remaining extraction space was occupied by mesial movement of the posterior teeth. In this study, the sagittal depth of the upper airway increased by approximately 1.5 mm, whereas the mesial movement of the molars was about 3 mm after treatment. The author believed that mesial movement of the molars was the most likely explanation for the increased depth of the upper airway.

Group 3: unspecified indications

Three articles, which did not describe their extraction indications, were included in this group [17–19]. All included patients were adolescents with four premolars extracted. Although certain increases in the upper airway volume were observed in both extraction and non-extraction patients, none of these results were statistically significant.

Discussion

This is the first systematic review assessing the effect of extractions in orthodontic treatment on the upper airway. Teeth extraction plays an essential role in orthodontic treatment, and three-dimensional changes in the stomatognathic system after teeth extraction have always been the focus of attention [22, 23]. In this systematic review, possible reasons for upper airway changes after orthodontic extraction treatment were analyzed. Impacts of study design and reliability of outcome measurements were also discussed to shed light on future studies.

The results of the present systematic review demonstrated that, during orthodontic treatment with extraction of premolars, large retraction of the anterior teeth and mesial movement of molars were the two main factors affecting the upper airway dimensions. Large retraction of the anterior teeth seemed to result in the reduction in the upper airway dimensions [13, 15, 16], whereas mesial movement of molars seemed to increase the dimensions [16].

The root of the tongue, soft palate, and posterior and lateral pharyngeal wall form the boundary of the oropharynx. Large retraction of the incisors led to dorsal movement of the anterior boundary of the oral cavity, which may affect the position of the tongue and soft palate and result in narrowing of the upper airway. Previous studies suggested that narrowing of the upper airway after mandibular setback surgery was due to the posterior displacement of the tongue [24, 25]. Jena et al. [26] demonstrated that in mandibular retrognathism subjects, the tongue base was positioned more posteriorly and inferiorly, and the dorsally positioned tongue pushed the soft palate backward and led to decreased oropharynx depth in the sagittal plane. Germec-Cakan et al. [16] reported a reduction of 2.1 ±1.5 mm in the middle airway space (depth of the airway along a parallel line to the Go–B line through the tip of the

Table 3 General information of the included articles

Author (year)	Study design	Image examination	Sample size	Gender M/F	Age (year)	Malocclusion	Extraction indication	Teeth extraction	Anchorage design
Chen [13]	RS	MSCT	30	–	Adults	Class I bimaxillary protrusion	Anteroposterior discrepancy	First four premolars	Maximum anchorage
Al Maaitah [14]	RS	Cephalograms	40	13/27	19.21±1.46 (18~23)	Class I bimaxillary protrusion	Anteroposterior discrepancy	First four premolars	NS
Wang [15]	RS	Cephalograms	44	8/36	21.19 (16~34)	Class I bimaxillary protrusion	Anteroposterior discrepancy	First four premolars	Maximum anchorage
Germec-Cakan [16]	RS	Cephalograms	13	11/2	18.1±3.7	Class I excessive crowding	Excessive crowding	First four premolars	Minimum anchorage
			13	11/2	17.8±2.4	Class I			Air-rotor stripping
			13	11/2	15.5±0.88	Class I bimaxillary protrusion	Anteroposterior discrepancy	First four premolars	Maximum anchorage
Valiathan [17]	RS	CBCT	E 20 NE 20	10/10 10/10	M 13.8±1.3 F 13.5±1.6	Class I	NS	Four premolars	NS
Shannon [18]	RS	CBCT	E 27 NE 61	11/16 30/31	13.5±2.87 13.2±1.95	NS	NS	Four premolars	NS
Stefanovic [19]	RS	CBCT	E 31 NE 31	16/15 16/15	12.97±1.15 12.86±0.74	Mixed Mixed	NS	First four premolars	NS

MSCT multi-slice computed tomography, *E* extraction, *NE* non-extraction, *RS* retrospective study, *NS* not specified

soft palate) and 3.8±3.3 mm in the inferior airway space (depth of the airway space along the Go–B line) in the maximum anchorage group after orthodontic extraction. Therefore, it could be suspected that large retraction of the anterior teeth led to backward movement of the tongue, which compressed the soft palate and narrowed the upper airway.

Another possible explanation for the upper airway dimension reduction after large incisor retraction was dorsal movement of the hyoid. However, the impact of backward and downward movement of the hyoid on upper airway dimensions remains controversial. Chen et al. [13] demonstrated that there was a significant correlation between the degree of hyoid retraction in the horizontal direction and the decrease in upper airway dimensions. The result was consistent with previous studies [24, 25]. On the contrary, Wang et al. [15] reported that altered hyoid position was an adaptation to prevent encroachment of the tongue into the pharyngeal airway, which was also supported by previous studies [27]. Therefore, the actual impact of hyoid position change on the upper airway could not be drawn from existing studies.

Intentional mesial movement of molars and anchorage loss seems to increase the space behind the tongue, which may play a vital role in improving the upper airway dimensions. In the study by Germec-Cakan et al. [16], the mean increase in upper airway space was approximately 1.5 mm after treatment. The author attributed this increase to a 3-mm mesial movement of the molars after resolution of anterior crowding in the minimum anchorage group. A narrowed upper airway after large retraction of the anterior teeth was reported in three articles in group 1 [13, 15, 16]. In these three studies, maximum anchorage was applied to prevent anchorage loss, thereby avoiding unwanted forward movement of molars. However, in the study by Al Maaitah et al. [14], another article in group 1, application of maximum anchorage was not mentioned, which may have contributed to the insignificant changes found in the upper airway.

Much variation among studies regarding the age of recruited subjects reduced the comparability. For adolescent patients, upper airway volume increases rapidly owing to craniofacial growth. On the contrary, the upper airway ceases to grow in adult patients. Thus, the growth potential should be taken into consideration when evaluating the effect of orthodontic extraction treatment on the upper airway in adolescents [17–19]. Craniofacial growth causes the length and volume of the upper airway to increase rapidly between 8 and 18 years old, with its peak around 13 years old [28, 29]. All three studies in group 3 reported an increase in upper airway volume in both extraction and non-extraction groups after orthodontic treatment. However, no significant difference was found between the two groups. All the patients in these studies ranged from 11 to 16 years old, which covered the rapid growth period. Rapid growth of the airway may have partially masked the effect of extractions on the upper airway, and

Table 4 Main outcomes and conclusions of the included articles

Author	Main outcomes			Conclusion
	Incisor/molars	Hyoid	Changes of the upper airway	
Chen [13]	The amounts of upper incisor retraction at the incisal edge and apex were 7.64±1.68 and 3.9±2.10 mm, respectively. ($P<0.05$)	The hyoid retraction was 2.96±0.54 mm in horizontal direction and 9.87±2.92 mm in vertical direction. ($P<0.05$)	The reduction in mean cross-sectional areas of the palatopharynx, glossopharynx, and hypopharynx were 21.02±7.89, 25.18±13.51, and 38.19±5.51 %, respectively. ($P<0.05$)	1. Large incisor retraction leads to narrowing of the upper airway in adult bimaxillary protrusion patients 2. There is a significant correlation among the retraction distance of the upper incisor, the retraction distance of the hyoid in the horizontal direction, and the decrease of the hypopharynx
Al Maaitah [14]	Upper and lower incisor inclination and lower incisor to A-Pog line had significant reduction	Hyoid position had no significant change	Upper airway dimension had no significant change	Extraction of the first premolars for the treatment of bimaxillary proclination does not affect upper airway dimensions
Wang [15]	The tips of upper and lower incisor were retracted by 6.84 and 4.95 mm, respectively. ($P<0.05$)	The hyoid retraction was 0.88±2.32 mm in horizontal direction and 1.24±3.42 mm in vertical direction. ($P<0.05$)	Decrease of SPP-SPPW, U-MPW, TB-TPPW, and V-LPW were 0.56±1.48, 0.85±1.77, 1.63±1.80, and 1.54±2.90, respectively. ($P<0.05$)	1. Following retraction of incisors, the pharyngeal airway became narrower 2. The changes of the pharyngeal airway size were no different between the hyperdivergent and nonhyperdivergent groups 3. The hyoid bone tends to move in a posterior and inferior direction 4. There was a significant correlation between the retraction distance of lower incisor and the airway behind the soft palate, uvula, and tongue
Germec-Cakan [16]	(1) In minimum anchorage group, the average upper and lower incisor retraction was 1.6±2.4 and 1.9±1.9 mm, respectively. The average mesial molar movement was 3 mm. ($P<0.05$) (2) In ARS group, mesial movement of upper and lower incisor was approximately 0.7 mm after treatment. ($P>0.05$) (3) In maximum anchorage group, the average upper and lower incisor retraction was 12.4±3.5 and 9.6±2.9 mm, respectively. ($P<0.05$)	Hyoid position had no significant change	(1) In minimum anchorage group, increase of superior and middle oropharynx size was 1.7±2.4 and 1.0±2.2 mm, respectively. ($P<0.05$) (2) In ARS group, no significant was observed in airway dimension (3) In maximum anchorage group, decrease of superior and middle oropharynx size was 2.1±1.5 and 3.8±3.3 mm, respectively. ($P<0.05$)	1. Superior and middle oropharynx size increased in subjects treated with extraction and minimum anchorage 2. In patients treated non-extraction by ARS, no significant change was observed in airway dimensions 3. Middle and inferior oropharynx size narrowed in subjects treated with extraction and maximum anchorage
Valiathan [17]	(1) In ExtG, the inclination and proclination of upper and lower incisor decreased significantly (2) In NExtG, the inclination of upper and lower incisor increased significantly without significant change in proclination	No measurement	Increase of oropharynx volume was 1082.6±2504.3 and 1701.1±3677.7 mm^3 for ExtG and NExtG, respectively. ($P>0.05$)	Extraction of four premolars with retraction of incisors does not affect oropharynx airway volume
Shannon [18]	No measurement	Hyoid position had no significant change	Increase of oropharynx volume were 2701.94±3728.40 mm^3 and 2674.46±3978.37 mm^3 for ExtG and NExtG, respectively ($P>0.05$)	1. There were net increases in oropharynx width, area, and volume for both ExtG and NExtG 2. There is no quantitative evidence that extracting premolars has any effect on oropharynx size

Table 4 (continued)

Author	Main outcomes			Conclusion
	Incisor/molars	Hyoid	Changes of the upper airway	
Stefanovic [19]	No measurement	No measurement	Increase of oropharynx volume were 1668.87±2477.18 and 1105.39±2832.79 mm^3 for ExtG and NExtG, respectively. (P>0.05)	An extraction or non-extraction choice for orthodontic treatment would not affect the pharyngeal airway

SPP-SPPW: perpendicular distance between soft palate center and posterior pharyngeal wall; U-MPW: perpendicular distance between the tip of uvula and posterior pharyngeal wall; TB-TPPW: distance between point of intersection of base of the tongue and extension of line B-Go and point of intersection of posterior pharyngeal wall and extension of line B-Go; V-LPW: perpendicular distance between the most posteroinferior point on the base of the tongue and posterior pharyngeal wall

ARS air-rotor stripping, *ExtG* extraction group, *NExtG* non-extraction group

different growth rates in adolescent patients may further complicate the interpretation of the effect of teeth extraction. Therefore, age should be taken as a crucial factor when assessing the effect of orthodontic extraction treatment on upper airway dimensions. In addition, the age gap between included patients should be as small as possible to minimize the effect of growth potential and rates on the reliability of outcomes.

Significant correlation has been found between the upper airway and different sagittal and vertical skeletal patterns [30–34]. In subjects with normal vertical facial patterns, the upper airway is largest with mandibular prognathism, followed by the normal mandible and mandibular retrognathism [30–32, 34]. In subjects with a normal sagittal facial pattern, the hyperdivergent group has a narrower anteroposterior pharyngeal dimension than the normodivergent group, and the dimension decreases, whereas the mandibular plane angle increases [30, 33]. Therefore, for adolescents with different craniofacial growth patterns, another possible impact factor is the varied growth potential of the upper airway. Thus, growth pattern should be taken into account when interpreting the effect of orthodontic extractions on the upper airway in adolescents. For adults, the growth pattern and degree of growth have been established, and therefore may have little effect on the outcome [15]. Hence, further studies are needed to address the effect of orthodontic extraction on the upper airway in adolescents with different skeletal patterns.

Malocclusion is another factor that should be taken into account. Different types of malocclusion have their own treatment protocols and indications for extractions. Patients in group 1 were diagnosed with class I bimaxillary protrusion, and the indication for extractions was anteroposterior discrepancy. After large retraction of the anterior teeth, a decrease in upper airway volume was noticed [13, 15, 16]. On the contrary, an increase in upper airway volume was observed in group 2 and these patients were diagnosed with class I crowding and treated with extraction of four premolars to eliminate the crowding. The remaining extraction space after resolution of crowding was used for mesial movement of molars, which imposed little influence on the anterior oral boundary [16]. Four premolars were extracted in both groups; however, the treatment protocol was different. As a result, extractions affected the upper airway in opposite ways.

Three imaging methods (cephalometrics, multi-slice computed tomography, and cone-beam computed tomography) were employed in the included studies, which might also affect the reliability and comparability of the outcomes. High correlations were reported between using lateral radiographs and three-dimensional magnetic resonance imaging scans to assess the pharyngeal airway [35]. However, the pharynx is a three-dimensional tube-

Table 5 Quality assessment of the included articles

Author (year)	Control group	Sample size	Selection criteria	Baseline characteristics	Outcome measurements	Method error analysis	Blinding in measurements	Score	Quality
Chen [13]	0	2	1	0	2	2	0	7	Medium
Al Maaitah [14]	0	2	2	0	2	2	0	8	Medium
Wang [15]	0	2	2	1	2	2	0	9	Medium
Germec-Cakan D [16]	2	0	1	1	1	2	0	7	Medium
Valiathan [17]	2	2	0	0	0	2	0	6	Low
Shannon [18]	2	2	0	0	0	2	0	6	Low
Stefanovic [19]	2	2	0	0	0	2	0	6	Low

shaped structure, and two-dimensional imaging may easily lose some of the dimensional information [36]. Thus, three-dimensional imaging is recommended for future studies.

The pathological mechanism of OSA is still unclear, and several factors are important, including anatomical factors leading to a narrowed upper airway and obesity [4]. Despite a narrowed airway playing a pivotal role in the pathogenesis of OSA, investigations found that the upper airway size did not consistently correlate with the severity of OSA, and many other factors such as body mass index, neck circumference, soft palate length, tongue hypertrophy, gender, age, and ethnicity were also vital determinants of the severity of OSA [37–41]. Therefore, there was not a direct link between altered airway and altered function in OSA patients. Considering the subjects included in our systematic review were all from a “normal” population (without snoring and OSA), the influence of an altered airway on function might be different from the abnormal upper airway in OSA patients. Unfortunately, through systematic retrieval, we found that no previous studies had focused on the impacts of airway size decrease on sleep quality and on the susceptibility to OSA in a normal population, which may be a promising research field in the future. Additionally, the imaging was done in an upright and awake situation, which may differ from supine and sleeping airway size [42]. In summary, although large retraction of the

Table 6 Groups of included articles

Group	Indication for extraction	Author (year)	Title
1	Anteroposterior discrepancy	Chen [13]	Effect of large incisor retraction on upper airway morphology in adult bimaxillary protrusion patients
		Al Maaitah [14]	First premolar extraction effects on upper airway dimension in bimaxillary proclination patients
		Wang [15]	Changes of pharyngeal airway size and hyoid bone position following orthodontic treatment of class I bimaxillary protrusion
		Germec-Cakan [16]	Uvulo-glossopharyngeal dimensions in non-extraction, extraction with minimum anchorage, and extraction with maximum anchorage
2	Crowding	Germec-Cakan [16]	Uvulo-glossopharyngeal dimensions in non-extraction, extraction with minimum anchorage, and extraction with maximum anchorage
3	Unspecified indications	Valiathan [17]	Effects of extraction versus non-extraction treatment on oropharyngeal airway volume
		Shannon [18]	Oropharyngeal airway volume following orthodontic treatment: premolar extraction versus non-extraction
		Stefanovic [19]	Three-dimensional pharyngeal airway changes in orthodontic patients treated with and without extractions

anterior teeth may decrease the upper airway dimensions, it remains unknown whether decreased airway size can affect sleep quality and increase susceptibility to OSA.

Limitations

The effect of orthodontic extraction treatment on the upper airway has been an emerging area of research in recent years. Therefore, it is worth appraising these studies to obtain a better understanding of the effect. However, because it is a new research direction, the number of retrieved literature was limited.

No meta-analysis was conducted because of great heterogeneity among the included articles, such as different growth potential, facial skeletal patterns, extraction indications, types of malocclusion, imaging analysis methods, landmarks, and reference points selected for measurements.

From an evidence-based point of view, a randomized controlled trial (RCT) was the least biased method for interventional research. However, there is no room to design RCTs for orthodontic extraction treatment because every orthodontic treatment plan, whether extraction or not, is established for an individual patient based on proper diagnosis. Orthodontists always provide several alternative solutions for patients according to the diagnosis and chief complaints and communicate with them to select the best plan together. Furthermore, it is unethical not to offer patients the option for extractions if they will benefit from this treatment. In addition, well-designed prospective or retrospective trials are of great value and cannot be ignored as a source of evidence [43].

The validity of the conclusions was significantly affected by the quality of included literature. Based on the quality assessment criteria, nearly half of the included articles were judged to be low quality evidence and some serious defects were found. The most obvious shortcomings were inadequate selection criteria descriptions and incomparable baseline characteristics. Further studies should better describe the selection criteria along with comparable baseline characteristics, such as airway growth potential, type of malocclusion, indication for extractions, and craniofacial growth pattern, to improve the scientific reliability of research results.

In addition, none of the included articles studied the long-term stability of the tongue, soft palate, hyoid, and the pharyngeal size after orthodontic treatment. Thus, the long-term effects of orthodontic extraction treatment on the upper airway need to be addressed in future studies.

Concerning these limitations, further well-designed prospective studies are required to elaborate the effects of orthodontic treatment on the upper airway.

Conclusions

1. Currently, it is difficult to draw any evidence-based conclusion because of the exceeding heterogeneity among included studies, and higher quality trials are required to provide reliable evidence.
2. Extractions with large retraction of the anterior teeth in adult bimaxillary protrusion cases could possibly lead to narrowing of the upper airway. Mesial movement of the molars appeared to increase the posterior space for the tongue and enlarge the upper airway dimensions. Although the effects of teeth extractions on upper airway dimensions seems to be related to the indications for extraction, accepted scientific evidence is still insufficient owing to the limited number of included studies. Higher quality trials are necessary to verify reliability.
3. The relationship between the upper airway size and the respiratory function has not been demonstrated. While there may be a decrease in the upper airway volume, there is no evidence that this would turn an airway more collapsible. None of the studies assessed in this review had actual functional assessment of breathing.

Acknowledgments This work was supported by the National Nature Science Foundation of China (No. 81070859) and the Research Fund for the Doctoral Program of Higher Education of China (No. 20110181110053).

Conflict of interest The authors have no conflicts of interest to declare.

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