SYSTEMATIC REVIEW

The use of magnetic resonance imaging in the evaluation of upper airway structures in paediatric obstructive sleep apnoea syndrome: a systematic review and meta-analysis

¹Romeo Patini, ²Mariantonietta Arrica, ³Enrico Di Stasio, ¹Patrizia Gallenzi and ¹Massimo Cordaro

¹Dentistry Unit of Head and Neck Clinical Area, School of Dentistry, Catholic University of Sacred Heart, Rome, Italy;

²Department of Surgery, Microsurgery and Medical Sciences, School of Dentistry, University of Sassari, Sassari, Italy;

³Molecular Clinical Biology Unit of Laboratory Medicine Clinical Area, Catholic University of Sacred Heart, Rome, Italy

Objectives: A systematic review was conducted to assess the effectiveness of MRI in evaluating upper airway structures in children affected by obstructive sleep apnoea syndrome (OSAS).

Methods: A literature search was performed in the Cochrane Central Register of Controlled Trials, Web of Science, Scopus and PubMed databases from their inception to 31/03/2016, including available randomized controlled trials and controlled clinical trials published in English assessing the use of MRI integrated with traditional polysomnography (PSG) among children up to 15 years of age affected by OSAS. The primary outcome to be evaluated was the efficacy of MRI in analyzing the upper airway total volume among healthy children compared with children affected by OSAS. Secondary outcomes were to compare the efficacy of MRI in analyzing the upper airway cross-sectional area in the areas adjacent to the adenoids and tonsils, adenoid and tonsil volume, and soft-tissue and maxillofacial bone parameters in the same sample. Results were expressed using a random-effects model and mean differences (MD) with 95% confidence intervals (CI).

Results: The search yielded 1005 titles in total; the selection process narrowed to 3 titles, which were all assessed as indicating an unclear level of risk of bias. The meta-analysis found evidence of MRI effectiveness in evaluating differences in the upper airway total volume between paediatric patients affected by OSAS and paediatric patients not affected by OSAS (MD -0.56 cm^3 ; 95% CI: -1.05 to -0.07).

Conclusions: Although MRI could be considered effective in evaluating upper airway structures in children affected by OSAS, based on the present evidence, PSG is still the golden standard and further studies are required to verify MRI reliability.

Dentomaxillofacial Radiology (2016) **45**, 20160136. doi: [10.1259/dmfr.20160136](https://doi.org/10.1259/dmfr.20160136)

Cite this article as: Patini R, Arrica M, Di Stasio E, Gallenzi P, Cordaro M. The use of magnetic resonance imaging in the evaluation of upper airway structures in paediatric obstructive sleep apnoea syndrome: a systematic review and meta-analysis. *Dentomaxillofac Radiol* 2016; **45**: 20160136.

Keywords: child; sleep apnoea; diagnosis; MRI

Introduction

Obstructive sleep apnoea syndrome (OSAS) is a common disorder in childhood characterized by repeated

episodes of upper airway obstruction during sleep. This syndrome affects 2% of children in Western countries, with peak incidence between 2 and 6 years of age.¹⁻⁴

If not treated promptly and properly, this syndrome can lead to neurodevelopmental disorders, learning

Correspondence to: Dr Romeo Patini. E-mail: romeopatini@hotmail.it

Received 4 April 2016; revised 19 June 2016; accepted 18 July 2016

defects, growth retardation, pulmonary hypertension and other serious cardiorespiratory sequelae.^{5,6}

OSAS is frequently associated with benign adenotonsillar hypertrophy, but other possible causes such as the anatomy of the craniofacial anomalies, abnormal neuromuscular tone and respiratory disorders have also been reported.²

A crucial factor in the genesis of OSAS is the increase in the soft-tissue volume. The speed of growth of the skeleton surrounding the upper airway is in fact lower than that of the characteristic soft tissues, in particular the lymphoid tissue. The content, therefore, grows faster than the container and this leads to a blocking of the airflow, causing the typical clinical and radiographic signs of the syndrome.

The shape, size and position of the craniofacial skeleton may determine the narrowing of an airway, since the bone tissue represents an incompressible limit for the oral cavity, nasal cavity and pharynx. These parameters can also indirectly affect the genesis of the syndrome as they alter normal muscle insertion sites.^{7–10}

The gold standard for the diagnosis of OSAS is polysomnography (PSG).

Several studies in the literature have tried to define the role of cephalometric skeletal models in identifying the predisposition to generation of the syndrome. Cephalometric analysis applied to OSAS diagnosis has been demonstrated to have several limits. Such limits include: the low resolution caused by soft tissues, as well as the orthostatic position taken by the patient during the examination, which does not simulate the position taken during sleep.^{11,12}

Other studies have examined the diagnostic potential of MRI, which allows the evaluation of the upper airway into its soft and skeletal components, in the same position taken by the patient during the night.^{13,14}

To the best of our knowledge, no systematic review has been reported that assessed this issue.

The aim of this systematic review was to evaluate the effectiveness of MRI in the evaluation of upper airway structures between paediatric patients affected by OSAS and those unaffected by OSAS and whether MRI could be used as a diagnostic examination in daily clinical practice.

Methods and materials

Protocol development and eligibility criteria

A detailed protocol was designed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.¹⁵ The following focused question formulated in the Patient, Intervention, Comparison and Outcome format was developed: “Is MRI effective in the evaluation of upper airway structures among paediatric patients affected by OSAS compared with patients who are healthy and could it be used as a diagnostic examination in daily clinical routine?”

Search strategy

Two calibrated investigators (RP and MA) performed a comprehensive and systematic electronic search in MEDLINE—PubMed, Web of Science, Scopus and the Cochrane Central Register of Controlled Trials (CENTRAL) from database inception to March 2016. Available human studies published in English were then selected.

The combination of Medical Subject Headings (MeSH) terms and free text words used for MEDLINE—PubMed database are as follows:

- (1) (“sleep apnoea” OR “sleep apnea” OR “sleep apnea syndrome” OR “sleep apnoea syndrome” OR “snoring*” OR “upper airway resistance syndrome” OR “disordered breathing” OR “hypopnea” OR “hypopnoea” [Title/Abstract])
- (2) (“sleep apnoea” OR “sleep apnea” OR “sleep apnea syndrome” OR “sleep apnoea syndrome” OR “snoring*” OR “upper airway resistance syndrome” OR “disordered breathing” OR “hypopnea” OR “hypopnoea” [MeSH])
- (3) (“diagnosis*” OR “determination” OR “assessment” OR “evaluation” [Title/Abstract/MeSH])
- (4) (radiography * OR cephalometry* OR tomography* [Title/Abstract/MeSH])
- (5) ((1) OR (2)) AND (3) AND (4).

The following combinations of MeSH terms and free text words were used for the CENTRAL database:

- (1) MeSH descriptor: [sleep apnoea] explode all trees
- (2) MeSH descriptor: [sleep apnea] explode all trees
- (3) MeSH descriptor: [sleep apnoea syndrome] explode all trees
- (4) MeSH descriptor: [sleep apnea syndrome] explode all trees
- (5) MeSH descriptor: [snoring*] explode all trees
- (6) MeSH descriptor: [upper airway resistance syndrome] explode all trees
- (7) MeSH descriptor: [disordered breathing] explode all trees
- (8) MeSH descriptor: [hypopnea] explode all trees
- (9) MeSH descriptor: [hypopnoea] explode all trees
- (10) “diagnosis*”:ti,ab,kw OR “determination”:ti,ab,kw OR “assessment”:ti,ab,kw OR “evaluation”:ti,ab,kw AND “radiography*”:ti,ab,kw OR “cephalometry*”:ti,ab,kw OR “tomography”:ti,ab,kw
- (11) ((1) OR (2) OR (3) OR (4) OR (5) OR (6) OR (7) OR (8) OR (9)) AND (10) filters: trials.

The combinations of keywords used for the Web of Science database are as follows:

- (1) [Topic] “sleep apnoea” OR “sleep apnea” OR “sleep apnea syndrome” OR “sleep apnoea syndrome” OR “snoring*” OR “upper airway resistance syndrome” OR “disordered breathing” OR “hypopnea” OR “hypopnoea”

- (2) [Topic] “diagnosis*” OR “determination” OR “assessment” OR “evaluation”
- (3) [Topic] radiography* OR cephalometry* OR tomography*
- (4) [Combine] (1) AND (2) AND (3).

The following combination of keywords was used for Scopus database:

- (1) KEY (“sleep apnoea” OR “sleep apnea” OR “sleep apnea syndrome” OR “sleep apnoea syndrome” OR “snoring*” OR “upper airway resistance syndrome” OR “disordered breathing” OR “hypopnea” OR “hypopnoea”)
- (2) KEY (“diagnosis*” OR “determination” OR “assessment” OR “evaluation”)
- (3) KEY (radiography* OR cephalometry* OR tomography*)
- (4) (1) AND (2) AND (3).

In addition, the bibliographies of all articles selected for inclusion were scrutinized in order to include as many studies as possible.

Selection criteria

Randomized controlled trials (RCTs) and controlled clinical trials (CCTs) are considered the most appropriate types of studies in drawing conclusions with strong scientific evidence. Thus, all available RCTs or CCTs published in English and conducted on human subjects were included with the aim of assessing the use of MRI integrated with traditional PSG. The additional criterion for inclusion was that the studies were conducted among healthy children aged 15 years or younger affected by OSAS. The primary outcome to be assessed was the upper airway total volume. Secondary outcomes were: the upper airway cross-sectional area (CSA) in the regions adjacent to the adenoids and tonsils, adenoid and tonsils volume, and soft-tissue and maxillofacial bone parameters (mid-sagittal CSA and volume of the tongue and soft palate, mid-sagittal CSA of hard palate and mandibular volume).

Studies were excluded if they were:

- Grey literature
- Case reports
- Case series
- Letters and narratives or retrospective reviews
- Studies dealing with non-healthy subjects
- Studies regarding the use of cephalometric evaluation or CT
- *In vitro* and animal studies.

Selection of studies

Screening was conducted independently and in duplicate, using specially designed data extraction forms by two reviewers (RP and MA). Any disagreements were solved through discussion and consultation with the co-author supervisor (PG) when necessary.

For studies appearing to meet the inclusion criteria, or for studies whose information in the title and abstract was insufficient to make a clear decision, the authors of this article decided to obtain and screen the full report. The studies rejected after full-text evaluation were recorded in the excluded studies table (Table 1), together with the reasons for exclusion. Detailed references are given in the appendix (Appendix A).

Exclusion of studies

18 studies were excluded from the review because they did not deal with the use of MRI for evaluating the upper airway total volume. 12 studies were excluded because they reported data about a population of adult patients; 1 study was excluded because it did not fit with the OSAS topic.

Data collection

The reviewers independently extracted the radiographical data through a structured form. Both primary and possible secondary outcomes were sought from all the included studies.

Quality assessment

All included studies were analyzed through the Cochrane Collaboration’s tool for assessing risk of bias, aiming to state their methodological quality.

Table 1 Table showing references of excluded studies with rationale for exclusion

References	Rationale for exclusion
Anantanarayanan et al ^{A2} (2013)	Not dealing with MRI
Caprioglio et al ^{A3} (2014)	Not dealing with MRI
Carotenuto et al ^{A4} (2011)	Not dealing with MRI
Celenk et al ^{A5} (2010)	Not dealing with MRI
Celikoglu et al ^{A6} (2014)	Not dealing with MRI
Donnelly et al ^{A8} (2001)	Not dealing with MRI
Gasparini et al ^{A9} (2012)	Not dealing with MRI
Goldstein et al ^{A11} (2004)	Not dealing with MRI
Golpe et al ^{A12} (2002)	Not dealing with MRI
Guilleminault et al ^{A13} (2013)	Not dealing with MRI
Guilleminault et al ^{A14} (2011)	Not dealing with MRI
Hänggi et al ^{A15} (2008)	Not dealing with MRI
Heller et al ^{A16} (2006)	Not dealing with MRI
Juliano et al ^{A20} (2009)	Not dealing with MRI
Kinzinger et al ^{A22} (2011)	Not dealing with MRI
Pirelli et al ^{A24} (2005)	Not dealing with MRI
Villa et al ^{A27} (2002)	Not dealing with MRI
Wolf et al ^{A30} (2010)	Not dealing with MRI
Abdel-Aziz et al ^{A1} (2014)	Population of adults
Gokce et al ^{A10} (2012)	Population of adults
Heo and Kim ^{A17} (2011)	Population of adults
Jäger et al ^{A18} (1998)	Population of adults
Jing et al ^{A19} (2012)	Population of adults
Kaur et al ^{A21} (2014)	Population of adults
Lam et al ^{A23} (2004)	Population of adults
Portier et al ^{A25} (1998)	Population of adults
Song et al ^{A26} (2015)	Population of adults
Virkkula et al ^{A28} (2006)	Population of adults
Watanabe et al ^{A29} (2002)	Population of adults
Yucel et al ^{A31} (2005)	Population of adults
Chen et al ^{A7} (2008)	Not dealing with OSAS

OSAS, obstructive sleep apnoea syndrome.

Assessment of heterogeneity

Assessment of heterogeneity was performed using Review Manager (RevMan) v. 5.2 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark, 2013).¹⁶

It was thus calculated through χ^2 test whether the observed differences across the results of the included studies were compatible with chance alone.

Heterogeneity was considered to be significant if the p -value was <0.1 .

The χ^2 statistics describing the percentage of total variation across studies due to heterogeneity were used to quantify heterogeneity, as reported in the following scheme:

- 0–40%: might not be important
- 30–60%: may represent moderate heterogeneity
- 50–90%: may represent substantial heterogeneity
- 75–100%: considerable heterogeneity.¹⁷

Data synthesis

The evaluation of the selected publications led to three studies with no considerable heterogeneity in terms of study design, study population demographics, diagnostic procedures, study period and methods of assessment of the total upper airway volume. Thus, a quantitative analysis of all data was performed.

In the meta-analysis performed, the mean differences were combined for continuous data using fixed-effects models. In case of heterogeneity among the studies, a random-effects model was used.¹⁸

In all three studies, single results were presented as mean values and standard deviation.

Results

Results of the search

The initial electronic search resulted in 479 titles from the MEDLINE—PubMed database, 526 titles from the CENTRAL database, 24 titles from the Scopus database and 340 titles from the Web of Science database. After the independent elimination of duplicate articles, a total of 1170 titles were considered for possible inclusion. A total of 1138 articles were removed based on their title and abstract; therefore, 32 full-text articles were selected. Among these studies, one study was included in the review (Figure 1).¹⁹ Two additional publications were recovered from the bibliography search of the selected article.^{1,14}

In conclusion, three CCTs were identified as potentially eligible for inclusion in this review.^{1,14,19}

Included studies

One trial was carried out in Italy and two trials were conducted in the USA.

All trials had a parallel group study design.^{1,14,19}

Two trials were conducted in a specialist public hospital^{1,14} and one trial at university dental clinics.¹⁹

Two trials received support from the same industry.^{1,14}

The three CCTs meeting the inclusion criteria were included for qualitative and quantitative analyses in this systematic review.

All articles investigated the possible use of MRI in making a diagnosis of OSAS in children through the evaluation of the total upper airway volume.^{1,14,19} One study investigated data concerning all the secondary outcomes evaluated in this systematic review,¹⁹ whereas the other two studies reported only a part of the secondary outcomes; in one case,¹ the data were presented graphically, preventing the authors of this article from retrieving them accurately.

Characteristics of the three included studies are summarized in Table 2.

Characteristics of participants

All studies included only paediatric patients (age range: 1.8–15 years). Patients affected by OSAS, whose diagnosis was previously confirmed by PSG, formed the test group, whereas healthy subjects matched according to age, sex, ethnicity, weight and height formed the control group. Control subjects were selected among a sample of patients evaluated with MRI for clinical problems not related to OSAS.

Among the control group, children were excluded if they matched at least one of the following exclusion criteria:

- (a) previously undergone operations on the upper respiratory tract
- (b) overweight or obese
- (c) syndromes notoriously associated with changes in craniofacial bones
- (d) evidence of brain tumour or a seizure disorder requiring therapy
- (e) chronic respiratory disease such as asthma or bronchopulmonary dysplasia.

Characteristics of the interventions

Cappabianca *et al*¹⁹ studied all children in the supine position and under conditions of wakefulness between 9 am and 2 pm in the bore of the same 1.5-T magnet (Symphony, Siemens, Erlangen, Germany) with the use of a head coil with the soft-tissue Frankfort plane perpendicular to the table. Axial scans were performed from the orbital floor up to the larynx and sagittal scans from the midline to the ears bilaterally. To highlight the air spaces, longitudinal relaxation time T_1 weighted axial and sagittal spin-echo images [repetition time (TR): 500 ms; echo time (TE): 11 ms] were obtained in two separate series. To highlight the pharyngeal soft tissues, a third sequence consisting of transverse relaxation time T_2 weighted sagittal turbo spin-echo images (TR: 3500 ms and effective TE: 85 ms; excitation train length: 8) was run in the axial plane.

Data and image matrices were 256×256 , the slice thickness was 4 mm with a 1-mm skip and the field of view (FOV) was 23 cm in all three sequences. A bandwidth of 10.7 kHz and two averages (number of excitations: 2) were used in all sequences.

Figure 1 Flowchart of the screening process. CCT, controlled clinical trial; CENTRAL, Cochrane Central Register of Controlled Trials; OSAS, obstructive sleep apnoea syndrome; RCT, randomized controlled trial.

Table 2 Table summarizing characteristics of the three included studies

Title	Author (year)	Type of study	Sample size
"Magnetic resonance imaging in the evaluation of anatomical risk factors for paediatric obstructive sleep apnoea–hypopnoea: a pilot study"	Cappabianca et al ¹⁹ (2012)	CCT	80
"Magnetic resonance imaging of the upper airway structure of children with obstructive sleep apnea syndrome"	Arens et al ¹ (2001)	CCT	36
"Upper airway size analysis by magnetic resonance imaging of children with obstructive sleep apnea syndrome"	Arens et al ¹⁴ (2003)	CCT	40

CCT, controlled clinical trial.

Arens et al¹ performed MRI with a 1.5-T Vision system (Siemens, Iselin, NJ). Images were acquired with a commercially available head coil. The patient head was positioned supine in the soft-tissue Frankfort plane. Axial and sagittal sequential T_1 weighted (TR, 650 ms; TE, 14 ms) and T_2 weighted (TR, 6000 ms; TE, 90 ms) images with 3-mm slice thickness and number of excitations: 1 were obtained from the orbital cavity to the larynx and from the midline bilaterally, respectively.

Arens et al¹⁴ performed MRI with a 1.5-T Vision system (Siemens), acquiring images with an anteroposterior volume head coil. The patient head was positioned supine in the soft-tissue Frankfort plane perpendicular to the table. Sequential T_2 weighted spin-echo axial sections were obtained, spanning from the orbital cavity to the larynx. The mean acquisition time was 2 min, spin-echo TR = 650 ms, TE = 14 ms, 192×256 matrix, slice thickness 3 mm with distance factor 0, one acquisition, FOV = 20–24 cm and rectangular FOV 6/8.

Characteristics of outcome measures

All trials reported the upper airway total volume measured in subjects in the test and control groups.

Risk of bias in included studies

The risk of bias is summarized in Figure 2.

Summarizing the risk of bias for each study, every trial was assessed as at unclear risk of bias, since all key domains were at low or unclear risk of bias.

Sequence generation and allocation concealment

All the trials gave no information about the method of sequence generation and allocation concealment and were assessed as being at unclear risk of bias for this domain.^{1,14,19}

Blinding of participants and personnel

This type of study did not address this outcome; so, the authors considered the included articles at unclear risk of performance bias.^{1,14,19}

Blinding of outcome assessment

In one trial, outcome assessors were blinded; so, it was considered at low risk of bias for this key domain.¹⁹ For the remaining trials, the blinding of outcome assessors is not clearly reported and for this reason, they were considered as at unclear risk of detection bias.^{1,14}

Incomplete outcome data

There were no missing outcome data in all studies.^{1,14,19}

Selective reporting

Information about selective outcome reporting was adequate in all the trials.^{1,14,19}

Other potential sources of bias

In all studies, there were other no apparent sources of bias; so, this domain was assessed as low risk.^{1,14,19}

Effects of interventions

Cappabianca et al¹⁹ showed a highly significant difference ($p < 0.001$) between the values of the combined upper airway volume of children with OSAS ($1.4 \pm 0.7 \text{ cm}^3$) and controls ($1.6 \pm 1.1 \text{ cm}^3$); their soft-tissue analysis also revealed similar results in terms of mid-sagittal CSA and volume of the tongue in both groups. But, a significantly larger ($p < 0.01$) soft-palate volume and mid-sagittal palate CSA in the OSAS group (3.9 ± 1.3 and $2.1 \pm 0.8 \text{ cm}^2$, respectively) compared with controls (3.1 ± 1.4 and $1.8 \pm 1.1 \text{ cm}^2$, respectively) was noted. The authors demonstrated alike that both the adenoid and tonsils were significantly larger in children with OSAS: the mean adenoid volume in children with OSAS was $9.1 \pm 1.8 \text{ cm}^3$ in comparison with $6.3 \pm 2.1 \text{ cm}^3$ in controls ($p < 0.01$) and the mean tonsillar volume in children with OSAS was 9.2 ± 1.5 vs $6.5 \pm 1.7 \text{ cm}^3$ in controls ($p < 0.01$). The CSA in the regions adjacent to the adenoids was $4.1 \pm 1.3 \text{ cm}^2$ in patients affected vs $2.7 \pm 1.1 \text{ cm}^2$ in controls ($p < 0.01$) and the CSA in the regions adjacent to the tonsils was $6.1 \pm 2.1 \text{ cm}^2$ in patients affected vs $4.3 \pm 1.6 \text{ cm}^2$ in controls ($p < 0.01$). Regarding facial skeletal structure, the author analysis showed that mid-sagittal CSA of the hard palate did not significantly differ between the two groups, whereas mandibular volume of the OSAS group was lower than that of the control group (22.2 ± 2.2 vs $25.4 \pm 2.4 \text{ cm}^3$; $p < 0.05$).

Arens et al¹ showed that the upper airway total volume of children affected by OSAS was significantly smaller than that of the control group ($1.5 \pm 0.8 \text{ cm}^3$ vs $2.5 \pm 1.2 \text{ cm}^3$; $p < 0.005$). The authors investigated all clinical parameters considered as secondary outcomes in this systematic review, but data were presented graphically, preventing the

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Arens et al (2001) ¹	?	?	?	?	+	+	+
Arens et al (2003) ¹⁴	?	?	?	?	+	+	+
Cappabianca et al (2012) ¹⁹	?	?	?	+	+	+	+

Figure 2 Risk of bias summary: review of author judgments on each risk of bias item for each included study.

authors of this review from retrieving them accurately. Significant differences between the two groups were demonstrated only in the soft palate ($p < 0.05$), tonsils ($p < 0.0005$) and adenoid volume ($p < 0.005$): 3.5 ± 1.1 , 9.1 ± 2.9 and $9.9 \pm 3.9 \text{ cm}^3$ in the OSAS group and 2.7 ± 1.2 , 5.8 ± 2.2 and $6.4 \pm 2.3 \text{ cm}^3$ in the control group, respectively.

Arens et al¹⁴ evaluated only the primary outcome of this systematic review, revealing that the upper airway total volume was smaller in the OSAS group than in the control group (1.1 ± 0.5 vs $1.8 \pm 0.8 \text{ mm}^3$, $p < 0.005$).

The meta-analysis of the three included trials (all at unclear risk of bias) found evidence to determine that MRI is an effective method for evaluating differences in the upper airway total volume between paediatric patients affected by OSAS and those not affected by OSAS (mean differences -0.56 cm^3 ; 95% confidence

intervals -1.05 to -0.07), opening a window to its possible use as a diagnostic test (Figure 3).

Discussion

The meta-analysis of the three selected CCTs suggests that MRI is effective in evaluating the total volume of the upper airway structures of paediatric patients affected by OSAS compared with patients who are healthy and that MRI could be a valid alternative diagnostic choice.

This finding has a relevant implication in clinical practice. In fact, considering that especially in severe OSAS, the clinicians are accustomed to using an additional radiological examination (telerradiography in lateral projection or CT) to better evaluate the signs of the syndrome,^{20,21} it confirms that an X-ray-free examination (which is MRI) can effectively replace traditional radiography or CT. Moreover, clinicians should consider that since adenotonsillar hypertrophy constitutes the most related element to sleep apnoea syndrome in children and that other soft-tissue and skeletal tissue structures could influence the symptoms and their severity,¹⁹ the use of an auxiliary examination would be able to accurately define such tissue dimensions.

In addition, MRI allows a better diagnostic evaluation; it can show anatomical structures in each plane of the space with the highest contrast resolution. Although this imaging technique enables the identification of cranio-metric landmarks with high resolution and allows linear, angular, volumetric and CSA measurements, some undeniable limitations related mainly to the long period of time required for execution, which increases the production of artefacts by movement, have to be considered.

On the other hand, the use of sedatives for reducing artefacts caused by the movement of the body during MRI execution can result in a reduction of muscle tone and cause a diagnostic error.²²

Considering the unclear risk of bias of the included studies and the limited number of patients hired, the evidence is only moderately sufficient to establish that MRI is effective in the evaluation of the structures of the upper airway in children with OSAS. For these reasons, further studies should be carried out to confirm the application of MRI for the evaluation of the outcomes assessed.

Figure 3 Forest plot of comparison: upper airway total volume in obstructive sleep apnoea syndrome (OSAS) subjects and healthy subjects. CI, confidence intervals; SD, standard deviation.

Conclusions

The results of the present meta-analysis suggest the conclusion that MRI has a potential in the evaluation of the three airway compartments that could contribute to obstruction (lumen, soft and skeletal tissue), leading to OSAS.

References

- Arens R, McDonough JM, Costantino AT, Mahboubi S, Tayag-Kier CE, Maislin G, et al. Magnetic resonance imaging of the upper airway structure of children with obstructive sleep apnea syndrome. *Am J Respir Crit Care Med* 2001; **164**: 698–703. doi: <http://dx.doi.org/10.1164/ajrcrm.164.4.2101127>
- Arens R, Sin S, Nandalike K, Rieder J, Khan UI, Freeman K, et al. Upper airway structure and body fat composition in obese children with obstructive sleep apnea syndrome. *Am J Respir Crit Care Med* 2011; **183**: 782–7. doi: <http://dx.doi.org/10.1164/rccm.201008-1249OC>
- Redline S, Tishler PV, Schluchter M, Aylor J, Clark K, Graham G. Risk factors for sleep-disordered breathing in children: associations with obesity, race, and respiratory problems. *Am J Respir Crit Care Med* 1999; **159**: 1527–32. doi: <http://dx.doi.org/10.1164/ajrcrm.159.5.9809079>
- Ali NJ, Pitson DJ, Stradling JR. Snoring, sleep disturbance, and behavior in 4–5 year olds. *Arch Dis Child* 1993; **68**: 360–6. doi: <http://dx.doi.org/10.1136/adc.68.3.360>
- Brouillette RT, Fernbach SK, Hunt CE. Obstructive sleep apnea in infants and children. *J Pediatr* 1982; **100**: 31–40. doi: [http://dx.doi.org/10.1016/S0022-3476\(82\)80231-X](http://dx.doi.org/10.1016/S0022-3476(82)80231-X)
- Perkin RM, Anas NG. Pulmonary hypertension in pediatric patients. *J Pediatr* 1984; **105**: 511–22. doi: [http://dx.doi.org/10.1016/S0022-3476\(84\)80413-8](http://dx.doi.org/10.1016/S0022-3476(84)80413-8)
- Mortimore IL, Marshall I, Wraith PK, Sellar RJ, Douglas NJ. Neck and total body fat deposition in non obese and obese patients with sleep apnea compared with that in control subjects. *Am J Respir Crit Care Med* 1998; **157**: 280–3. doi: <http://dx.doi.org/10.1164/ajrcrm.157.1.9703018>
- Ayappa I, Rapoport DM. The upper airway in sleep: physiology of the pharynx. *Sleep Med Rev* 2003; **7**: 9–33. doi: <http://dx.doi.org/10.1053/smr.2002.0238>
- Katz ES, D'Ambrosio CM. Pathophysiology of pediatric obstructive sleep apnea. *Proc Am Thorac Soc* 2008; **5**: 253–62. doi: <http://dx.doi.org/10.1513/pats.200707-111MG>
- Cistulli P. Craniofacial abnormalities in obstructive sleep apnoea. *Respirology* 1996; **3**: 167–74. doi: <http://dx.doi.org/10.1111/j.1440-1843.1996.tb00028.x>
- Caballero P, Terreros-Caro JG, Prados C, Garcia Rio F, Alvarez-Sala JL, Alvarez-Sala R. Image techniques in the evaluation of the upper airway in the obstructive sleep apnea syndrome. *Sleep Breath* 1997; **2**: 76–80. doi: <http://dx.doi.org/10.1007/BF03038870>
- Hoekema A, Hovinga B, Stegenga B, De Bont LG. Craniofacial morphology and obstructive sleep apnoea: a cephalometric analysis. *J Oral Rehabil* 2003; **30**: 690–6. doi: <http://dx.doi.org/10.1046/j.1365-2842.2003.01130.x>
- Schwab RJ, Gupta KB, Geffter WB, Hoffman EA, Pack AI. Upper airway soft tissue anatomy in normals and patients with sleep disordered breathing: significance of the lateral pharyngeal walls. *Am J Respir Crit Care Med* 1995; **152**: 1673–89. doi: <http://dx.doi.org/10.1164/ajrcrm.152.5.7582313>
- Arens R, McDonough JM, Corbin AM, Hernandez EM, Maislin G, Schwab RJ, et al. Linear dimensions of the upper airway structure during development: assessment by magnetic resonance imaging. *Am J Respir Crit Care Med* 2003; **167**: 65–70. doi: <http://dx.doi.org/10.1164/ajrcrm.165.1.2107140>
- Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol* 2009; **62**: 1–34. doi: <http://dx.doi.org/10.1016/j.jclinepi.2009.06.006>
- The Nordic Cochrane Centre, The Cochrane Collaboration. *Review manager (RevMan) v. 5.2*. Copenhagen, Denmark: The Nordic Cochrane Centre, The Cochrane Collaboration; 2013.
- Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003; **6**: 557–60. doi: <http://dx.doi.org/10.1136/bmj.327.7414.557>
- Higgins JP, Green S. *Cochrane handbook for systematic reviews of interventions (v. 5.1.0)*. The Cochrane Collaboration; 2011. [Updated March 2011]. Available from: www.cochrane-handbook.org
- Cappabianca S, Iaselli F, Negro A, Basile A, Reginelli A, Grassi R, et al. Magnetic resonance imaging in the evaluation of anatomical risk factors for pediatric obstructive sleep apnoea—hypopnoea: a pilot study. *Int J Pediatr Otorhinolaryngol* 2013; **77**: 69–75.
- Enciso R, Shigeta Y, Nguyen M, Clark GT. Comparison of cone-beam computed tomography incidental findings between patients with moderate/severe obstructive sleep apnea and mild obstructive sleep apnea/healthy patients. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2012; **114**: 373–81. doi: <http://dx.doi.org/10.1016/j.oooo.2012.03.014>
- Vieira BB, Itikawa CE, de Almeida LA, Sander HS, Fernandes RM, Anselmo-Lima WT, et al. Cephalometric evaluation of facial pattern and hyoid bone position in children with obstructive sleep apnea syndrome. *Int J Pediatr Otorhinolaryngol* 2011; **75**: 383–6. doi: <http://dx.doi.org/10.1016/j.ijporl.2010.12.010>
- Moon J, Han DH, Kim J, Rhee C, Sung M, Park J, et al. Sleep magnetic resonance imaging as a new diagnostic method in obstructive sleep apnea syndrome. *Laryngoscope* 2010; **120**: 2546–54. doi: <http://dx.doi.org/10.1002/lary.21112>

In addition to PSG, considerably less invasive MRI might be proposed to better investigate the roles of adenoids, tonsils and soft-tissue hypertrophy in causing OSAS in children.

Thus, clinicians should be more careful in designing larger, at least single-blinded RCTs in the future, which could better evaluate the efficacy of MRI in adjunction to PSG among both children and adults affected by OSAS.

Appendix A

List of excluded full text articles and principal reason for exclusion

- Abdel-Aziz M, Azab NA, Rashed M, Talaat A. Otolaryngologic manifestations of diffuse idiopathic skeletal hyperostosis. *Eur Arch Otorhinolaryngol* 2014; **271**: 1785–90. *Exclusion criteria*: the study population is not composed by children.
- Anantanarayanan P, Manikandhan R. Cephalometric evaluation of airway changes following mandibular distraction in patients with nocturnal desaturations during sleep secondary to TMJ ankylosis. *J Maxillofac Oral Surg* 2013; **12**: 17–20. *Exclusion criteria*: the article is not dealing with MRI.
- Caprioglio A, Meneghel M, Fastuca R, Zecca PA, Nucera R, Nosetti L. Rapid maxillary expansion in growing patients:

- correspondence between 3-dimensional airway changes and polysomnography. *Int J Pediatr Otorhinolaryngol* 2014; 78: 23–7. *Exclusion criteria:* the article is not dealing with MRI.
- A4. Carotenuto M, Esposito M, Pascotto A. Facial patterns and primary nocturnal enuresis in children. *Sleep Breath* 2011; 15: 221–7. *Exclusion criteria:* the article is not dealing with MRI.
- A5. Celenk M, Farrell ML, Eren H, Kumar K, Singh GD, Lozanoff S. Upper airway detection and visualization from cone beam image slices. *J Xray Sci Technol* 2010; 18: 121–35. *Exclusion criteria:* the article is not dealing with MRI.
- A6. Celikoglu M, Buyuk SK, Sekerci AE, Ucar FI, Cantekin K. Three-dimensional evaluation of the pharyngeal airway volumes in patients affected by unilateral cleft lip and palate. *Am J Orthod Dentofacial Orthop* 2014; 145: 780–6. *Exclusion criteria:* the article is not dealing with MRI.
- A7. Chen YL, Tan CT, Huang HM. Long-term efficacy of micro-debrider-assisted inferior turbinoplasty with lateralization for hypertrophic inferior turbinates in patients with perennial allergic rhinitis. *Laryngoscope* 2008; 118: 1270–4. *Exclusion criteria:* the article is not dealing with OSAS.
- A8. Donnelly LF, Strife JL, Myer CM. Is sedation safe during dynamic sleep fluoroscopy of children with obstructive sleep apnea? *Am J Roentgenol* 2001; 177: 1031–4. *Exclusion criteria:* the article is not dealing with MRI.
- A9. Gasparini G, Di Rocco C, Saponaro G, Marianetti TM, Foresta E, Rinaldo FM, et al. Evaluation of obstructive sleep apnea in pediatric patients with facio-craniofacial: a brief communication. *Childs Nerv Syst* 2012; 28: 1135–40. *Exclusion criteria:* the article is not dealing with MRI.
- A10. Gokce SM, Gorgulu S, Gokce HS, Bengi O, Sabuncuoglu F, Ozgen F, et al. Changes in posterior airway space, pulmonary function and sleep quality, following bimaxillary orthognathic surgery. *Int J Oral Maxillofac Surg* 2012; 41: 820–9. *Exclusion criteria:* the study population is not composed by children.
- A11. Goldstein NA, Pugazhendhi V, Rao SM, Weedon J, Campbell TF, Goldman AC, et al. Clinical assessment of pediatric obstructive sleep apnea. *Pediatrics* 2004; 114: 33–43. *Exclusion criteria:* the article is not dealing with MRI.
- A12. Golpe R, Jiménez A, Carpio R. Home sleep studies in the assessment of sleep apnea/hypopnea syndrome. *Chest* 2002; 122: 1156–61. *Exclusion criteria:* the article is not dealing with MRI.
- A13. Guilleminault C, Huang YS, Quo S, Monteyrol PJ, Lin CH. Teenage sleep-disordered breathing: recurrence of syndrome. *Sleep Med* 2013; 14: 37–44. *Exclusion criteria:* the article is not dealing with MRI.
- A14. Guilleminault C, Monteyrol PJ, Huynh NT, Pirelli P, Quo S, Li K. Adeno-tonsillectomy and rapid maxillary distraction in prepubertal children, a pilot study. *Sleep Breath* 2011; 15: 173–7. *Exclusion criteria:* the article is not dealing with MRI.
- A15. Hänggi MP, Teuscher UM, Roos M, Peltomäki TA. Long-term changes in pharyngeal airway dimensions following activator-headgear and fixed appliance treatment. *Eur J Orthod* 2008; 30: 598–605. *Exclusion criteria:* the article is not dealing with MRI.
- A16. Heller JB, Gabbay JS, Kwan D, O'Hara CM, Garri JJ, Urrego A, et al. Genioplasty distraction osteogenesis and hyoid advancement for correction of upper airway obstruction in patients with treacher collins and nager syndromes. *Plast Reconstr Surg* 2006; 117: 2389–98. *Exclusion criteria:* the article is not dealing with MRI.
- A17. Heo JY, Kim JS. Correlation between severity of sleep apnea and upper airway morphology: cephalometry and MD-CT study during awake and sleep states. *Acta Otolaryngol* 2011; 131: 84–90. *Exclusion criteria:* the study population is not composed by children.
- A18. Jäger L, Günther E, Jörg G, Reiser M. Fluoroscopic MR of the pharynx in patients with obstructive sleep apnea. *Am J Neuroradiol* 1998; 19: 1205–14. *Exclusion criteria:* the study population is not composed by children.
- A19. Jing J, Zhang J, Loy AC, Wong BJ, Chen Z. High-speed upper-airway imaging using full-range optical coherence tomography. *J Biomed Opt* 2012; 17: 110507. *Exclusion criteria:* the study population is not composed by children.
- A20. Juliano ML, Machado MA, de Carvalho LB, Zancanella E, Santos GM, do Prado LB, et al. Polysomnographic findings are associated with cephalometric measurements in mouth-breathing children. *J Clin Sleep Med* 2009; 5: 554–61. *Exclusion criteria:* the article is not dealing with MRI.
- A21. Kaur S, Rai S, Kaur M. Comparison of reliability of lateral cephalogram and computed tomography for assessment of airway space. *Niger J Clin Pract* 2014; 17: 629–36. *Exclusion criteria:* the study population is not composed by children.
- A22. Kinzinger G, Czapska K, Ludwig B, Glasl B, Gross U, Lisson J. Effects of fixed appliances in correcting Angle Class II on the depth of the posterior airway space: FMA vs Herbst appliance—a retrospective cephalometric study. *J Orofac Orthop* 2011; 72: 301–20. *Exclusion criteria:* the article is not dealing with MRI.
- A23. Lam B, Ooi CG, Peh WC, Lauder I, Tsang KW, Lam WK, et al. Computed tomographic evaluation of the role of craniofacial and upper airway morphology in obstructive sleep apnea in Chinese. *Respir Med* 2004; 98: 301–7. *Exclusion criteria:* the study population is not composed by children.
- A24. Pirelli P, Saponara M, Attanasio G. Obstructive Sleep Apnoea Syndrome (OSAS) and rhino-tubular dysfunction in children: therapeutic effects of RME therapy. *Prog Orthod* 2005; 6: 48–61. *Exclusion criteria:* the article is not dealing with MRI.
- A25. Portier F, Portmann A, Czernichow P, Delagrange E. Diagnosis of sleep apnea syndrome (SAS) by home polysomnography. Comparison with laboratory polysomnography. *Am J Respir Crit Care Med* 1998; 157: A649. *Exclusion criteria:* the study population is not composed by children.
- A26. Song M, Bao J, Wang X, Li S. Diagnosis of glossopharyngeal obstruction using nasopharyngeal tube versus CT scan in obstructive sleep apnea-hypopnea syndrome. *Eur Arch Otorhinolaryngol* 2015; 272: 1175–80. *Exclusion criteria:* the study population is not composed by children.
- A27. Villa MP, Bernkopf E, Pagani J, Broia V, Montesano M, Ronchetti R. Randomized controlled study of an oral jaw-positioning appliance for the treatment of obstructive sleep apnea in children with malocclusion. *Am J Respir Crit Care Med* 2002; 165: 123–7. *Exclusion criteria:* the article is not dealing with MRI.
- A28. Virkkula P, Bachour A, Hytonen M, Salmi T, Malmberg H, Hurmerinta K, et al. Snoring is not relieved by nasal surgery despite improvement in nasal resistance. *Chest* 2006; 129: 81–7. *Exclusion criteria:* the study population is not composed by children.
- A29. Watanabe T, Isono S, Tanaka A, Tanzawa H, Nishino T. Contribution of body habitus and craniofacial characteristics to segmental closing pressures of the passive pharynx in patients with sleep-disordered breathing. *Am J Respir Crit Care Med* 2002; 165: 260–5. *Exclusion criteria:* the study population is not composed by children.
- A30. Wolf L, Yedidya T, Ganor R, Chertok M, Nachmani A, Finkelstein Y. Automatic cephalometric evaluation of patients suffering from sleep-disordered breathing. *Med Image Comput Comput Assist Interv* 2010; 13: 642–9. *Exclusion criteria:* the article is not dealing with MRI.
- A31. Yucel A, Unlu M, Haktanir A, Acar M, Fidan F. Evaluation of the upper airway cross-sectional area changes in different degrees of severity of obstructive sleep apnea syndrome: cephalometric and dynamic CT study. *Am J Neuroradiol* 2005; 26: 2624–9. *Exclusion criteria:* the study population is not composed by children.