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Review Article

Assessment of obstruction level and selection of patients for obstructive sleep apnoea surgery: an evidence-based approach

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Abstract

Introduction: Obstructive sleep apnoea has long been recognised as a clinical syndrome; however, high quality evidence on the effects of surgery for this condition is still missing. Despite this, a consensus seems to be evolving, albeit based on limited evidence, that surgery should be offered as a second line treatment to suitable patients with obstructive sleep apnoea.

Aims: This article aims to assess the different methods of investigating upper airway obstruction in patients with obstructive sleep apnoea, in respect to these methods' relevance to surgical treatment, via a systematic review of the literature.

Methods: The Cochrane Controlled Trials Register, Medline and EMBASE were searched from 1966 onwards. The search was performed in August 2008. A total of 2001 citations were retrieved.

Results and conclusion: There is not yet a generally accepted way to assess surgical candidacy based on the level of obstruction. Better organised clinical studies with well defined endpoints are needed. In the meanwhile, it appears that sleep nasendoscopy, acoustic reflectometry and pressure catheters can all provide useful information, and their use may be decided upon based on the experience and resources available in individual departments.

Key words: Obstructive Sleep Apnea Syndrome; Cephalometry; Polysomnography; Fluoroscopy; Computerised Tomography; Magnetic Resonance Imaging; Pressure; Acoustics; Endoscopy; Lasers

Introduction

Although obstructive sleep apnoea (OSA) has long been recognised as a clinical syndrome, its management was for many years based on level three evidence. Wright and colleagues' 1997 systematic review constituted a timely 'wake-up call' drawing attention to the need for evidence on the effects of OSA and on the efficacy of its main treatment – continuous positive airway pressure (CPAP).[1] Since then, significant evidence has been collected on the clinical impact of OSA as well as the effectiveness of CPAP and mandibular advancement splints.[2,3]

However, high quality (i.e. level one or two) evidence on the effects of surgery for OSA is still missing. This has resulted in conflicting statements: some authors deny any role for surgery in OSA, while others consider surgery as an (almost) blanket treatment for any form of OSA.[4,5]

Nevertheless, a consensus has evolved, based on limited evidence, that surgery should be offered as a second line treatment to suitable patients with OSA. In this systematic review, we assess the different methods for investigating upper airway obstruction in patients with OSA, in respect to these methods' relevance to surgical treatment.

Pathophysiology of obstructive sleep apnoea and the role of the narrow airway

Current thinking on the pathophysiology of OSA focuses on the balance of pressures model. According to this model, the size of the upper airway depends on the balance between forces tending to collapse the airway and those tending to maintain airway patency.

There is a significant amount of evidence from imaging studies suggesting that there are specific anatomical differences in the upper airway of patients with OSA, compared with controls.[6] Using more sophisticated imaging techniques, including computed tomography (CT) scanning, acoustic reflection and magnetic resonance imaging (MRI), it has been shown that patients with apnoea have a smaller airway lumen than controls, predisposing to airway

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collapse. Patients with OSA tend to have an oropharyngeal airway with the long axis anteroposteriorly rather than laterally, as well as an increased length, both of which increase collapsibility and place the dilator muscles at a disadvantage.[6]

Intuitively, an anatomical problem suggests a surgical solution. Different methods have been suggested in order to assess the level of obstruction in individual patients, and to help tailor surgery accordingly.

Obstructive sleep apnoea surgery and identification of the anatomical level of obstruction

Any attempt to characterise the level of obstruction in a particular patient with OSA, in order to tailor surgery, is fraught with controversy. It is often difficult to be certain that the morphology we observe in the upper airway is causally linked with the patient's apnoeic events. The terminology used can also be potentially misleading. This controversy and potentially misleading information are reflected in Rama and colleagues' suggestion that the use of any additional studies to precisely characterise the dynamic obstruction of OSA patients, in order to justify a given surgical procedure, should be abandoned.[7]

However, we feel that, before abandoning surgery as useless, an attempt should be made to identify the anatomical abnormality using a suitable test method. Ideally, this method should be anatomically and physiologically sensible, with findings that correlate with objective indices of OSA (such as the apnoea–hypopnoea index (AHI)), and should be proven to improve the results of surgery. Good measurement characteristics include accuracy, low test–retest variability and low inter-rater variability. Moreover, the method should be practical and easy to perform, non-invasive, cheap and involve no radiation. The studies assessing the method need to have a control group, be randomised and blinded, assess variability, and measure characteristics, while using transparent and reproducible success criteria.

Such a test method could be: dynamic or static; one-, two- or three-dimensional; involve an awake patient or one in natural or artificial sleep; and could be based on imaging, sound analysis, reflectometry, pressure measurement or endoscopy.

Materials and methods – search strategy

The Cochrane Controlled Trials Register, Medline and EMBASE were searched from 1966 onwards. The search was performed in August 2008. Different combinations of expanded medical subject headings were used, as shown in Appendix 1. A total of 2001 citations were retrieved.

Flexible pharyngoscopy with Meuller manoeuvre

In 1985, Sher *et al.* were the first to introduce the use of flexible pharyngoscopy with Meuller manoeuvre to assist the selection of patients for uvulopalatopharyngoplasty.[8] Following inhalation via a closed mouth and nostrils, a collapse (retropalatal–hypopharyngeal) is observed endoscopically. Fujita introduced a three-grade system to describe the location of the collapse.[9]

To research this topic, we searched Medline from 1966 to August 2008. Seventy citations were identified, of which 54 referred to adult patients with OSA or sleep disordered breathing; exclusion of reviews and case reports reduced the number to 30.

In eight of these studies, the Meuller manoeuvre was used to select patients for OSA surgery.[8,10–16] No conclusions could be derived from these studies. Only seven studies assessed the correlation between the Mueller manoeuvre and surgical success. In four of these studies, the Mueller manoeuvre was found to be useful, while in three it did not predict success. None of these seven studies met the quality criteria for level two evidence. Other studies assessed the correlation between Mueller manoeuvre results and sleep nasendoscopy (no correlation was found), pressure measurements (no correlation), oxygen desaturation index in OSA patients (explained 31 per cent of variability), flash or awake MRI (good correlation), AHI (some correlation or good correlation), propofol-induced sleep pharyngolaryngoscopy (Mueller manoeuvre underestimated tongue base obstruction) and flextube reflectometry (mediocre correlation).[17–24]

Despite the above, we feel that the Mueller manoeuvre remains a useful technique. It is the cheapest, easiest and most convenient method of assessing the level of obstruction in OSA. Although static, it has been shown to correlate, at least in part, with objective OSA indices and other, more complex methods. Mueller manoeuvre results have a relatively low inter-rater variability, and the technique's reliability increases if effort is taken into account.[25,26] Even more importantly, following standardisation using videoendoscopy and measurements of surface and collapsibility, the correlation between Mueller manoeuvre results and OSA improves significantly.[27]

Cephalometry

The use of modern cephalometry to assess the level of obstruction in OSA was introduced by Riley *et al.* in 1983; current measurements are based on studies by Woodson *et al.*[28,29] X-rays of the maxilla, mandible and upper airway are taken with the patient standing upright with his or her head in the cephalostat in the horizontal Frankfurt plane, at end-expiration. Measurements include the degree of retrognathia and tongue base collapse and the length of the soft palate.

In their meta-analysis, Miles *et al.* located 95 studies referring to cephalometry; 12 of these studies correlated cephalometric measurements with OSA.[30] Of the measurements reported in these 12 studies, only the mandibular body length demonstrated a significant association with and diagnostic accuracy for OSA. However, of 10 treatment efficacy studies located by Miles *et al.*, none satisfied their qualitative criteria sufficiently to be included in the meta-analysis.

Our search criteria on this topic are included in Appendix 1. One hundred and thirty-four papers were identified, including 36 studies published after 1997 (i.e. when the last meta-analysis was performed). From these publications, six key studies were selected.[10,31–35]

In the study by Hochban *et al.*, cephalometry was used to select 38 patients to undergo maxillomandibular advancement.[31] In 37 of these 38 patients, the AHI fell to less than 10. However, it is difficult to reach any conclusions from this study, as there was no comparison group. Another study assessed 60 OSA patients undergoing uvulopalatopharyngoplasty, and found that no cephalometric variable could predict success, although the success criteria were not clearly defined.[10] In the study by Lee *et al.*, 35 OSA patients underwent multilevel surgery.[32] Again, cephalometry was used for patient selection, resulting in the absence of a control group. Similarly, in a study published in *Chest* in 1999, 50 patients selected by cephalometry underwent maxillomandibular advancement, resulting in a reduction of average AHI from 59 to 5.4 – an impressive result but, once again, without a control group.[33] Similar weaknesses were apparent in the studies by Riley *et al.* and Wagner *et al.*[34,35]

In another study, Millman *et al.* assessed 46 patients undergoing uvulopalatopharyngoplasty.[36] In 16 of the 46, surgery was successful, defined as an AHI of less than 20 or reduced by 50 per cent. Following multiple regression analysis (accounting for age, AHI and body mass index (BMI)), a mandibular plane to hyoid bone distance of less than 21 mm was found to correlate significantly with post-operative AHI ($r = 0.52$, $p = 0.04$), as did a pre-operative AHI of less than 38 and the absence of retrognathia.[36] In another study, a mandibular plane to hyoid bone distance of less than 27 mm was found to correlate with surgical success, as did the absence of retrognathia or a long airway.[37] In a further study, Yao *et al.* showed an improved minimal posterior airway space ($p = 0.04$), posterior uvular space ($p = 0.06$), mandibular plane to hyoid bone distance ($p = 0.06$) and central incisor to tongue base distance ($p = 0.02$) in 44 patients undergoing cephalometric studies after multilevel surgery, although, interestingly, none of these changes correlated with surgical success.[22]

Somnofluoroscopy

Somnofluoroscopy is a cineradiographic observation of the upper airway with simultaneous polysomnography, performed during sleep. Concerns regarding radiation exposure have restricted its use.

We identified 17 studies, four of which were considered the most important.[13,38–40]

Suratt *et al.* introduced the method in 1983, while Katsantonis and Walsh used it to select 25 patients for uvulopalatopharyngoplasty.[39,41,42] Pepin *et al.* combined it with CT and demonstrated the level of obstruction in 11 patients, despite the lack of rapid eye movement (REM) sleep in the patients involved.[43] Finally, Tsushima *et al.* introduced a digital variation of the somnofluoroscopy technique.[40]

Somnofluoroscopy is a dynamic method which can record actual sleep, and which can be used in conjunction with electroencephalogram (EEG) data.

However, somnofluoroscopy involves radiation, can record only a few apnoeic events, is only two-dimensional and needs highly specialised interpretation, thereby limiting its use.

Computed tomography

Our literature search on this topic revealed 134 studies in adults, narrowed to 40 after excluding case reports and reviews.

The first study was published by Haponik *et al.*[44] Static CT scanning in 20 OSA patients and 10 controls revealed significant differences in the cross-sectional area of the nasopharynx, oropharynx and hypopharynx. In another study, three-dimensional reconstruction of CT images showed lower airway volumes and larger tongue volumes in 25 OSA patients, despite a lack of controls.[45] In another study, cine CT in eight sleeping patients showed dynamic evidence of anatomical obstruction during polysomnography-recorded apnoeas, but, again, there were no controls.[46] However, a further study showed no consistent difference in the airway of 12 awake apnoea patients, compared with 17 controls.[47] Nevertheless, Gislason *et al.* demonstrated that, of 34 patients undergoing uvulopalatopharyngoplasty for OSA, responders had smaller airways on CT.[48] Similarly, in another study with an 83 per cent response rate to uvulopalatopharyngoplasty, success was predicted by the tongue volume and the airway ratio.[49]

Conversely, it has been shown that, in sleeping patients, apnoeic events correlated well with cephalometry (i.e. mandibular plane to hyoid bone distance) but not with awake airway CT.[43] However, another study found that CT measurements had an 87 per cent specificity and a 64 per cent sensitivity in distinguishing OSA patients.[50] Other authors have demonstrated that three-dimensional airway CT scanning identified dynamic but not static obstruction in OSA patients.[51] In a more recent study using three-dimensional CT, the retropalatal area diameter was highly predictive of OSA.[52]

Computed tomography has the advantages of providing good, objective measurement of the airway, allowing cross-sectional and three-dimensional evaluation, and of being non-invasive.

However, CT is relatively costly, involves radiation, is not appropriate for nocturnal studies, can produce movement artefacts and can measure only a few apnoea events.

Magnetic resonance imaging

Magnetic resonance imaging was first used for the investigation of OSA in 1989. Fatty deposits in the soft palate and parapharyngeal space were demonstrated in six OSA patients, compared with five healthy controls.[53]

Three key studies have evaluated the role of MRI in assessing OSA.[54–56]

Schoenberg *et al.* described a combined assessment of OSA syndrome with dynamic MRI and parallel EEG registration.[55] Donelly *et al.* used cine MRI to depict upper airway motion during sleep.[54] Schwab *et al.* used volumetric MRI to show that increased volume of the lateral pharyngeal walls and the tongue increased the risk of OSA.[56]

Magnetic resonance imaging provides excellent soft tissue resolution that can be combined with cephalometry for bony details; it also enables three-dimensional volumetric assessment and involves no radiation.

However, MRI is expensive, noisy (and hence can interfere with sleep), can interfere with EEG assessment and pacemakers, can produce artefacts, and is relatively contraindicated in patients who are claustrophobic or obese.

In conclusion, there are not yet enough studies to assess the usefulness of MRI in selecting patients for OSA surgery.

Pressure catheters

Our search strategy for this topic is shown in Appendix 1. We located 79 studies, from which eight relevant studies were identified.

In principle, a pressure measuring system includes a transducer, which converts mechanical pressure movement into an electrical signal. The transducer is usually connected to a fluid-filled catheter, via which the pressure waveform travels from the airway to the transducer. More modern pressure catheter systems involve a catheter-tip transducer that can replace a fluid-filled system.[57]

In the first of the eight identified studies (a study which introduced the use of pressure catheters for the assessment of OSA), the inspiratory pressure along the supraglottis, oropharynx and nasopharynx was measured using an oesophageal balloon catheter in nine patients.[58] In the second study, transducer catheters were used to measure pressure at various levels during sleep.[59] In the third study, polysomnography recording was linked to pressure measurements performed using four-tip silicone pressure catheters in 20 patients. Of these 20 patients, 14 had airway collapse confined to or initiated at the oropharyngeal region. Uvulopalatopharyngoplasty was performed in four of these 14 patients, two of whom had a favourable response.[60] In the fourth study, pressure probes failed to reveal any change in sleep architecture.[61] In the fifth study, 22 patients who had undergone uvulopalatopharyngoplasty unsuccessfully were investigated using pressure monitoring, and residual obstruction at the hypopharyngeal level was demonstrated.[62] In the sixth study, 30 OSA patients underwent simultaneous polysomnography and pressure monitoring; obstruction events were clearly identified in all.[63] In the seventh study, pharyngoesophageal manometry using four pressure transducers was shown to be equally accurate in identifying the degree of OSA, compared with polysomnography ($r = 0.9$).[64]

One of the most useful studies advocating pressure catheter evaluation was that by Tvinnereim *et al.*, which demonstrated the importance of accurately determining the anatomical level of pharyngeal obstruction (partial or complete) prior to surgical intervention.[65] In order to identify the anatomical level of obstruction, and hence the correct operative site, a system comprising micropressure transducers contained in a fine, flexible catheter was devised (Apnea-Graph; MRA Medical-Medical Ltd Pipcot, Orchard Rise, Longborough, Moreton-in-Marsh, Gloucestershire GL56 0RG, UK). This system provided pressure recordings from the upper aerodigestive tract together with polysomnography recordings, in order to identify the obstruction level. Moreover, this study presented a new surgical procedure, the plasma-mediated, radiofrequency-based, coblation-assisted upper airway procedure. This procedure (when preceded by accurate localisation of the level of obstruction using the Apnea-Graph) was shown to have very promising long-term results, in addition to being very well tolerated and cost-effective (as it could be performed as an out-patient procedure under local anaesthesia).[65]

Pressure catheters have the advantage that measurements are recorded during sleep and cause minimal disruption to the sleep architecture. Furthermore, they enable recording over a long period of time, and have a good correlation with polysomnography.

However, it is not clear if pressure catheters measure obstruction or simply pressure differences. The relevant anatomy is not depicted, and the movement or dislodgement of pressure probes can easily introduce artefacts. Finally, pressure catheters by definition can only assess the lower limit of the airway obstruction.

Acoustic reflectometry

The search strategy used for this literature review is given in Appendix 1. A total of 51 studies were located, of which 25 were selected.

The rationale of acoustic reflectometry is based upon the fact that changes in the cross-sectional area of the upper airway lead to changes in impedance, which in turn lead to a change in sound reflection. A computer software program is used to convert the amplitude and temporal changes between the transmitted and reflected waves into the corresponding change in the airway cross-sectional area.[66] Acoustic reflectometry is performed through a mouthpiece or nosepiece (measuring either one or both nostrils), or using a flexible tube sited in the oropharynx.[24,67–70]

Acoustic reflectometry has the advantage of being a relatively safe, quick and easy method for assessing the pharyngeal airway.[66] It can be used during sleep, its measurements have been validated with MRI and its use causes minimal disruption to the sleep pattern.

There are, however, certain limitations. Acoustic reflectometry is dependent on the position of the patient, of the mouthpiece and wave tube, and of the velum and tongue. Also, the cross-sectional area of the pharyngeal airway varies with breathing. All these factors require standardisation to achieve repeatability of acoustic reflectometry results.[66]

Another study demonstrated that acoustic reflectometry is relatively accurate in identifying cross-sectional area changes at the retropalatal level, but not as good at the retrolingual level.[71] Finally, acoustic reflectometry gives no clear account of the anatomy, and there are only a few reported studies in the literature, none of which report any correlation with surgical success.

Acoustic analysis

Our search strategy for acoustic analysis retrieved 57 articles, of which 22 were selected; six of these correlated snoring sound with OSA.[67,72–76]

Van Brunt *et al.* found acoustic analysis to be sufficiently sensitive to screen patients with suspected OA.[76]

Three studies correlated snoring frequencies with the level of obstruction.[77–79] More specifically, it was found that the fundamental frequency of snoring, when originating from the palate, is in the 60–120 Hz range, while much higher fundamental frequencies are present when snoring originates from the tongue base, epiglottis and/or larynx.[77] This is very important, as pre-operative identification of palatal flutter as the cause of snoring has been shown to lead to a superior outcome following palatal stiffening procedures.[77]

Acoustic analysis is cheap, non-invasive, involves no radiation, is easy to perform at home, does not interfere with sleep, can be assessed simultaneously with polysomnography, and can record multiple obstructive episodes. Based on the sound frequency spectrum, acoustic analysis can distinguish between simple snoring (giving a single peak at a lower frequency) and snoring coexistent with OSA (giving multiple frequency peaks of various amplitudes).[80]

By differentiating between these two groups, acoustic analysis constitutes a useful tool for screening for OSA amongst patients who snore.

On the other hand, acoustic analysis has poor sensitivity and specificity, there are no studies correlating it with an objective assessment of the obstruction site, and there is no visualisation of complex patterns of obstruction. Moreover, different instruments and devices have been used by different investigators, and this makes data from different laboratories difficult to compare.[80] In addition, acoustic analysis has been found to have poor diagnostic accuracy for multisegmental snoring.

In summary, acoustic analysis may be useful for screening prior to polysomnography and/or other site assessment procedures, but it is unlikely in itself to be sufficiently sensitive and specific to guide treatment.

Sleep nasendoscopy

Our literature search retrieved 101 papers, 21 of which were key studies in adults.

Sleep nasendoscopy was introduced in 1991 by Croft and Pringle at the Royal National Throat, Nose and Ear Hospital, and can be performed with the patient either sedated or asleep.[81] The investigation is based on sedation with 2.5–5 mg midazolam. Assessment of obstructive events is based on the grading system of Croft and Pringle.[82]

Since its introduction, various studies have assessed sleep nasendoscopy, with conflicting results. One early study criticised the method, based on the author's finding that snoring could not be produced in 18 per cent of snorers, and could be produced in 45 per cent of non-snorers.[83] However, the sedation method used in that study was not as indicated, as the anaesthetists aimed to provide general anaesthesia rather than ideal conditions for sleep nasendoscopy.

On the contrary, in a more recent study, Berry *et al.* demonstrated that the use of a computer-controlled infusion system using propofol as the anaesthetic agent caused 100 per cent of snorers to snore, while 100 per cent of non-snorers did not snore.[84] This result was obtained after matching the two groups for BMI, and was clearly statistically significant ($p < 0.001$).

In another study, polysomnography with continuous endoscopy during diazepam-induced sleep did not give any information on REM sleep apnoeas.[85] However, a study assessing uvulopalatopharyngoplasty results in snorers showed that the use of sleep nasendoscopy as a tool to plan treatment improved success rates from 61 to 95 per cent.[86] In a more recent study of 30 snorers with OSA, video sleep nasendoscopy was shown to be a valuable technique for the study of upper airway dynamics in OSA, and was also useful for CPAP titration.[87] Another study claimed that sleep nasendoscopy had a poor predictive value in selecting snoring patients for laser-assisted uvulopalatopharyngoplasty.[88] However, the same study showed that surgical success rates were 100 per cent in grade 1 (tongue base obstruction) patients, 94 per cent in grade 2A, 84 per cent in grade 2B and 50 per cent in grade 3. Despite this, with only two grade 3 patients, the study lacked sufficient power to clearly demonstrate a statistically significant difference.[89]

Sleep nasendoscopy involves no radiation, is dynamic, can assess multiple areas of obstruction, is easy to perform, and can be combined with video and other objective measurements as well as polysomnography.

However, sleep nasendoscopy does not assess normal sleep, and the sedative used (midazolam, diazepam or propofol) could affect the sleep stages. This problem is partially overcome by the use of a computer-controlled infusion system delivering propofol. This system tightly maintains blood and brain concentrations of the sedative agent at set levels, through a negative feedback loop. Hence, the correct depth of sedation is achieved to cause muscle relaxation and produce snoring but not respiratory depression.[84] Two additional drawbacks of sleep nasendoscopy are that its evaluation is subjective and operator-dependent, and only a few apnoeic episodes can be recorded.

An audit of over 2400 nasendoscopies performed at the Royal National Throat, Nose and Ear Hospital over a 10-year period showed that sleep nasendoscopy grading correlated well with AHI and mean oxygen desaturation, and found that sleep nasendoscopy was a useful adjunctive method of identifying the anatomical site of snoring, resulting in better targeted treatment.[90]

Conclusion

In patients with OSA, there is not yet a clear, well defined method to assess surgical candidacy based on the level of obstruction, although sleep nasendoscopy, acoustic reflectometry and the use of pressure catheters have all shown promising results. Acoustic reflectometry is an objective examination that has the advantage of being able to assess the pharyngeal airway during sleep.[66] Its measurements have been validated with MRI, and its use causes minimal disruption to the sleep pattern; however, it cannot provide information from direct visualisation, unlike sleep nasendoscopy. Conversely, pressure catheters have the advantage of recording measurements during sleep and over a long period of time, while causing minimal disruption to the sleep architecture. However, sleep nasendoscopy offers the advantages of direct visualisation of the upper airway dynamics, no radiation and assessment of multiple areas of obstruction. It is easy to perform and can be combined with video and other objective measurements as well as polysomnography. The major drawback of sleep nasendoscopy is a lack of objectivity; however, a clearly defined sedation protocol can significantly improve its accuracy.

Better organised clinical studies with well defined endpoints are needed. In the meanwhile, it appears that sleep nasendoscopy, acoustic reflectometry and pressure catheters can all provide useful information, and their use may be decided upon based on the experience and resources available in individual departments.

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Appendix 1. Search strategy terms

Overall search

The medical subject heading (MeSH) search terms were: ((surg* and palate) OR (surg* and uvula) OR (surg* and pharynx) OR (uvulopalatopharyngoplasty) OR (UPPP) OR (UVPP) OR (UPP) OR (palatoplasty) OR (pharyngoplasty) OR (palatopharyngoplasty) OR (PPP) OR (uvulopalatoplasty) OR (LAUP) OR (tracheostomy) OR (mini-tracheostomy) OR (surg* and maxillo-facial) OR (surg* and maxillofacial) OR (genioglossal advancement) OR (maxillo-mandibular advancement) OR (maxillo-mandibular osteotomy) or (maxillary advancement) or (mandibular osteotomy) OR (intrapalatine resection) OR (tongue volume reduction) OR (inferior sagittal osteotomy) OR (hyoid bone suspension) OR (hyoid suspension) OR (hyoid myotomy) OR (surg* and upper-airways) OR (surg* and nasal) OR (septoplasty) OR (polypectomy) OR (adenoidectomy) OR (tonsillectomy) OR (adeno tonsillectomy) OR (glossectomy) OR (lingualplasty) OR (radiofrequency)). These terms were combined in various ways with AND (Sleep) AND ((apnoea) OR (apnea) OR (sleep disordered breathing) OR (sleep related respiratory disorders)) AND Adult [age limit] to generate a wide search.

Mueller manoeuvre

The MeSH search terms used included: (Muller[All Fields] OR Mueller[All Fields]) AND ("sleep"[MeSH Terms] OR Sleep[Text Word]) AND ((apnea[Text Word] OR apnoea[Text Word] OR "apnea"[MeSH Terms]) OR (apnea[Text Word] OR apnoea[Text Word] OR "apnea"[MeSH Terms]) OR ("sleep apnea syndromes"[MeSH Terms] OR sleep disordered breathing[Text Word]) OR (("sleep"[MeSH Terms] OR sleep[Text Word]) AND related[All Fields] AND respiratory[All Fields] AND ("disease"[MeSH Terms] OR disorders [Text Word])).

Cephalometry

The MeSH search terms used included: (Sleep) AND ((apnoea) OR (apnea) OR (sleep disordered breathing)) OR (sleep related respiratory disorders) AND Adult [age limit] AND Cephalom*.

Acoustic reflectometry

The MeSH search terms used included: Acoust* AND reflec* AND (Sleep) AND ((apnoea) OR (apnea) OR (sleep disordered breathing) OR (sleep related respiratory disorders)).

Pressure catheters

The MeSH search terms used included: ("pressure"[MeSH Terms] OR pressure [Text Word]) AND (sensor[All Fields] OR ("catheterization"[MeSH Terms] OR catheter[Text Word]) OR ("methazole"[Substance Name] OR probe[Text Word])) AND ("sleep"[MeSH Terms] OR Sleep[Text Word]) AND ((apnea[Text Word] OR apnoea [Text Word] OR "apnea"[MeSH Terms]) OR (apnea[Text Word] OR apnoea [Text Word] OR "apnea"[MeSH Terms]) OR ("sleep apnea syndromes"[MeSH Terms] OR sleep disordered breathing [Text Word]) OR (("sleep"[MeSH Terms] OR sleep[Text Word]) AND related[All Fields] AND respiratory [All Fields] AND ("disease"[MeSH Terms] OR disorders[Text Word])) AND "adult" [MeSH Terms].

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