Sleep cine magnetic resonance imaging—A dynamic evaluation of the airway

Sally R. Shott, MD

From the Department of Otolaryngology—Head and Neck Surgery, University of Cincinnati, Cincinnati Children’s Medical Center, Cincinnati, Ohio.

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It has become more apparent in recent years that increasing numbers of children continue to have obstructive sleep apnea despite previous removal of the tonsils and adenoids. This occurs not only in children in “at-risk” populations, such as those with Down syndrome and obesity, but also in otherwise “normal” children. Sleep cine magnetic resonance imaging (MRI) provides a high-resolution examination of the airway during sleep without ionizing radiation exposure and allows for identification of site or sites of residual airway obstruction. This technique is particularly helpful since the diagnostic examination performed in awake adults for sleep apnea is not often possible in the pediatric population. The technique of sleep cine MRI and examples of its use are presented. Sample patient scenarios are used to illustrate how it can assist with treatment planning. Anesthesia use during the cine MRI is discussed.

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Although removal of the tonsils and adenoids (T&A) is the most common initial surgical intervention for obstructive sleep apnea (OSA) in children, studies have shown that residual airway obstruction after this surgery is not only common in some populations of children such as in children with Down syndrome (DS) and in obese children but also more frequent than previously believed in otherwise typical, or “normal,” children. Mitchell, in 2007, showed a 10 to 20% incidence of persistent sleep apnea in a group of 79 “typical” children, ie, without major medical problems, after T&A. Tauman et al, using a much more strict definition of “surgical cure,” showed complete normalization of all components evaluated in a sleep study in only 25% of their test population of “typical” children. This compares to the 5% total success rate seen in the article by Shott et al, where a similarly strict definition of “cure” was used in a group of children with DS. If “cure” is defined as more similar to the definitions used in the study by Mitchell, almost 50 to 70% of the children with DS in this study continued to have OSA after T&A.

It is therefore becoming more common to be presented with a child who has persistent OSA despite previous T&A where further interventions may be needed, both surgical and medical.

If there is persistent obstruction and OSA after T&A, the first step is to define the sites or sites of residual obstruction. In the surgical treatment of OSA in adults, many of the treatment protocols follow pathways determined by the patient’s degree of, or grade of, obstruction. The Mueller maneuver and the various grading systems used in adults, such as the Friedman Palate Position Grading system, the Fujita, and/or the Mallampati scoring methods, are not easily obtained in the pediatric population. Children simply are not always able to fully cooperate and the oral cavity examination is often challenging and rarely consistent. In addition, even if cooperation is possible, in their critical review of the techniques of airway evaluation, Stuck and Mauer point out that the sites of obstruction detected in awake patients by the Mueller maneuver and these grading systems do not always correlate with sites of obstruction during sleep. Because of the limitations implicit in exam-
ining the airways of young patients, other methods of assessment have been developed for evaluating and identifying the site or sites of obstruction that may persist after T&A in the pediatric population and/or in patients who are either more difficult to examine or are inconsistent in their examination.

At our institution, Cincinnati Children’s Hospital Medical Center, we routinely use the sleep cine magnetic resonance imaging (MRI) to evaluate these more complex patients with persistent OSA. Cine MRI provides a high-resolution examination of the dynamic airway without added risk of ionizing radiation exposure. Images of the airway can be simultaneously gathered in different projections without overlap of structures as is seen with fluoroscopic studies. It is particularly helpful in evaluating children with multiple sites of obstruction. It can identify both static and dynamic sites of obstruction and has been helpful in identifying the sites or sites of obstruction in over 90% of the patients we have studied.5 The MRI images are obtained with mild sedation administered by an anesthesiologist. The type of anesthetic agent used is important in trying to mimic natural sleep as closely as is possible.

Patients are imaged in a supine position with the neck in a neutral position from the level of the nasopharynx down to the level of the cervical trachea. Midline sagittal cine, axial cine, and sagittal and axial fast spin-echo inversion recovery T2-weighted images are done. Studies are performed on a 1.5 T MRI Unit (Signa Excite HD; GE Healthcare, Milwaukee, WI) with the patients in a supine position and in a head and neck vascular coil or a cervical spine coil. One hundred twenty-eight consecutive images are done over approximately 2 minutes during episodes of airway obstruction and/or oxygen desaturation, so each image represents roughly 1 second. The images, done within seconds of each other, can then be presented in a “cine” or movie format. It is important to avoid using positive pressure ventilation and artificial airways during the examinations.

Initially, cine MRI studies were done in adults10-13 and showed distinct differences in the amount of airway obstruction in awake versus sleeping examinations. Cine MRIs have been used to successfully diagnose vocal cord mobility, tracheomalacia, and vascular compression of the trachea in children.14 It has also been used in the evaluation of velopharyngeal insufficiency.15 Donnelly et al applied similar techniques to the upper airway in children, first studying children without sleep apnea who required MRIs for other reasons. These studies showed that in children without OSA there is minimal motion in the airway, less than 5 mm of movement, at level of the nasopharynx, the posterior oropharynx, and the hypopharynx.16 However, in children with polysomnographically confirmed OSA, on sleep cine MRI evaluation, there is greater than 5 mm of movement at these 3 levels of the airway.17 Motion in the airway can be further classified as static patent, dynamic patent, static collapsed, or dynamic collapsed.

Due to the increased brightness of lymphoid tissue compared to surrounding soft tissue and muscle on T2-weighted images, the cine MRI also clearly delineates adenoid regrowth or presence as well as lingual tonsillar hypertrophy as contributing factors to airway obstruction (Figure 1). Adenoid enlargement is reported if residual adenoid tissue is greater than 12 mm in thickness and if there is intermittent obstruction of the posterior nasopharynx seen on the sagittal cine MRIs.5 Lingual tonsil hypertrophy has been defined being thicker than 10 mm in diameter and abutting the posterior pharyngeal wall.18

The dynamic sagittal cine segments provide a good assessment for glossoptosis, with abnormal posterior motion of the tongue during sleep (Figure 2). Pharyngeal collapse is seen when the tongue, the posterior pharyngeal wall, and the velum oppose each other, causing nasopharyngeal and oropharyngeal obstruction. Cine MRI axial views of the hypopharynx allows one to characterize the pattern of obstruction in either an anterior to posterior direction or a more lateral wall movement and collapse. If there is both anterior–posterior and lateral wall collapse, a circumferential pattern of collapse is present (Figure 3).

Donnelly has published a well-organized “how I do it” article on how to do cine MRI sleep studies, including anatomic descriptions, magnetic resonance techniques, image interpretations, and commonly seen findings.19

Because it is a dynamic examination, this type of evaluation allows one to determine if the airway obstruction is due to adenoid regrowth, lingual tonsil hypertrophy, macroglossia, both relative and true macroglossia, glossoptosis, or hypopharyngeal collapse. There may be an isolated level of obstruction or there can be multiple sites of obstruction. By viewing the cine images more slowly, one can often assess primary and then secondary levels of obstruction.

The use of sleep cine MRIs has provided a better understanding of the various site or sites of potential obstruction that can occur (Figure 4).20 This radiologic study can assist in surgical planning. We have found that it is not uncommon for patients to have multiple sites of obstruction and these can be seen concomitantly on the same noninvasive examination. Table 1 shows the incidence of various sites of

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Figure 1 Due to increased brightness of lymphoid tissue compared to surrounding soft tissue and muscle on T2-weighted images, the cine MRI also clearly delineates adenoid regrowth (A) or recurrence as well as lingual tonsillar hypertrophy (L). Note the absence of retroglossal space in this patient.
obstruction in a group of 29 children with DS who continued to have persistent OSA after T&A.  

Practical applications and use of sleep cine MRIs

At Cincinnati Children’s Hospital, we have a Sleep Team Meeting once a month to review children with more complex OSA. Participants include members of the pulmonary department who are board certified in sleep science and who read the sleep studies, a nurse practitioner who works with the children and their families with continuous positive airway pressure (CPAP) therapy, members of the pediatric otolaryngology department, a dentist interested in the use of dental appliances for sleep apnea, as well as members of the radiology department. There is also input from oral/maxillofacial surgeons and psychologists who work with behavior modification to improve CPAP compliance. For each child, we review the various symptoms associated with their OSA, their previous medical and surgical history, their sleep studies, and also their sleep cine MRI. All of these factors come into play in the process of making recommendations for treatment.

For example, patient A had undergone a T&A several years ago but presented to the office with her mother complaining of chronic open mouth breathing, restless sleep, and falling asleep at school. Her examination confirmed chronic mouth breathing. Nasopharyngoscopy was not tolerated in the office and even lateral neck x-rays were difficult because of the patient having a developmental delay. As seen in the cine MRI sagittal view of Figure 5, this child had evidence of adenoid regrowth and hypertrophy. The cine sagittal views also showed evidence of glossoptosis and macroglossia. However, by slowing down the cine views of the MRI, it appeared that the nasal obstruction occurred prior to the base of tongue obstruction. Her sleep study showed mild residual OSA. Because of her chronic mouth breathing, poor sleep, and falling asleep at school, it was felt that the adenoid regrowth was the major source of obstruction. Revision adenoidectomy was suggested with the understanding that the base of tongue obstruction might also have to be addressed. Her postoperative sleep study was much improved and her symptoms improved such that she is no longer snoring and no longer falling asleep at school. Therefore, no other interventions were suggested.

By contrast, patient B, a young man with DS, had severe OSA with significant hypoxemia and hypercarbia on his sleep study, done after his T&A. Although his parents reported improvement in his symptoms, he was still falling asleep at school and on the bus home. Attempts using CPAP had failed. On the sagittal cine MRI views, his sleep cine MRI showed evidence of relative macroglossia, glossoptosis, and significant enlargement of his lingual tonsils (Figure 6). Axial cine views showed circumferential collapse at the level of the hypopharynx. Due to these findings, a surgical approach was recommended, starting with a lingual tonsillectomy. The plan was then to perform a postoperative sleep study 3 months after this surgery and consider further surgery on the base of tongue, addressing the macroglossia and glossoptosis, if needed. As his postoperative sleep study after the lingual tonsillectomy was significantly improved, the second surgery was not necessary.
Anesthesia

Although the ideal would be to do the sleep cine MRI under natural sleep, this is not practical. In addition to difficulties in achieving spontaneous sleep during the daytime hours, there is the problem with the very noisy environment of the gradient-echo sequences used to create the cine MRI images. Even those who fall asleep would be awakened by this noise.

Due to the at-risk population requiring this study, we feel it is important to have a staff anesthesiologist present for the study to provide safe and effective anesthesia. Unfortunately, anesthesia agents cause increased airway collapsibility and obstruction through a combination of both airway relaxant effects and respiratory depression. The pharyngeal muscle tone, which is decreased in natural sleep, is even more compromised in the face of anesthetic effects. The ideal anesthetic agent therefore should provide a state as similar as possible to physiological sleep with spontaneous breathing, without the need for artificial airway support via oral or nasal airway adjuncts.

Sedatives and anesthetic drugs commonly used for radiographic studies include propofol, pentobarbital, benzodiazepines, ketamine, and dexmedetomidine. Mahmoud et al in their commentary on the anesthetic challenges of doing sleep MRIs reviewed the pros and cons of these various drugs. Propofol and barbituates can worsen upper airway obstruction and cause respiratory depression and apnea. Benzodiazepines relax the pharyngeal muscles, causing obstruction. Ketamine has been shown to have no effect on pharyngeal musculature in adults and has been used successfully in a few reported cases when combined with dexmedetomidine.22

At our institution, the anesthesiologists use dexmedetomidine, an alpha-2 adrenergic agonist, as their drug of choice for the sleep MRIs.22 This drug works similarly to clonidine but with a higher sensitivity to the alpha-2 receptors. The sedative properties parallel natural non-rapid eye movement sleep with minimal respiratory depression.23 There is also a more reliable response to this drug compared to other anesthetic agents with fewer episodes of oxygen desaturation and airway obstruction compared to those

<table>
<thead>
<tr>
<th>Causes of persistent obstructive sleep apnea despite previous T&amp;A in children with Down syndrome as depicted on static and dynamic cine magnetic resonance imaging (MRI)</th>
<th>21</th>
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<tbody>
<tr>
<td>Glossoptosis</td>
<td>63%</td>
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<tr>
<td>Recurrent adenoids</td>
<td>63%</td>
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<tr>
<td>Macroglossia</td>
<td>74%</td>
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<tr>
<td>Enlarged lingual tonsils</td>
<td>30%</td>
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<tr>
<td>Hypopharyngeal collapse</td>
<td>22%</td>
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Twenty-seven patients, mean age 9.9 years.
anesthetized with propofol. This is particularly advantageous in the children with more severe OSA. A prospective study, evaluating the dose–response effects of dexmedetomidine on the upper airway collapse in children without sleep apnea, was done at our institution. This showed minimal changes to the upper airway with increased doses compared to the lower doses and no relationship with increased clinical signs of airway obstruction.

Endoscopic evaluation of the airway under general anesthesia is another common way to examine the airway. However, in addition to the increased risk and expense of this type of evaluation requiring a general anesthesia and done in the operating room setting, there is a concern that the use of general anesthetics, including propofol and sevoflurane, has greater effects on airway dynamics compared to physiological sleep with increased muscle relaxation. This potentially causes more misinterpretation of airway site obstruction. In contrast, the patients sedated with dexmedetomidine are sedated but still easily arousable. This is not commonly seen with other sedatives. This has led to our institution’s better success with completing successful sleep cine MRIs without the need of oral airways or nasal trumpets.

Conclusions

Sleep cine MRIs of the airway provide a consistent, noninvasive technique to evaluate for site, or sites, of obstruction in patients who have persistent OSA after initial treatment with T&A. Children are not exposed to ionizing radiation with this technique. Because of the ability to record and review the studies, interpretations are more consistent than office examinations, which also may not mimic obstruction during sleep. Each child will have a unique pattern of obstruction and treatment planning and surgical interventions can be tailored for that specific child’s needs. The use of dexmetomidine decreases the effects of muscle relaxation associated with use sedative anesthetic agents, providing safer and more consistent results.

References