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Impact of airway management strategies on magnetic resonance image quality

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Abstract

Background: Use of general anaesthesia or deep sedation during magnetic resonance imaging (MRI) studies leads to pharyngeal muscle relaxation, often resulting in snoring and subsequent vibrations with head micromotion. Given that MRI is very susceptible to motion, this causes artifacts and image quality degradation. The purpose of our study was to determine the effectiveness of different airway management techniques in overcoming micromotion-induced MRI artifacts.
Methods: After obtaining institutional review board approval, we conducted a retrospective study on the image quality of central nervous system MRI studies in nine patients who had serial MRIs under general anaesthesia. All data were obtained from electronic records. We evaluated the following airway techniques: use of no airway device (NAD); oral, nasal, or supraglottic airway (SGA); or tracheal tube. To assess MRI quality, we developed a scoring system with a combined score ranging from 6 to 30. We used the linear mixed model to account for patient-dependent confounders.
Results: We assessed 85 MRI studies from nine patients: 48 NAD, 27 SGA, four oral, four nasal, and two tracheal tube. Arithmetical mean combined scores were 21.6, 27.6, 20.3, 15.3, and 29.5, respectively. The estimated mean combined scores for the NAD and SGA cohorts were 22.0 and 27.3, respectively, showing that SGA use improved the combined score by 5.3 (P<0.0001).
Conclusions: The use of an SGA during MRI studies under general anaesthesia or deep sedation significantly improves image quality.

Key words: airway management; artifacts; magnetic resonance imaging

Magnetic resonance imaging (MRI) is instrumental for the evaluation of central nervous system (CNS) pathology. In oncological patients, it is frequently used to establish an initial diagnosis, to assess patient response to treatment, and to perform surveillance for possible recurrence. The major drawback of MRI is its long acquisition time, during which the patient must lie still inside the bore of the magnet. Almost all paediatric patients[1–3] and many adult patients undergoing MRI studies are unable to cooperate and require sedation or general anaesthesia (GA).

Propofol is the preferred agent for deep sedation and GA in the MRI setting because of its short half-life and rapid metabolism.[4] However, propofol frequently leads to relaxation of the pharyngeal muscles, often resulting in snoring and subsequent vibrations and head micromotions. As MRI is susceptible to motion, this causes

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Editor's key points

- The image qualities of magnetic resonance imaging (MRI) can be affected by movement of patients.
- The MRI qualities of the central nervous system were compared retrospectively between anaesthetized patients whose airways were managed with different methods (no airway device, the use of an oral or a nasal airway, a supraglottic airway, or a tracheal tube).
- The use of a supraglottic airway was associated with the best MRI qualities.

artifacts and image quality degradation, and lowers the diagnostic value of the studies. To prevent airway obstruction and improve image quality, various airway devices have been used. To our knowledge, previous studies have addressed the safety, compatibility, and ferromagnetic interference of airway devices in the electromagnetic field, but not the effects of anaesthesia-induced micromotion artifacts on image quality.[5–7] We hypothesized that by preventing anaesthesia-induced partial airway obstruction, through the use of various airway devices, we would mitigate MRI motion artifacts, which would result in improvements in image quality.

Given that oncological patients undergo multiple MRI studies at regular intervals, the use of different airway techniques, ranging from no airway device (NAD) to pharyngeal or tracheal airways, can be studied in the same patient. Also, studying patients who have undergone serial MRI studies would reduce patient-related variables, such as differences in airway anatomy or body habitus. In this retrospective study, we evaluated the image quality of serial CNS MRI studies in nine patients for whom different airway management techniques were used.

Methods

After obtaining institutional review board approval, we conducted a retrospective review of the CNS MRI studies of patients at The University of Texas MD Anderson Cancer Center who met all of the following inclusion criteria: (i) the patient had undergone sedation or GA; (ii) the patient had at least five serial MRI studies performed at our institution; (iii) there was at least one MRI session with an airway device and one session without an airway device; and (iv) only one type of airway device was used during each session. All imaging studies reviewed were performed between September 2007 and August 2015.

Information regarding patient characteristics and the airway management technique used to maintain a patent airway were collected from the electronic medical records. The airway management techniques used in the study participants were NAD, oral airway, nasal airway, supraglottic airway (SGA), or tracheal tube. The subtypes of SGA used included the disposable Laryngeal Mask Airway (LMA Unique™), the LMA Supreme™, the classic LMA™ (all manufactured by Teleflex Inc., Research Triangle Park, NC, USA), and the iGel (Intersurgical Ltd, Wokingham, UK).

To determine the image quality of each MRI sequence, we developed a scoring system with the following scores: score of 1 (non-diagnostic), score of 2 (poor quality but some diagnostic value), score of 3 (average), score of 4 (good), and score of 5 (excellent). Six standard MRI sequences were analysed [axial T2, axial fluid-attenuated inversion recovery (FLAIR), axial T1 precontrast, and T1 postcontrast in the axial, coronal, and sagittal planes], and a combined score ranging from 6 to 30 was assigned to each MRI session. The scoring was performed by a neuroradiologist with >20 yr of experience (T.L.C.), who was blinded to the type of airway management technique used. If there were repeated sequences (during the same study session), the one with the higher score was counted, because the better sequence determines the ultimate image quality. Magnetic resonance imaging was performed using a 1.5 or 3 T system.

Our study used series of MRI studies from a limited number of patients. For each patient, there was at least one study with and one without an airway device. For statistical analysis, we used the linear mixed model, which is a method of analysing repeated measurements, which in our study corresponded to serial MRI acquisitions. The model took into account correlations of the scores within the same patient, thus eliminating patient-dependent variables (e.g. individual airway anatomy or body habitus) as potential confounders, and enabled the use of each patient as their own control. A compound symmetry structure was used when estimating the covariance structure and mean scores. All tests were two sided, and P-values of ≤ 0.05 were considered statistically significant. Statistical analysis was carried out using SAS version 9 (SAS Institute, Cary, NC, USA). If a statistical analysis using the linear mixed model could not be performed for an airway management technique because of small group size, and thereby an estimated mean score could not be calculated, only the simple arithmetic mean was used for comparison.

Results

A total of 85 MRI studies were conducted in the four paediatric and five adult patients (four females and five males, with ages ranging from 10 months to 72 yr; Table 1 and Fig. 1). The

Table 1 Patient characteristics. Age range is related to the period of time in which the series of MRI studies were conducted. F, female; M, male; MRI, magnetic resonance imaging

Patient no.	Sex	Age range (yr)	Height [cm; mean (SD)]	Weight [kg; mean (SD)]	BMI [kg m^{-2}; mean (SD)]	No. of MRI studies
1	F	18–19	168.5 (0.47)	112.0 (15.3)	39.7 (5.4)	7
2	M	8–14	149.7 (13.7)	43.4 (10.7)	19.0 (1.3)	14
3	M	10 months to 2 yr	83.97 (6.18)	13.7 (1.8)	19.4 (1.3)	14
4	M	8–11	130.9 (1.7)	26.0 (1.4)	15.2 (0.84)	9
5	F	42–45	183 (0)	64.4 (1.3)	19.2 (0.4)	5
6	F	72	167.6 (0)	51.9 (5.2)	18.5 (1.9)	7
7	M	63–66	182 (0)	96.4 (6.4)	29.1 (1.9)	14
8	F	47–49	148.4 (0.6)	85.6 (4.5)	38.8 (1.6)	5
9	M	4–6	117.7 (1.5)	21.8 (1.5)	15.7 (1.1)	10

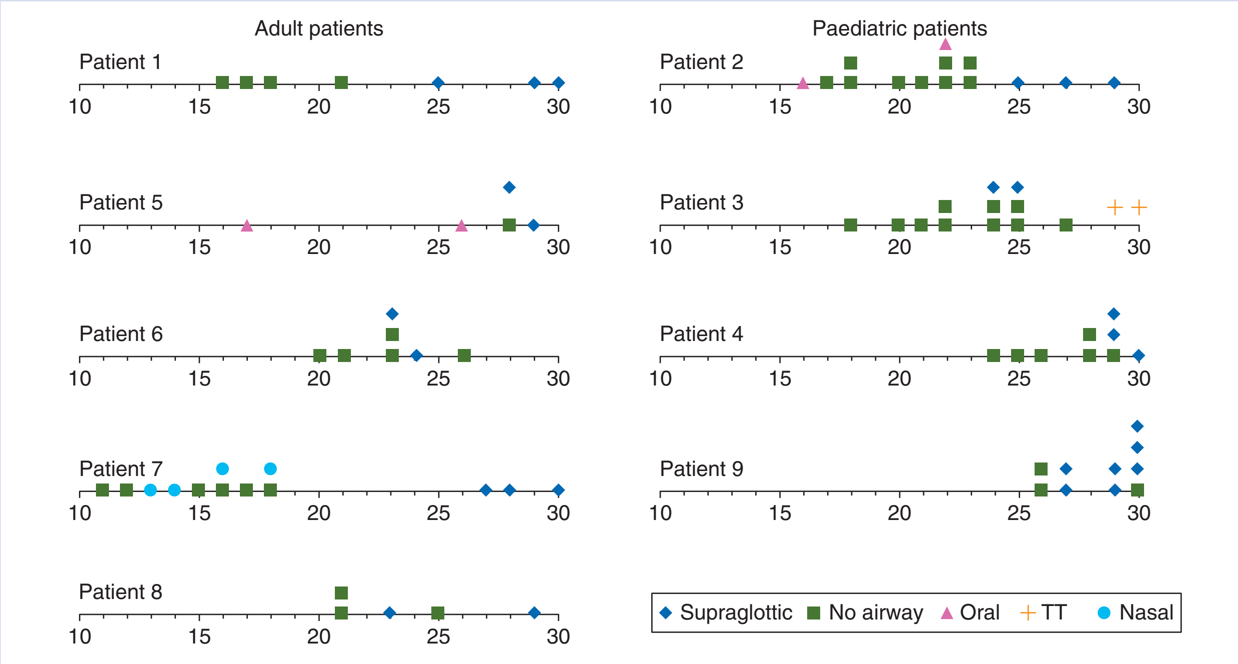

Fig 1 The scales show the combined magnetic resonance imaging (MRI) quality scores of serial MRI studies for each patient. Each scale represents a patient, and each symbol represents an MRI study. Note that there is a trend of studies, with supraglottic airways (SGAs) showing higher scores than studies performed without airways. The lowest and highest possible combined scores are 6 and 30, respectively. The scales in the figure start from 10, because none of the studies had a score <10. TT, tracheal tube.

combined MRI quality scores and the airway management technique used for each MRI study of each patient are shown in Fig. 1. Forty-eight studies (56%) were performed with NAD, 27 (32%) with SGA, four (5%) with oral airway, four (5%) with nasal airway, and two (2%) with tracheal tube, and the arithmetic means for image quality scores were 21.6, 27.6, 20.3, 15.3, and 29.5, respectively (Table 2). All patients were breathing spontaneously, except patient with a tracheal tube (controlled ventilation). The SGA devices were used to perform the following numbers of studies: LMA Unique™, *n*=14; LMA Supreme™, *n*=8; classic LMA™, *n*=4; and iGel™, *n*=1; and the arithmetic means for image quality scores were 28.5, 27.3, 26.3, and 23.0, respectively. Fifty-six studies were performed using a 1.5 T and 29 studies using a 3 T MRI system. These groups provided combined mean scores of 22.64 and 24.59, respectively.

Owing to the small sample sizes of studies using the oral airway, nasal airway, tracheal tube, and different subtypes of SGAs, we performed statistical analysis only on the two larger cohorts of NAD and the combined SGA studies. The estimated mean scores for the two cohorts were 22.0 (range: 11–30) for NAD and 27.3 (range: 23–30) for the SGAs. Thus, the use of SGAs during MRI studies improved the combined score by 5.3 (P<0.0001; Table 3 and Fig. 2). The distribution of the combined scores for NAD studies was much wider than those for SGA studies (Fig. 3).

The following reasons for sedation were documented in the electronic medical records: (i) young age (<18 yr) in 47 (55.3%) of MRI studies; (ii) claustrophobia in 26 (30.6%); (iii) increased risk for airway obstruction in 10 (11.8%); (iv) low pain threshold in one (1.2%); and (v) high anxiety in one (1.2%).

Propofol was used in all patients. The ranges for individual minimal and maximal propofol infusion rates were as follows (all in μg kg^{-1} min^{-1}): 50–250 and 75–250 in the NAD group; 100–200 and 150–250 in the oral airway group; 40–130 and 50–150 in the nasal airway group; and 75–250 and 75–300 in the SGA group, respectively. The anaesthesia records were incomplete

Table 2 Arithmetical means of combined magnetic resonance imaging quality scores for each airway management technique. NAD, no airway device

Airway management technique	No. of studies	Combined score [arithmetical mean (SD)]
NAD	48	21.6 (4.5)
Supraglottic	27	27.6 (2.3)
Oral	4	20.3 (4.7)
Nasal	4	15.3 (2.2)
Tracheal	2	29.5 (0.7)

Table 3 Summary of linear mixed model results estimating combined magnetic resonance imaging quality score for supraglottic airway and no airway device groups, and the difference between the two. LCL, lower confidence limit; SE, standard error; UCL, upper confidence limit

Airway management technique	Estimated mean score	SE	95% LCL	95% UCL	P-value
Supraglottic airway	27.3	1.04	24.89	29.69	
No airway	22.0	0.97	19.71	24.20	
Difference	5.3	0.77	3.56	7.11	0.0001

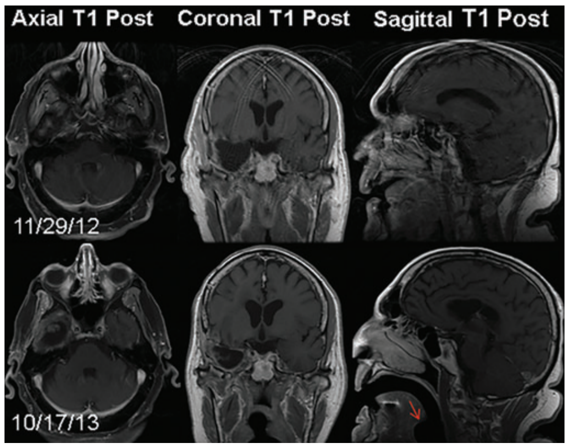

Fig 2 Serial magnetic resonance imaging (MRI) studies (axial, coronal, and sagittal T1-weighted postcontrast imaging) of the same patient. The study on the top row is without an airway device and had a score of 12 out of 30, whereas the study on the bottom row is with a supraglottic airway (LMA Unique™; arrow) and had a score of 27.

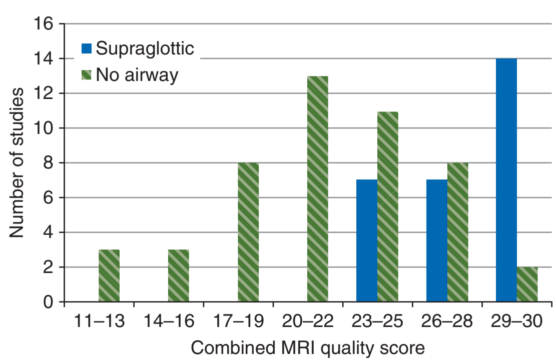

Fig 3 Distribution of the combined magnetic resonance imaging (MRI) quality scores for studies with no airway device and studies with a supraglottic airway. Note that all studies with a supraglottic airway are of very good or excellent quality.

for one of the two patients in tracheal tube group; and for the remaining one study, the minimal and maximal infusion rates were 100 and 122 μg kg^{-1} min^{-1}, respectively. In one study (with NAD), the minimal oxygen saturation was transiently <80%, in eight studies it was 80–90%, and in 76 studies it was ≥90%. Midazolam, hydromorphone, and fentanyl were used in conjunction with propofol in three, three, and four of the studies, respectively. There were no airway-related complications associated with the use of SGA, oral, nasal, and tracheal tubes.

Discussion

Our retrospective study evaluated the MRI image quality in patients undergoing serial MRI studies under deep sedation or GA. The two main cohorts of patients underwent MRIs with NAD or SGA. This is reflective of our clinical practice, which aims at minimizing airway instrumentation (NAD) or using minimally invasive airway techniques (SGA) rather than the tracheal tube. Our results showed that MRI studies performed using SGAs had significantly improved image quality compared with MRI studies performed using NAD (Fig. 2). In addition to the difference between the estimated mean scores, the minimal scores also differed greatly between the SGA group and NAD group (23 *vs* 11, respectively), which means that the use of an SGA ensured consistently high image quality (Fig. 3). The infusion rates for propofol were similar between the NAD and SGA groups, which represented the two largest cohorts of patients. This supports previous reports that the SGA is minimally invasive and well tolerated by patients.[8–10] Nasal airways required lower infusion rates of propofol compared with the oral airways, but the total number of patients was small, so further studies would be required to determine the significance of this observation.

The SGA group in our study was a heterogeneous group consisting of four different SGA devices. We did not perform a statistical analysis for each SGA group because the samples sizes were too small. However, we observed that all studies done with SGAs showed an overall high image quality, with combined scores ranging from 23 to 30.

One might think that SGAs, although decreasing motion artifacts caused by pharyngeal muscle vibrations, might at the same time lead to another type of MRI artifact: magnetic susceptibility artifacts, which degrade image quality and diagnostic value. A previous *in vitro* simulation study investigated the extent of magnetic susceptibility artifacts caused by six different types of SGA devices: the classic LMA™, the LMA ProSeal™, the LMA Unique™, the Ambu® Disposable Pharyngeal Mask, the LMA Supreme™, and the iGel™. That study found a prominent amount of artifacts with the LMA ProSeal™, a moderate amount of artifacts with the classic LMA™, LMA Unique™, and LMA Supreme™, and no artifacts with the Ambu® Disposable Pharyngeal Mask or iGel™.[6] The authors explained that the artifacts were caused by the presence of a metal spring containing a small amount of ferromagnetic material in the pilot balloons that were placed directly in the head MRI coil. These artifacts did not occur in our study, because in all our patients the pilot balloons were taped outside the field, as recommended by Dr Archie Brain, the inventor of the LMA.[11] This is an important technical point, which illustrates that *in vitro* study results may not necessarily have significant effects in clinical practice. The exception is the LMA Proseal™, which has a stainless-steel coil reinforcing the airway tube.[12] The presence of this coil (as opposed to the metal spring in the pilot balloon) is the source of major head and neck MRI artifacts and renders the LMA Proseal™ MRI incompatible.

The iGel™ has been reported to be a safe and useful device for MRI because of the lack of ferromagnetic components. A case series of 10 patients undergoing MRI under GA with the iGel™ device showed that the iGel™ provided diagnostically adequate MRI quality without magnetic susceptibility artifacts.[5] Although this observation provided valuable insights into the use of iGel™ during MRI and a direction for future studies, its design did not allow for an objective conclusion because of the lack of a control group and an objective evaluation of the image quality. Taxak and colleagues[7] reported two patients undergoing brain MRI with the iGel™, which yielded very good image quality without artifacts. Although it has been reported to be very MRI friendly, we found in our clinical experience, for CNS imaging, that the iGel™ interfered with the proper positioning of our MRI head coils, which made it difficult to use in the majority of our patients. In contrast with the iGel™, the classic LMA™ and LMA Unique™ interfered the least with the use of our MRI coils and were easy to place from the front of the patient. The LMA Supreme™ was also very easy to use and offered the advantage of gastric access, but in some patients the rigid shaft would occasionally interfere with the positioning of the MRI coil and required minor adjustments to maintain the device in place. It appears that the 'optimal' SGA for MRI has yet to be developed.

Although deep sedation is used in only some adult patients, children almost always require deep sedation or GA.[1–3] Several alternatives, such as sleep manipulation, adaptation of the physical environment, and anxiolysis by using a disposable pacifier and oral sucrose solutions, have been discussed and to some extent have led to clinical application, but there are limited scientific data about the effectiveness of these alternatives.[2] Some newer MRI technologies, such as Ultra-fast MRI, make MRI acquisition without GA possible for paediatric patients,[13] but their clinical applications are not as wide as those of conventional MRIs. Ultra-fast MRI is mostly used for the evaluation of ventriculoperitoneal shunts, macrocephaly screening, and surveillance of intracranial cysts, but its limited resolution renders it inadequate for parenchymal pathologies, such as tumours, and diseases affecting myelination.[14] Conventional MRI is thus still considered the gold standard and an important and valuable tool for evaluating paediatric pathologies, and effective use of airway devices during MRI acquisition is increasingly coming to clinicians' attention.[15]

Our study has some limitations. The first limitation is the number of patients, which can be considered low. The reason for this was the highly selective features of our inclusion criteria, which required the presence of serial CNS MRI studies with sedation, performed both with and without airway devices per patient. However, these highly selective inclusion criteria decreased potential confounding patient-related differences, such as airway anatomy. In other words, every patient was used as their own control. Being a tertiary referral centre for cancer, where a high number of patients with CNS tumours are regularly followed up using MRI, gave us the opportunity to study multiple patients undergoing serial MRIs under anaesthesia, during which different airway management techniques were used. Despite the relatively low number of patients, the high total number of MRI studies allowed us to apply an appropriate analytical method and obtain meaningful statistically significant results.

The second limitation was the limited number of MRI studies performed using nasal, oral, or tracheal airways (four, four, and two studies, respectively). These numbers did not reach the power to perform a statistical analysis. Future research with higher numbers of nasal, oral, and tracheal studies is needed to gain a better understanding of the effect of airway management strategies using these devices on image quality. Despite the low numbers, we observed certain trends. First, oral and nasal airways did not improve the image quality compared with NAD. Second, image quality was equivalent with the use of the tracheal tube and SGA, which suggests that the less invasive SGA may be preferred in the MRI environment in patients at low risk for aspiration.

A potential third limitation could be the analysis of data without differentiating between 1.5 and 3 T. It is known that a 3 T system is more susceptible to motion artifacts and thereby may increase the chance of image degradation. We reviewed the two groups separately. We did not observe any differences in trend and postulated that the potential confounding effect of different field strengths was most likely to be negligible. If we only included studies performed on either 1.5 or 3 T, it would reduce the number of studies available for review and thus decrease the statistical power of the study.

During the past 20 yr, MRI has become an increasingly important tool for the diagnosis of CNS pathology. The new, more powerful MRIs and advanced scanning sequences allow clinicians to explore beyond the anatomical boundaries of imaging and venture into neurological connectivity networks and molecular and physiological imaging. Unfortunately, this means that, for many patients, the time spent in an MRI scanner is getting longer. Many patients with medical and psychological conditions (e.g. claustrophobia, anxiety, and chronic pain) will not be able to cooperate during these longer acquisition times. It is therefore important to develop, in collaboration with radiologists, time-efficient anaesthetic techniques and airway strategies or algorithms that interfere minimally with magnetic resonance image quality. We believe that our study will pave the way for the development of such strategies. To determine which airway devices and anaesthetic practices are optimal for patients undergoing MRI studies, there is a need for future randomized controlled trials comparing patients who undergo MRI with different types of SGA devices. The goal is to obtain high-quality magnetic resonance images while at the same time maintaining high throughput.

In conclusion, our study showed that different airway management strategies vary in their influence on the quality of magnetic resonance images, and SGAs cause a significant and consistent improvement in the image quality in both paediatric and adult patients. To determine which airway devices and anaesthetic practices are optimal for patients undergoing MRI studies, there is a need for future randomized controlled trials comparing different types of SGA devices.

Authors' contributions

Study design, study conduct, and writing paper: F.E.U.K., T.L.C., D. Z.F.

Data collection: F.E.U.K., Y.H., A.D., E.C.

Revision of the manuscript: F.E.U.K., T.L.C., Y.H., A.D., E.C., D.Z.F.

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Declaration of interest

None declared.

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