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CLINICAL INFORMATION

High frequency jet ventilator – a new approach in the management of anesthesia for pediatric Cardiac Magnetic Resonance Imaging: case series☆

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KEYWORDS
Pediatrics;
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Abstract
Background and objectives: Cardiac Magnetic Resonance Imaging (MRI) is a technique used for evaluation of children with congenital heart diseases. General anesthesia ensures immobility, particularly in uncooperative patients. However, chest wall movements can limit good quality scans. Prolonged apnea may be necessary to decrease respiratory motion artefacts, potentially leading to hypoxemia and other adverse events. The use of a high frequency jet ventilator may be a solution avoiding chest wall movements.
Case report: We report four cases of pediatric patients, ASA II, aged between 4 and 15 years-old, scheduled for cardiac MRI. General anesthesia was proposed and parental informed consent was obtained. After general anesthesia was induced, an uncuffed endotracheal tube was inserted. Then, a 7Fr × 40 cm catheter was placed through the endotracheal tube. The proximal outlet of the catheter was attached through a connecting tube to a high frequency jet ventilator (Monsoon III®, Acutronic Medical Systems). Good quality MRI images were obtained. At the end of the procedures, we observed increased salivation and increased end-tidal CO_2 (60–70 mmHg), in all patients. The patients were extubated after normocapnia was achieved and neuromuscular blockade reversed. Following appropriate recovery time, the four children were discharged home the same day.
Conclusions: This case series demonstrates that the use of a high frequency jet ventilator for cardiac MRI was feasible, safe, providing good quality cardiac imaging and avoiding anesthesia personnel to be inside the hazardous environment of MRI room. Future studies are needed to confirm its safety and efficiency in pediatric patients.

☆ This work was carried out in Centro Hospitalar de Vila Nova de Gaia/Espinho, Porto, Portugal.
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PALAVRAS-CHAVE
Pediatria;
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Exame de ressonância magnética;
Ventilação a jato de alta frequência

Ventilação a jato de alta frequência – uma nova abordagem no manejo da anestesia para ressonância magnética em cardiologia pediátrica: série de casos

Resumo
Justificativa e objetivos: A ressonância magnética (RM) cardíaca é uma técnica usada na avaliação de crianças com cardiopatias congênitas. A anestesia geral garante imobilidade, especialmente em pacientes não cooperadores, porém, os movimentos da parede torácica podem limitar a boa qualidade dos exames. A apneia prolongada pode ser necessária para diminuir os artefatos do movimento respiratório, potencialmente levando à hipoxemia e outros eventos adversos. O uso de ventilação a jato de alta frequência pode ser uma solução para evitar os movimentos da parede torácica.
Relato de caso: Relatamos quatro casos de pacientes pediátricos, ASA II, com idades entre 4–15 anos, programados para ressonância magnética cardíaca. Uma anestesia geral foi proposta e assinaturas em termo de consentimento livre e esclarecido foram obtidas dos pais. Após a indução da anestesia geral, um tubo endotraqueal sem balonete foi inserido. Em seguida, um cateter de 7Fr × 40 cm foi inserido através do tubo endotraqueal. A saída proximal do cateter foi conectada, mediante um tubo conector, a um sistema de ventilação a jato de alta frequência (Monsoon III®, Acutronic Medical Systems). Imagens de ressonância magnética de boa qualidade foram obtidas. Ao final dos procedimentos, observamos aumento tanto de salivação quanto de CO_2 expirado (60–70 mmHg) em todos os pacientes. Os pacientes foram extubados após a obtenção de normocapnia e reversão do bloqueio neuromuscular. Após o tempo de recuperação apropriado, as quatro crianças receberam alta no mesmo dia.
Conclusões: Esta série de casos demonstra que o uso de um sistema de ventilação a jato de alta frequência para ressonância magnética cardíaca é viável e seguro, além de fornecer imagens cardíacas de boa qualidade e evitar a presença da equipe de anestesia dentro do ambiente de risco da sala de ressonância magnética. Estudos futuros são necessários para confirmar sua segurança e eficiência em pacientes pediátricos.

Introduction

Cardiac Magnetic Resonance Imaging (MRI) is an advanced technique used to obtain high quality images of the heart. It allows visualization of both the cardiac anatomy and ventricular function, being an invaluable tool for the evaluation of complex cardiomyopathies. Obtaining high quality images often requires a relative long period of exposition for each scan (several minutes) and needs full patient cooperation aiming maximum immobility.

Children with congenital heart diseases represent a frequent population submitted to cardiac MRI, either for diagnosis or prognostic purposes after corrective surgery. In most cases, these children are submitted to general anesthesia and connected to an intermittent positive pressure ventilator to assure full immobility and cooperation. Hereafter, periods of apnea are induced, during critical scans, to eliminate respiratory motion artefacts. Prolonged apnea has been proven to lead to hypoxemia and other adverse events during cardiac MRI.[1] Moreover, these periods of apnea are induced by the anesthesiologist, whom has to manually disconnect the patient from Intermittent Positive Pressure Ventilation (IPPV), increasing the length of the whole MRI procedure.

Over recent years, there has been an increased use of High Frequency Jet Ventilation (HFJV) for several procedures that require immobility.[2] We have already used manual jet ventilation (Manujet III® system, VBM Medical Inc®) in our Center for managing children in the MRI, but there are a few drawbacks. In this case series, we present four cases of pediatric patients safely submitted to cardiac MRI using general anesthesia and connected to a high frequency jet ventilator (Monsoon III®, Acutronic Medical Systems).

The conduction and publication of this case series was acknowledged and approved by our institution's ethical committee.

Case report

General anesthesia was proposed and parental informed consent was obtained, for all four patients. Table 1 describes the characteristics of the patients. None of them had predictability of difficult airway, nor a known allergy. They had no previous recorded adverse events during anesthesia or surgery. Two anesthesiologists were present throughout the cardiac MRI procedures. They were outside the MRI room, but with direct view over the patients and monitoring equipment, through a window. All patients had good ventricular function, previously measured on transthoracic echocardiography.

Table 1 Patient characteristics.

Patient	Gender, age and weight	ASA classification	Past medical history	Indication for MRI
Patient 1	Male, 4 years, 20 kg	II	Corrected congenital PV stenosis – previous percutaneous dilation	Evaluate dimensions of RV and PV function
Patient 2	Male, 6 years, 23 kg	II	Oligophrenia; Surgically corrected IVC	Evaluate residual IVC and presence of PHT
Patient 3	Male, 7 years, 26 kg	II	Surgically corrected MS and hypoplastic aortic arch	Evaluate cardiac anatomy and residual disease
Patient 4	Male, 15 years, 40 kg	II	Oligophrenia	Exclusion of HCM

IVC, Interventricular Communication; HCM, Hypertrophic Cardiomyopathy; MS, Mitral Stenosis; PHT, Pulmonary Hypertension; PV, Pulmonary Valve; RV, Right Ventricle.

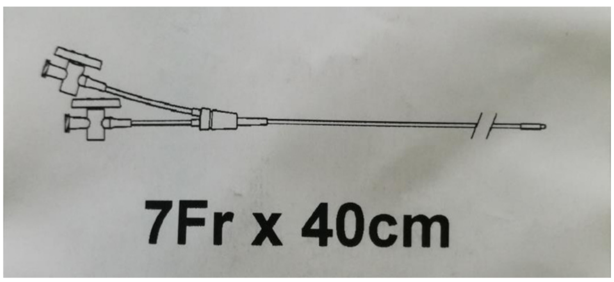

Figure 1 7Fr × 40 cm catheter.

The patients were monitored with pulse oximetry, 3-lead electrocardiography and non-invasive blood pressure. A portable capnograph was used intermittently. No neuromuscular blockade monitoring device was used. Anesthesia was induced in the MRI room with intravenous Propofol 1% bolus 3 mg.kg^{-1} followed by Rocuronium 0.6 mg.kg^{-1}. After laryngoscopy with a Macintosh blade, an appropriate size uncuffed Endotracheal Tube (ETT) was inserted and its correct location in the trachea was confirmed by lung auscultation and normal capnography/capnometry. The initial End-Tidal CO_2 ($EtCO_2$) was measured and registered. Then, a 7Fr × 40 cm catheter with an inflatable balloon tip (Fig. 1) was placed through the ETT in a way that the distal tip of the catheter was placed exactly at the distal tip of the ETT (this was achieved by previous measurement and marking on the catheter).

The balloon at the tip was never inflated and the proximal outlet for its insufflation was closed. The other proximal outlet of the catheter was attached through a connecting tube to the high-frequency jet ventilator (Figs. 2 and 3). The

Figure 3 Monsoon III®, Acutronic Medical Systems.

ventilator was placed, with appropriate caution and safety measures, inside the 1.5 Tesla MRI room, beyond the 0.5 mT Gauss line.

A nasogastric tube was placed in all patients, to prevent stomach insufflation. The patients were covered in comfortable blankets. Protective supports for the head and members were guaranteed and ocular protection was applied. General anesthesia was maintained with Propofol 1% at 10 mg.kg^{-1}.h^{-1} and Rocuronium boluses as needed.

Ventilation parameters ranged as follows: respiratory rate = 100–120 cycles.min^{-1}; inspiratory time = 40%; Driving Pressure (DP) = 0.5–0.7 bar; FiO_2 = 1.0; climatisation = 5–8. In Patient 1 the respiratory rate was 100 cycles.min^{-1}. In

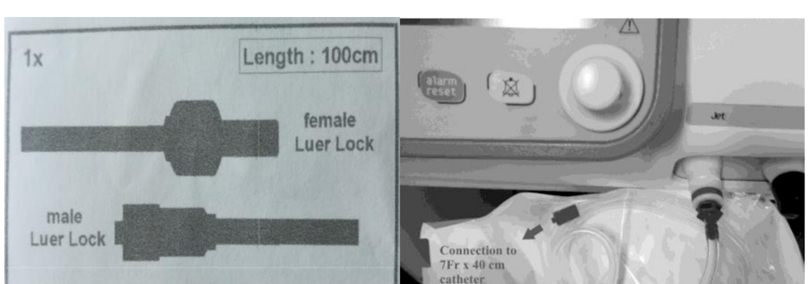

Figure 2 Connecting tube.

Table 2 End-tidal CO_2 measurements.

Patient	$EtCO_2$ at the beginning of the procedure (mmHg)	$EtCO_2$ at the end of the procedure (mmHg)
Patient 1	37	70
Patient 2	38	60
Patient 3	40	62
Patient 4	37	66

Patients 2, 3 and 4 the respiratory rate was increased to 120 cycles.min^{-1} to decrease thoracic motion. In Patient 1 and 2 the DP was 0.7 bar; DP was reduced to 0.5 bar in Patients 3 and 4 to further decrease thoracic motion. We observed increased salivation in all patients, during the procedures. The climatisation (humidification) was in level 8 (maximum level) in Patient 1, but was reduced to level 5 in Patients 2, 3 and 4, in an attempt to decrease salivation. In these patients, we used continuous low-pressure oral aspiration to drain the excess salivation. During the procedures, no device malfunctioning was noted. The lower recorded peripheral O_2 saturation was 97% and the patients remained hemodynamically stable throughout the general anesthesia.

Good quality MRI images were obtained. The maximum length of total image acquisitions was 35 min, with no interruptions. At the end of the procedures, we observed an increase in $EtCO_2$, in all patients (Table 2). When the image acquisitions were over, the high frequency ventilation was disconnected and the catheter was removed. Ventilation was provided by intermittent positive pressure, through the ETT, until normocapnia. The nasogastric tube was removed in continuous aspiration. The patients were extubated after neuromuscular blockade reversion with intravenous Sugamadex 2 mg.kg^{-1}. There was an episode of small volume vomiting in Patient 1, after extubation, with no pulmonary aspiration. Following appropriate recovery time, the four children were discharged home the same day.

Discussion

HFJV consists on the intermittent delivery of an air jet stream, at high frequencies, through a small-bore cannula or catheter positioned in the airway, followed by passive expiration. HFJV has proved to be a valuable tool for out-of-the-operating room anesthesia, particularly in procedures in which near complete immobility of the thoracic and abdominal structures is necessary through the respiratory cycle (examples include cardiac arrhythmias ablations and radiological procedures).[2] Cardiac MRI is another example in which HFJV can be of use, because even small respiratory movements can cause image artefacts.

Despite this advantage, HFJV has some limitations worth of mentioning: it is not possible to measure $EtCO_2$ continuously; high respiratory rates limit the time for expiration, which could lead to a build-up of an intrinsic PEEP, dynamic hyper-insufflation and barotraumas[3]; and high intrathoracic pressures may compromise venous return, which can be particularly problematic in children with congenital heart diseases. These children are known to have a higher rate of complications when receiving general anesthesia, than the general pediatric population.[4]

Some side effects that we were able to minimize included elevated $EtCO_2$, gastric distension and excessive salivation. High respiratory frequencies impair proper air exhalation and CO_2 wash-out. To overcome this effect, we had set the goal to measure $EtCO_2$ and ventilate the patients with intermittent positive pressure ventilation at 30 min in order to achieve normocapnia. As all procedures took less than 35 min, we dismissed that step. To prevent gastric distension, a nasogastric tube was placed to allow passive gastric emptying. We acted to counteract high salivation by decreasing the climatisation (humidification) level and by applying continuous low pressure oral aspiration.

In our Center, manual jet ventilation is already being used in children undergoing cardiac MRI. However, with our experience, this method does not provide near constant airway pressures, it requires anesthesia personnel to be inside the hazardous environment of MRI room and higher $EtCO_2$ measurements were obtained at the end of the procedures. A high frequency jet ventilator allowed us to undertake the MRI procedures in less time, as no interruptions had to be made to induce breath holds.

In this case series, we used the Monsoon III® (Acutronic Medical Systems), despite not being non-ferromagnetic free for MRI environment. Qualified MRI technicians established, before the cases, the safest ventilator position beyond the 0.5 mT Gauss line (concerning the risks of projectile effect, device malfunctioning and image artefacts). Neither of these risks were verified and good quality MRI images were obtained.

Some alternatives to HFJV could be used. High Flow Nasal Oxygen (HFNO) is a therapy that allows delivery of heated and fully humidified gas with a FiO_2 of nearly 100%. HFNO administered at 70 litres/min for 10 min allowed median apnea time of 14 minutes.[5] Despite these advantages, HFNO requires a spontaneous ventilating patient for proper pre-oxygenation, patient cooperation for connecting the high-flow system and subsequent induction of apnea for removing respiratory motion artefacts on MRI. It may also increase the risk of burns and at our institution we don't have the possibility to apply such a high flow in the MRI setting. Another alternative way to induce apnea without the need to intubate the patients would be to maintain sedation with spontaneous ventilation and then pharmacologically induce apnea. This could be achieved, for example, by administering a high dose of a short duration of action opioid as Alfentanil. However, this approach comes with some risks: arterial desaturation from apnea without oxygenation and side effects from administering a high dose opioid. Intubation could also be avoided by inserting the HFJV catheter directly into the trachea and then connecting it to the ventilator. We opted to pass the catheter through an ETT as an additional safety measure, assuring control over the airway at any time and avoiding the need for prolonged bag-mask ventilation at the end of procedures (manoeuvre for decreasing the CO_2 build-up), which would cause additional stomach insufflation

We found only a report in literature where a different type of high frequency ventilation was used for cardiac MRI − High Frequency Oscillatory Ventilation (HFOV). In this report, HFOV proved to be feasible and well tolerated, with image quality equivalent to that obtained with conventional ventilation with breath-holding technique.[6] However, there is a lack of well-designed studies evaluating its efficacy.

Conclusions

This case series demonstrates that the use of a high-frequency jet ventilator for the anesthetic management of children undergoing cardiac MRI was feasible and safe, providing good quality cardiac imaging in less time. Anesthesia personnel was able to be outside the hazardous MRI environment. No major side effects were observed. Future studies are needed to confirm its safety and efficiency in pediatric patients submitted to cardiac MRI.

Conflicts of interest

The authors declare no conflicts of interest.

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