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The Dose of Propofol Required to Prevent Children from Moving during Magnetic Resonance Imaging

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Background: Intravenous propofol offers several advantages as an anesthetic for children undergoing magnetic resonance imaging. However, the dose of propofol required to prevent movement during magnetic resonance imaging is likely to be less than that required for surgical anesthesia.

Methods: Thirty children between the ages of 1 and 10 years, undergoing elective magnetic resonance imaging as outpatients were randomly assigned to receive a propofol infusion at a rate of 50, 75, or 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ during the imaging procedure. Anesthesia was induced with inhalation of halothane, nitrous oxide, and oxygen, and a 2 $\text{mg} \cdot \text{kg}^{-1}$ loading dose of propofol. Immediately after insertion of an intravenous catheter, inhaled anesthetics were discontinued and the propofol infusion started. The children then were observed for movement during the scan.

Results: There were no significant differences among the three groups with respects to mean age (4.4 ± 2.0 yr), weight (17.6 ± 5.1 kg), induction time (11 ± 3 min), scan duration (55 ± 26 min), or recovery time (30 ± 8 min). Five of ten patients who received 50 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ moved during the scan, three of ten patients who received 75 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ moved, and none of the children who received 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ moved.

Two patients experienced a decrease of arterial oxygen saturation to less than 95% after receiving the initial bolus of propofol. The arterial oxygen saturation returned to normal within 15 s without specific treatment other than continued supplemental oxygen. There were no episodes of hypoxemia during image acquisition. None of the children experienced nausea or vomiting.

Conclusions: Following induction of anesthesia with halothane, nitrous oxide, and a 2 $\text{mg} \cdot \text{kg}^{-1}$ loading dose of propofol, infusion of propofol at a rate of 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ effectively prevents children from moving during elective magnetic resonance imaging. A transient decrease in arterial oxygen saturation can occur after the initial bolus of propofol. Recovery from anesthesia is rapid and without nausea or vomiting. (Key words: Anesthesia, pediatric. Anesthetics, intravenous: propofol. Magnetic resonance imaging.)

SEVERAL techniques have been described for anesthetizing children undergoing magnetic resonance imaging (MRI) or other painless radiologic procedures. These include oral or rectal administration of hypnotic drugs,¹ intramuscular ketamine or barbiturates,² and general anesthesia with endotracheal intubation. Oral, rectal, and intramuscular methods of drug administration are affected adversely by the unpredictable onset and depth of anesthesia, discomfort associated with drug administration, and prolonged recovery periods associated with them. General anesthesia with endotracheal intubation can result in trauma to the airway and requires muscle relaxants or a deeper level of anesthesia in order to prevent unwanted movement. The ideal anesthetic should meet the following conditions: (1) It should allow for adequate oxygenation and ventilation with spontaneous respiration. (2) It should give the anesthesiologist the ability to titrate and maintain stable drug concentrations. (3) It should prevent undesired movement. (4) It should offer rapid rates of induction and recovery. (5) It should produce a minimum of side effects such as nausea, sore throat, pain, or dysphoria. (6) It should have minimal requirements for special MRI-compatible equipment.

Intravenous anesthesia meets several of the criteria described above. In particular, an intravenous anesthetic without endotracheal intubation allows for careful titration of sedatives to achieve clinical effect and eliminates the need for a nonferromagnetic anesthesia machine.

Propofol may have many of the characteristics of the ideal intravenous anesthetic for MRI. However, the MRI

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environment is quite different from that of the operating room, and the dose of intravenous propofol required to prevent unwanted movement during MRI is likely to be less than that required for surgical anesthesia.

The purpose of this study was to determine the minimum effective infusion rate of intravenous propofol required to prevent children from moving during elective MRI.

Methods

After obtaining Institutional Review Board approval and parental consent, children between the ages of 1 and 10 yr, with American Society of Anesthesiologists physical statuses of 1 or 2, undergoing elective MRI as outpatients were enrolled into the study. Those with suspected elevated intracranial pressure or having a full stomach were excluded. Children were randomly assigned to receive an infusion of propofol at the rate of 50, 75, or 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ during the scan (groups 1, 2, and 3, respectively). These doses were chosen based on clinical observations that propofol infusions at rates of 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ were effective in preventing children from moving during MRI. For the purposes of this study, the propofol infusion rate that prevented movement in at least nine out of ten patients would be considered an effective dose.

The anesthesiologists were prepared to control ventilation with a bag and mask system, insert an oral or nasal airway, or intubate the trachea at any time during the procedure. Induction of anesthesia was accomplished with inhalation of halothane (up to 3%), nitrous oxide (70%), and oxygen (30%) using an anesthesia machine (mode 71 Standard, North American Drager, Telford, PA) located in a room adjacent to the MRI scanner. Immediately after anesthesia was induced, an intravenous cannula was inserted, and the halothane and nitrous oxide were discontinued. Glycopyrrolate (5 $\mu\text{g} \cdot \text{kg}^{-1}$) and a loading dose of propofol (2 $\text{mg} \cdot \text{kg}^{-1}$) were given to each patient. The children then were moved into the scanner room and placed on the MRI table. Oxygen (5–6 $\text{l} \cdot \text{min}^{-1}$ via a See-thru Oxygen Mask, Hudson, Temecula, CA) was administered to all patients. A syringe pump (model number AS20GH, Baxter Healthcare, Hooksett, NH) was used to deliver a continuous infusion of propofol at the predetermined dosage. If the airway was partially or completely obstructed, the neck was extended slightly and the chin was supported with a tape "chin-strap". If positioning the head did not create a patent airway, an

oral or nasal airway was inserted before the child was inserted into the bore of the imaging device, and the child was excluded from further study. Arterial oxygen saturation (SpO_2) (Biochem, Waukesha, WI), expired carbon dioxide (model 515R, Biochem, Waukesha, WI), and blood pressure (Dinamap Vital Signs Monitor, Critikon, Tampa, FL) were measured using MRI-compatible devices. In addition, patients were observed constantly by an anesthesiologist who remained in the room throughout the scan. No attempt was made to reduce auditory stimulation to the patient. If a child moved during the imaging sequence, the time was noted, a 1–2 $\text{mg} \cdot \text{kg}^{-1}$ bolus of propofol was given, and the continuous infusion rate was increased to 100–150 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. After the imaging sequence was completed, the propofol infusion was discontinued. Patients then were transferred to the recovery area located in a room adjacent to the scanner where they were observed by a recovery room nurse and monitored with standard recovery room equipment. Children were discharged to the care of their parents after full recovery of consciousness and motor control. Recovery time was defined as the time span from completion of the scan to discharge.

Differences among groups 1, 2, and 3 were compared with 3-way analysis of variance for continuous variables and contingency table analysis for noncontinuous variables. All data are expressed as the mean \pm SD. *P*-values of less than 0.05 were considered significant.

Results

Thirty-two children were enrolled into the study. Two children were excluded from the study before imaging because they required insertion of an oral airway. Of the remaining patients, 10 were girls and 20 were boys. The mean age of the 30 children studied was 4.4 yr (SD \pm 2.0 yr), and the mean weight was 17.6 kg (SD \pm 5.1 kg). The mean time required for induction of anesthesia, insertion of the intravenous cannula, and transfer onto the MRI table was 11 min (SD \pm 3 min). The brain was imaged in 21 patients, the lumbar or cervical spine in 6, the heart and great vessels in 2, and the knee in 1. The mean imaging time was 55 min (SD \pm 26 min, range 30–145 min), including the time required to repeat inadequate scans. A full set of images without motion artifact was completed for all children.

There were no significant differences among the three groups with respect to age, weight, gender, induction time, or scan duration (table 1). Movement occurred

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Table 1. Patient and Demographic Data

	Group 1 50 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$	Group 2 75 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$	Group 3 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$
Age (yr)	4.6 \pm 2.2	3.8 \pm 1.8	4.7 \pm 2.1
Weight (kg)	17.8 \pm 5.3	15.5 \pm 4.0	19.5 \pm 5.7
Gender (female/male)	5/5	3/7	2/8
Induction time (min)	11 \pm 3	11 \pm 2	11 \pm 3
Scan time (min)	58 \pm 35	47 \pm 13	59 \pm 27
Recovery time (min)*	27 \pm 6 (n = 5)	25 \pm 7 (n = 7)	34 \pm 8 (n = 10)

Values are reported as the mean \pm standard deviation.

* Children who moved during the scan were excluded because they received additional propofol.

in five of the ten children who received propofol at a rate of 50 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (group 1), and three of the ten children who received 75 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (group 2). None of the children who received 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (group 3) moved during the imaging process (fig. 1). Movement occurred an average of 32 min (range, 20–60 min) after the propofol infusion was started. There was no relationship between the time of movement and the infusion rate of propofol. There was no relationship between incidence of movement and the patients' ages or weights or the duration of the scans.

Two patients experienced a decrease of SpO_2 to less than 95%. Both episodes occurred after the initial intravenous bolus of propofol produced transient apnea. The only treatment required to resume an adequate respiratory pattern and arterial oxygen saturation was gentle stimulation and continued administration of supplemental oxygen. Neither episode of arterial ox-

xygen desaturation lasted longer than 15 s. No child experienced arterial desaturation during the imaging process. There were no episodes of hypotension (systolic blood pressure < 70 mmHg), bradycardia (heart rate < 50 beats per min), or tachycardia (heart rate > 150 beats per min) during the study.

Excluding those children who moved during the scan and consequently received an additional dose of propofol, the mean recovery time was 30 min (n = 22, SD \pm 8 min, range 15–60 min). Again, excluding those children who moved during the scan and consequently received an additional dose of propofol, there was no relation between the propofol dose and the time to discharge. None of the children experienced nausea or vomiting.

Discussion

Intravenous propofol offers several potential advantages for anesthetizing children undergoing MRI. Intravenous drug delivery allows for precise, rapid titration to the desired effect. This is in contrast to the relatively slow and unpredictable onset of sedation that occurs when sedatives such as chloral hydrate, benzodiazepines, barbiturates, or ketamine are given orally, nasally, rectally, or intramuscularly. In the event that the child awakens during a scan, intravenous administration of additional amounts of a drug is easier, has a more rapid effect, and is less disruptive than administration by alternate routes.

Continuous intravenous infusion of propofol eliminates the need for a nonferromagnetic, MRI-compatible anesthesia machine. The substitution of intravenous induction, as described by Bready *et al.*,³ for the inhalation induction used in this study eliminates the need for an anesthesia machine. This would be partic-

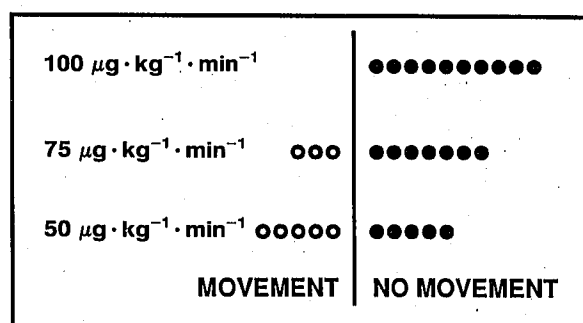


Fig. 1. Incidence of movement with each dose of propofol. Open circles represent children who moved during the imaging process. Closed circles represent children who did not move. None of the children who received 100 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ of propofol moved, three of ten children who received 75 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ moved, and five of ten who received 50 $\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ moved.

ularly beneficial at institutions where the number of anesthetics administered in the MRI suite does not justify the purchase of a dedicated MRI-compatible anesthesia machine. In addition, an intravenous infusion pump is easily portable compared to an anesthesia machine.

The pharmacokinetic properties of propofol may make it an ideal anesthetic for children undergoing MRI; however, the minimum dose required to prevent movement under these conditions has not been determined. The absence of painful stimulation during MRI would suggest that the dose of propofol required to prevent undesired movement might be significantly less than that required for surgical procedures.

Our results demonstrate that after induction of anesthesia with halothane, nitrous oxide, and a $2 \text{ mg} \cdot \text{kg}^{-1}$ bolus of propofol, propofol infusion at the rate of $100 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ prevented all ten children who received this dose from moving during the scan. Using the analysis described by Hanley⁴ to interpret the fact that no child who received this dose of propofol moved, we can conclude with 79% confidence this anesthetic induction combined with an infusion rate of $100 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ will prevent at least 90% of children from moving during an MRI scan.

The above dose is considerably less than $348 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, which, when combined with nitrous oxide, is reported to prevent 95% of adults from moving in response to surgical stimulation.⁵ We are not aware of any studies that describe the dose of propofol required when it is the sole anesthetic used for operative procedures in children.

Conscious sedation of adults^{6,7} can be achieved with propofol infusion rates as low as $16\text{--}50 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, and deep sedation of adults undergoing surgery under regional anesthesia^{8,9} can be achieved with infusion rates of $50\text{--}100 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. We believe the lower doses used for conscious sedation of adults would not be effective for sedation of children because conscious sedation generally is inadequate for preventing young children from moving. The need for deeper levels of sedation in children may account for the higher infusion rate required to prevent unwanted movement in this study.

In addition, children may require larger doses of propofol than adults to experience comparable levels of sedation. Several authors have suggested that the induction dose of propofol for children may be 50% larger and that the maintenance infusion rate may be 25% larger than that required by adults.¹⁰⁻¹² This may

be explained in part by the greater central compartment volume in the child *versus* that in the adult.¹⁰ It is possible that there also are significant pharmacodynamic differences between children and adults who receive propofol.

Recently, in a similar study, Bready *et al.*³ reported that a continuous propofol infusion of $25 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ was effective in preventing children aged 1-7 yr from moving during computerized tomography. Bready *et al.* used a larger initial dose of propofol (mean, $2.8 \text{ mg} \cdot \text{kg}^{-1}$) because halothane and nitrous oxide were not used for induction of anesthesia. In addition, the duration of the scans were short (mean duration, 30 min; range, 17-58 min), and the loud noise that accompanies MRI was absent during computer-tomographic scans. It is noteworthy that the two children in the study by Bready *et al.* who moved after receiving an initial bolus of propofol and did not receive a subsequent continuous infusion moved at 11 and 13 min, indicating that a single bolus would be effective for procedures lasting fewer than 10 min.

Martin *et al.*¹³ recently described the advantages of total intravenous anesthesia with propofol for pediatric patients outside the operating room at infusion rates of $50\text{--}300 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. However, the anesthetic technique used in their study included the use of neuromuscular blockade and insertion of an endotracheal tube.

Based on published pharmacokinetic parameters for the use of propofol in pediatric patients,¹⁰ we simulated the blood propofol concentration *versus* time for our patients (fig. 2). Because the pharmacokinetic data were corrected for weight and our dosing in this study was based on weight, a single line was used to describe each of our study groups. The time of lowest blood concentration, as predicted by our pharmacokinetic simulation, was 19.5 min in group 1, 22 min in group 2, and 27 min in group 3. It should be emphasized that these are simulations, and no blood propofol concentrations were measured in this study. It is possible that those patients who moved had a lower blood concentration than the population average would suggest, secondary to between-patient differences in clearance and volume of distribution.

The average time between the administration of the initial propofol bolus and patient movement was 32 min. This was 5-10 min later than the calculated nadir of blood propofol concentration shown in figure 2. It is likely that the halothane administered during induction, contributed in declining fashion with time, to the

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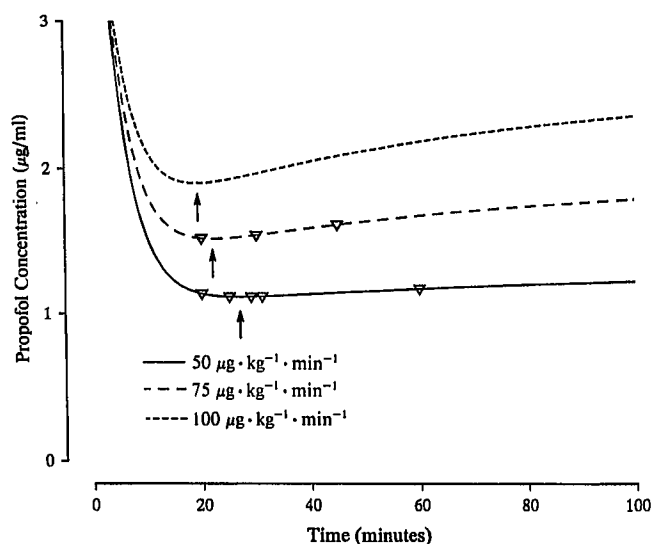


Fig. 2. A computer simulation of blood propofol concentrations that would be expected with each infusion rate. This was derived using pharmacokinetic data reported by Marsh *et al.* for children aged 1–12 yr.¹⁰ The arrows represent the predicted nadir in blood propofol concentrations for each infusion scheme. The open triangles represent the times at which movement actually occurred.

early anesthetic effect, obviating early movement that might otherwise have been present.

Goodman *et al.*¹⁴ examined the effects of propofol on respiration in adults when used as the sole anesthetic and found that tidal volume, minute ventilation, and the response to carbon dioxide were reduced by a continuous infusion of $100 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. In addition, the majority of patients studied became apneic after receiving the initial propofol bolus of $2.5 \text{ mg} \cdot \text{kg}^{-1}$, an observation also made by others.¹¹ Allsop *et al.*¹⁵ described resting end-tidal carbon dioxide measurements of 50 mmHg in adult volunteers who received $100 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ of propofol.

More recently, Vangerven *et al.*¹⁶ found that propofol infusion at rates of $50\text{--}110 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ to spontaneously ventilating children undergoing MRI did not result in an elevated end-tidal carbon dioxide or capillary carbon dioxide. In our study, only a capnometer was used, so we cannot quantitate the respiratory changes caused by propofol. However, we would not expect the degree of respiratory depression to be significantly different from that reported by Vangerven, despite our brief use of halothane and nitrous oxide. It should be noted that we were always ready to provide positive pressure ventilation or intubate the trachea if ventilation was judged to be inadequate.

Hemoglobin oxygen desaturation secondary to apnea occurred in two patients, and several others experienced transient apnea not associated with a decrease in SpO_2 . It is possible that a smaller initial loading dose might have reduced the incidence of apnea without having significantly increased the incidence of movement. There were no episodes of arterial desaturation during the time the children were inside the bore of the imaging device.

It was thought that presence of an oral or nasal airway, although not a contraindication to the general use of this technique, would result in an added noxious stimulus, making subsequent comparison among patients more difficult. Therefore, children who required insertion of an airway were excluded from further study. It is noteworthy that only 2 of 32 children required insertion of an airway, and none required endotracheal intubation.

Before conducting this study, we observed that some children accumulate saliva in the posterior pharynx during the course of a scan. Not infrequently, this precipitates a cough. For this reason, glycopyrrolate was given to all children immediately after the intravenous catheter was inserted.

No child developed hypotension, tachycardia, or bradycardia as a result of this technique. This is not unexpected considering that these children all were of American Society of Anesthesiologists physical status 1 or 2, the dose of propofol used was relatively small, and the propofol was administered by continuous infusion. In addition, our use of glycopyrrolate to reduce secretions may have prevented bradycardia from occurring.

Neither postanesthetic nausea nor vomiting occurred in our study. The antiemetic properties of propofol may have been responsible for this result.^{17,18} However, the incidence of nausea for patients undergoing these procedures is unknown. In addition, patients were free from other common postanesthetic problems such as muscle pain, sore throat, and urinary retention. We found no relationship between the dose of propofol and the time spent in the recovery room.

In summary, following induction of anesthesia with halothane, nitrous oxide, and a $2 \text{ mg} \cdot \text{kg}^{-1}$ loading dose of propofol, a propofol infusion at a rate of $100 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ effectively prevents children from moving during elective MRI. This intravenous technique provides the anesthesiologist with the ability to titrate rapidly and maintain stable drug concentrations during the MRI procedure, thus ensuring that anesthesia

is administered in a timely and consistent manner. Recovery from this type of anesthesia is rapid and not accompanied by nausea or vomiting.

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