Intraocular Pressure in Pediatric Patients During Prone Surgery

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BACKGROUND: Intraoperative intraocular pressure (IOP) in the prone position and IOP changes over time have not been evaluated in pediatric surgical patients. We sought to determine time-dependent changes in IOP in children undergoing surgery in prone position.

METHODS: Thirty patients undergoing neurosurgical procedures in prone position were included. Using a pulse-mode pneumatonometer, IOP was measured in supine position after induction and before emergence of anesthesia and in prone position before the start and after the end of surgery. IOP changes over time in the prone position were assessed with a linear mixed model (i.e., random slope and intercept model) to adjust for the within-patient correlation.

RESULTS: IOP in prone position increased by an average of 2.2 mm Hg per hour ($P < 0.001$). Sixty-three percent of patients (95% confidence interval [CI], 46%–81%) had at least 1 IOP value exceeding 30 mm Hg, and 13% (95% CI, 1%–25%) had at least 1 IOP value exceeding 40 mm Hg while prone. Mean IOP increased 7 mm Hg (95% CI, 6–9) during the position change from supine to prone ($P < 0.001$) and decreased 10 mm Hg (95% CI, 9–12) after changing the position from prone back to supine ($P < 0.001$).

CONCLUSIONS: Changing position from supine to prone significantly increases IOP in anesthetized pediatric patients. Moreover, the IOP continued to increase during surgery and reached potentially harmful values, especially when combined with low mean arterial blood pressures that are common during major surgery. (Anesth Analg 2013;116:1309–13)

Vision loss is a devastating perioperative complication[1,2] that has been reported as a complication of cranial vault reconstruction,[3] spine surgery,[4] and orbital surgery.[5] A United States national study estimated the overall incidence of perioperative visual loss to be 2.4 per 10,000 cases (0.02%), but that the risk is 0.03% for spinal fusion and 0.09% for cardiac surgery.[6]

An unexpected finding from analysis of the Nationwide Inpatient Sample was an alarmingly high risk of pediatric patients developing postoperative visual loss after all surgical procedures (odds ratio 6.9 versus adults). The odds ratio for developing visual loss in patients younger than 18 years after spinal fusion surgery was 5.8,[7] whereas the odds ratio of young patients to develop cortical blindness versus adults across all procedures was 64.[6] The reason for the increased visual loss risk in pediatric patients is not clear, but an embolic mechanism seems more likely than stroke (which is uncommon in children).[6] There are nonetheless only sporadic published reports of postoperative visual loss in pediatric patients.[3–5,8–10]

The causes of vision loss after spine surgery in prone position remain poorly understood, but appear to be multifactorial and may include impaired perfusion of the eye, occlusion of retinal vessels, or an "eye compartment syndrome" caused by increased orbital pressure and decreased perfusion secondary to use of large amounts of crystalloids.[11] Inadequate ocular perfusion pressure can cause retinal ischemia and may contribute to postoperative visual loss.[12,13] Ocular perfusion pressure is commonly defined as the difference between mean arterial blood pressure and intraocular pressure (IOP).[14] At a given mean arterial pressure, retinal perfusion pressure is determined by IOP. Factors that influence perioperative IOP are thus of considerable interest. IOP can be influenced by general anesthesia, fluid balance, and end-tidal carbon dioxide partial pressure. Aqueous humor flow, choroidal blood volume, central venous pressure, and extraocular muscle tone also contribute.[15] Positioning is yet another factor that influences IOP during surgery.[16] For example, IOP is increased by prone[17,18] and deep Trendelenburg[19] positions, with the increases being comparable with and without general anesthesia.[19,20] IOP also continues to increase over time in the prone position,[16,19–21] an effect that is thought to result from continued production of aqueous fluid by the ciliary body inside the eye[19] or to the accumulation of edema in the orbit.[11] With only a single exception,[18] all studies have found a time-dependent increase in IOP in adults.

The normal distribution of IOP is well established in unanesthetized, pediatric subjects.[22] However, intraoperative IOP and the extent to which it changes over time have

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yet to be evaluated fully in pediatric patients. Furthermore, the effect of prolonged prone positioning remains unknown in pediatric patients. We thus sought to determine time-dependent changes in IOP in children undergoing surgery in the prone position.

METHODS

With approval of the University of Texas Southwestern IRB and written consent from parents, we enrolled consecutive patients from newborn to 18 years of age who were scheduled for neurosurgery in prone position with an expected duration exceeding 2 hours. Patients with a history of increased IOP or glaucoma, known visual impairment, heart failure, or ASA physical status scores >3 were excluded.

Both induction and maintenance of anesthesia were left to the discretion of the anesthesiologist, but typically included propofol (1.5–3.0 mg/kg), fentanyl (1–2 mcg/kg), vecuronium (0.1 mg/kg), and sevoflurane or isoflurane at approximately 1 minimum alveolar concentration. All patients were given dexamethasone 0.5 mg/kg[1] shortly after induction. Arterial blood pressure was monitored from an arterial catheter. Mechanical ventilation was adjusted to provide an end-tidal Pco_2 near 35 mm Hg. Anesthetic administration was adjusted as necessary to maintain mean arterial blood pressure and heart rate about 20% below preinduction values.

As is routine in these cases, the patient's head was secured with skull pins which allowed free access to the eyes while avoiding any direct mechanical pressure to the globe. The patient's head was elevated 10^0 to reduce venous stasis.

Patients were given 5 to 7 mL/kg lactated Ringer's solution in the immediate postinduction period, which was followed by 5 mL/kg/h maintenance hydration. Additional lactated Ringer's solution was given as necessary to replace blood loss (usually in a 3:1 ratio) and to maintain mean arterial blood pressure about 20% below the preinduction value, heart rate within 20% of the preoperative value, and urine output ≥0.5 mL/kg/h. Blood was transfused as necessary to maintain a hematocrit ≥30%.

Morphometric and demographic characteristics were recorded, along with mean arterial blood pressure, blood loss, fluid administration, urine output, and the duration of surgery. IOP was measured with a Model 30 Classic Tm pulse-mode pneumatonometer (Reichert Technologies, Depew, NY). The pneumatonometer is self-calibrating and records 40 values per second; we thus made a single measurement for each eye at each time point. All measurements were performed by the same investigator (RBP). This system is well validated in pediatric patients.[23]

IOP was recorded first with patients supine 15 minutes after anesthetic induction but before the head was positioned in pins; second, 15 minutes after patients were turned prone; third, at the end of surgery while the patient was still in prone position; and fourth, 10 minutes after patients were turned supine at the end of surgery before tracheal extubation. When possible, IOP was determined in each eye at each measurement interval. Anesthesia was discontinued only after the final IOP measurements in supine position.

IOP changes over time in the prone position were assessed using a linear mixed model (i.e., a random slope and intercept model) with an unstructured covariance matrix to adjust for the within-patient correlation. This model assumes that patient effects (intercepts) and time effects (slopes—IOP changes over time) are random (i.e., differ among patients). The average IOP change per hour in the prone position was estimated with 95% confidence interval (CI). In addition, percentages of patients who had at least 1 IOP in the prone position exceeding 30 and 40 mm Hg were reported along with Wald confidence limits.

We assessed the IOP change from supine to prone position by comparing the initial measurement in the supine position and the first measurement in the prone position. Similarly, the IOP change from prone back to supine position was also assessed by comparing the final measurement in the prone position and the measurement in the supine position after changing back from the prone position. Pressures were compared with paired Student *t* tests. The corresponding mean (95% CI) of the IOP changes were estimated.

A total sample size of 26 was required to be able to detect a change of 2 mm Hg or more per hour in IOP at the 0.05 significance level and 90% power, assuming an SD of 3 mm Hg and a correlation of 0.5 based on previous experience. A total sample size of 30 patients was thus selected. SAS statistical software 9.2 for Windows (SAS Institute, Cary, NC) was used for all analyses.

Table 1. Demographics Baseline and Intraoperative Characteristics (*N* = 30)

Variables	Statistics[a]
Age, mo	104 (58)
Weight, kg	38 (25)
Length, cm	131 (33)
Gender (male), %	40
ASA physical status class	1.7 (0.6)
Type of surgery, %	
Lumbar laminectomy for tethered cord	43
Craniotomy	13
Chiari decompression	43
Volatile anesthetic used, %	
Isoflurane	38
Desflurane	4
Sevoflurane	58
Length of surgery, h	4.3 (1.3)

[a]Summary statistics presented as mean (SD) or % of patients.

RESULTS

Thirty pediatric patients were included in the study. Table 1 provides the summary of the demographics baseline and intraoperative characteristics. Blood loss was minimal in all patients, and none required blood replacement.

The change of IOP over time during the prone position did not vary by eye side ($P = 0.19$, assessment of interaction). We thus averaged IOP for the left and right sides when both were available at a given time point, or used the nonmissing IOP measurement when only 1 was available.

IOP changed approximately linearly over time in patients with >2 prone measurements (Figs. 1 and 2); a random slope and intercept model was therefore used to assess IOP change over time during the prone position. The estimated average slope was 2.2 (95% CI, 1.5–2.9) mm Hg per hour, indicating an average of 2.2 mm Hg increase in

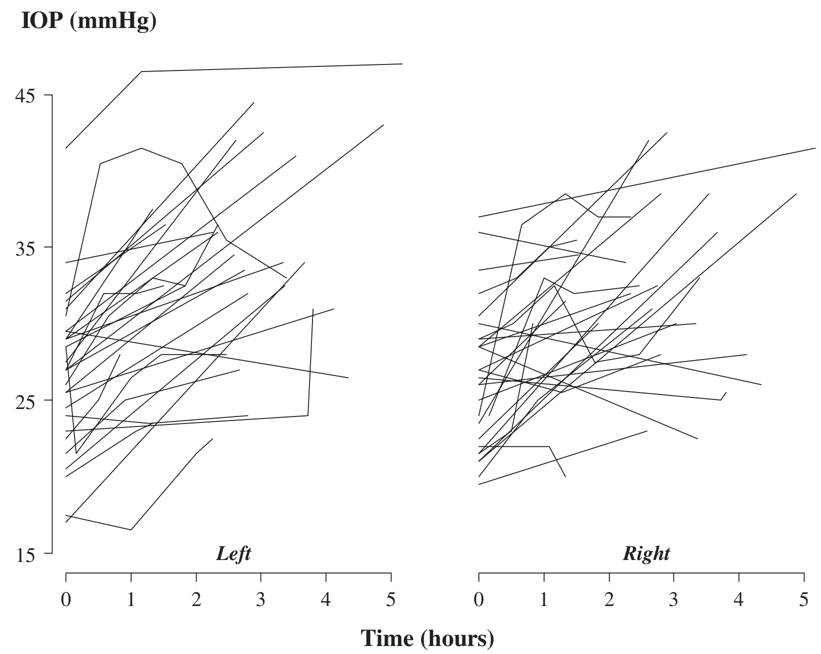

Figure 1. Left and right eye intraocular pressure (IOP) for 30 pediatric patients undergoing surgery in prone position. Zero on x-axis refers to the first IOP measurement in prone position. Each line represents IOP measurements for each patient.

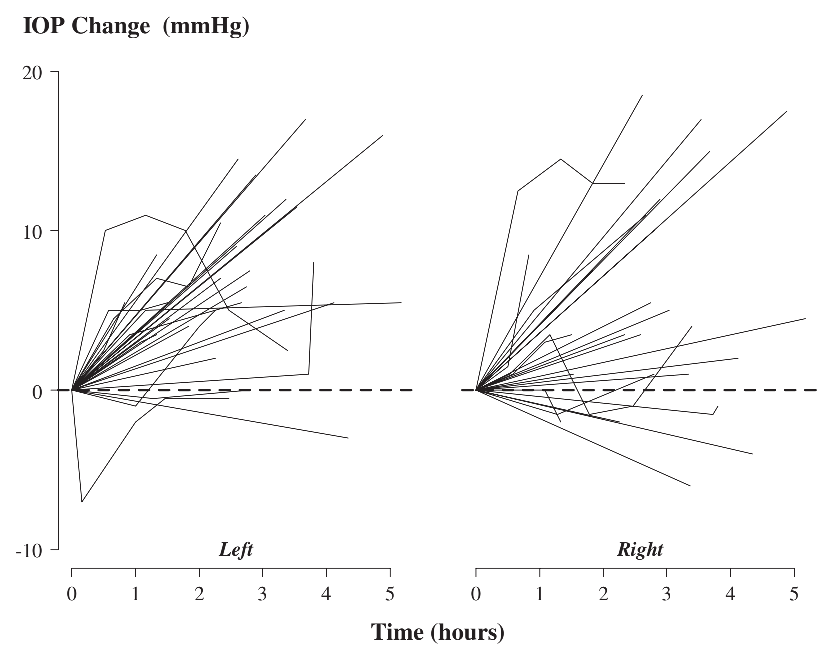

Figure 2. Changes in intraocular pressure (IOP) over time from first prone position (left and right eye) for 30 pediatric patients undergoing surgery in prone position. Zero on x-axis refers to the first IOP measurement in prone position; zero on y-axis (dashed line) refers to no change in IOP. Each line represents changes in IOP for each patient.

IOP per hour in prone position ($P < 0.001$; Fig. 3, middle panel).

Sixty-three percent of patients (95% CI, 46%–81%) had at least 1 IOP value exceeding 30 mm Hg, and 13% (95% CI, 1%–25%) had at least 1 IOP value exceeding 40 mm Hg while prone.

The observed mean (SD) of IOP was 19 (3) mm Hg for the initial measurement in the supine position and 27 (5) mm Hg for the first measurement in the prone position (Fig. 3, left panel). Mean IOP thus increased 7 (95% CI, 6–9) mm Hg during the position change from supine to prone ($P < 0.001$).

The observed mean (SD) of IOP was 32 (6) mm Hg at the last IOP measurement in the prone position and 22 (4) mm Hg in the supine position after changing back from the prone position (Fig. 3, right panel). Mean IOP thus decreased 10 (95% CI, 9–12) mm Hg after changing the position from prone back to supine ($P < 0.001$). One patient did not have IOP measured in supine position after changing back from prone position; thus 29 patients were included in this analysis.

DISCUSSION

Our results indicate that in pediatric patients mean IOP increased 7 (95% CI, 6–9) mm Hg during the position change from supine to prone ($P < 0.001$) and decreased 10 (95% CI, 9–12) mm Hg after changing the position from prone back

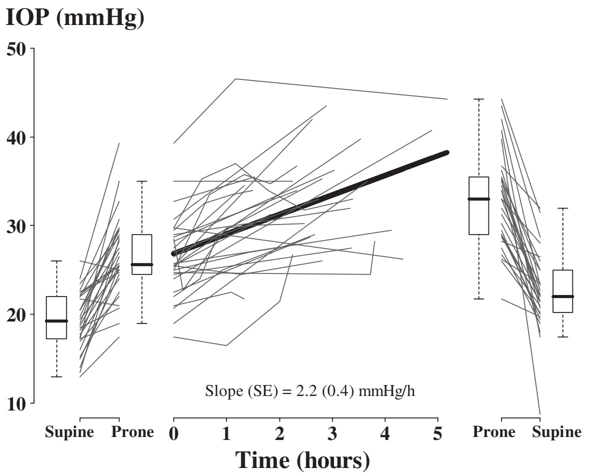

Figure 3. Average (left and right eye) intraocular pressure (IOP) for 30 pediatric patients undergoing surgery in prone position. Left panel: Box plots of IOP in the initial supine position and the first measurement in the prone position, and a plot of individual changes from supine to prone position. Middle panel: Plot of the IOP over time from the first IOP measurement in prone position. Right panel: Box plots of the final IOP measurement in the prone position and IOP in the final supine position, and a plot of individual changes from prone back to supine position. Each line represents changes in IOP for each patient. The middle, upper, and lower edges of the box indicate the 50th, 75th, and 25th percentile of the data. The ends of the vertical lines indicate 1.5 times the interquartile range.

to supine ($P < 0.001$). IOP in prone position increased by an average of 2.2 mm Hg per hour ($P < 0.001$). These results are comparable with those in adults.[4,5]

IOP in children is generally low, reaching adult pressures at about 12 years of age. For example, IOP in a normal pediatric population ranges from a mean (SD) of 8 (3) mm Hg in infants younger than 1 year to 15 (3) mm Hg in children aged 11 to 12 years.[5,22] These values were slightly lower than the 19 (3) mm Hg we observed in our patients while supine after induction of anesthesia. The discrepancy might result from differing approaches to IOP determination because previous measurements were made with conventional tonometry rather than applanation pneumotonometry as in our study. The distinction is important as Eisenberg et al.[23] found that conventional tonometry significantly underestimates IOP in pediatric patients; in contrast, applanation pneumotonometry remained accurate.

Sugata et al.[24] showed that the choice of anesthetic (sevoflurane or propofol) does not have significant effect on IOP changes during short periods of prone surgery; however, changes in body position have a noticeable effect. IOP increased from 19 (3) mm Hg while supine to 27 (5) mm Hg after patients were initially turned prone. IOP then decreased from 32 (6) mm Hg while prone at the end of surgery to 22 (4) mm Hg in the supine position. The effect of changing position was thus similar at the beginning and end of surgery.

As in adults, IOP increased over time in the prone position. However, the slope was only 2.2 (0.4) mm Hg/h. Consequently, mean pressure was 32 (6) mm Hg at the end of procedures lasting 4.3 (1.3) hours. We found that 63% of our pediatric patients (95% CI, 46%–81%) had IOP exceeding 30 mm Hg, and 13% (95% CI, 1%–25%) had IOP exceeding 40 mm Hg while prone. Sustained increases in IOP over time have been reported to have negative effects both in animal and humans studies.[12,13] It is thus plausible that IOPs exceeding 40 mm Hg in our patients could have put them at risk of visual loss.

Blood flow to the optic nerve head is regulated and thus remains relatively constant despite changes in IOP.[20] The IOP at which autoregulation fails in pediatric patients is unknown, but in adult volunteers IOP remained nearly constant until ocular pressures reached 40 mm Hg.[25] Even if 40 mm Hg were the safe threshold in pediatric patients, 13% of our patients exceed this pressure. However, it is conceivable that blood flow in the optic nerve is lower in infants and approaches adult values in older children. It is thus concerning that IOP exceeded 30 mm Hg in more than half of the patients we evaluated during prone surgery.

Grant et al.[21] evaluated the anatomy of the posterior optic nerve in volunteers laying supine or prone for 5 hours by using ultrasound imaging. In the prone position only, there was a thickening of the choroid layer which progressed over time, along with an increase in optic nerve diameter. These results support the hypothesis that time-dependent increases in IOP result at least partially from orbital venous congestion and its effect on episcleral venous congestion.

That being said, the clinical implications of increased IOP remain poorly understood. Thus, while pressures exceeding 40 mm Hg are certainly concerning, it is unknown whether relatively brief periods (i.e., hours) at such pressures actually provoke visual loss. Ocular perfusion pressure, by definition, depends on mean arterial blood pressure, but blood pressure is often low during surgery which presumably aggravates risk. We also note that it is difficult to accurately assess visual ability in infants and children and that much postoperative visual loss may never be detected clinically or even in studies. Finally, IOP, and changes in IOP during surgery, varied considerably from patient to patient. A consequence is that the average values we report poorly predict individual pressures; a corollary is that without individual IOP measurements, it will be difficult to predict a given patient's pressure at any particular time.

Reported differences in IOP among studies may result from various methods used to position patients' heads and from various methods for measuring IOP. The head was supported by scalp pins in all our patients; consequently, there was no direct pressure on the eyes at any time.

Our study was far too small to establish a cause and effect relation between IOP changes and visual loss, and that was never among our goals. Instead, we sought to determine time-dependent changes in IOP in children undergoing surgery in prone position. Due to technical difficulties with IOP assessment during prone position, we measured IOP only before and after surgery in most patients. We were thus unable to fully characterize the shape of the IOP curve over time and have assumed based on limited data that it is approximately linear. The mean duration of surgery was 4.3 (1.3) hours. We do not know whether IOP would continue to increase during longer operations, or if it would reach a plateau.

In summary, changing from supine to the prone position significantly increases IOP in anesthetized pediatric patients. Moreover, IOP progressively increased during surgery and often reached potential harmful values.

DISCLOSURES

Name: Peter Szmuk, MD.
Contribution: This author helped design and conduct the study and write the manuscript.
Attestation: Peter Szmuk has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.
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Attestation: Daniel I. Sessler has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.
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