Effects of Prone and Reverse Trendelenburg Positioning on Ocular Parameters

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ABSTRACT

Background: In a pilot study of awake volunteers, intraocular pressure (IOP), choroid layer thickness, and optic nerve diameter were shown to increase in the prone position over 5 h with a nonsignificant trend of attenuation using a 4-degree increase of table inclination. These effects have previously not been isolated from anesthetic and fluid administration over a prolonged period, using an adequate sample size.

Methods: After institutional review board approval, 10 healthy volunteers underwent IOP measurement (Tono-Pen XL, Medtronic Solan, Jacksonville, FL) as well as choroidal thickness and optic nerve diameter assessment (Sonomed B-1000, Sonomed, Inc., Lake Success, NY, or the S System-ABD, Innovative Imaging, Inc., Sacramento, CA) on a Jackson table (Orthopedic Systems, Inc., Union City, CA), during 5 h horizontal prone and 5 h 4-degree reverse Trendelenburg positioning. Measurements were assessed as initial supine, initial prone, and hourly thereafter. Vital signs were recorded at each position and time point.

Results: IOP, choroidal thickness, and optic nerve diameter were observed to increase with time in the prone position. A small degree of reverse Trendelenburg attenuated the increase in choroidal thickness but not IOP or optic nerve diameter.

Conclusions: Prolonged prone positioning increases IOP, choroid layer thickness, and optic nerve diameter independent of anesthetics and intravenous fluid infusion and 4 degrees of table inclination (15 cm of head to foot vertical disparity) may not attenuate these effects.

What We Already Know about This Topic

❖ Prone position and long duration of surgery may predispose patients to ischemic optic neuropathy and visual loss
❖ Intraocular pressure increases with prone positioning

What This Article Tells Us That Is New

❖ In healthy volunteers, intraocular pressure and choroid/optic nerve width increase progressively over 5 h in the prone position
❖ Elevating the head of the bed 4° minimally affects these variables, suggesting that such positioning may not protect against ischemic optic neuropathy

PERIOPERATIVE visual loss is a devastating event occasionally associated with nonocular surgery. In a review of 60,965 anesthesia cases, it occurred at an incidence of approximately 1 of 61,000 in nonocular surgical procedures.1 After prone spine surgery, the estimates of permanent deficits are as high as 1 of 1,100.2 In the spine surgery cases, the majority are attributed to ischemic optic neuropathy (ION) with posterior ischemic optic neuropathy (PION) predominating over anterior ischemic optic neuropathy (AION).3 Multiple risk factors are reported to be associated with the perioperative development of ION, but two predominant factors are the prone position and duration of surgery.4

The anterior or intracranial portion of the optic nerve (also referred to as the optic nerve head) includes the optic disc and the portion of the nerve within the scleral canal. The circulation of the optic nerve head is derived from the oph-
thamic artery, through the central retinal artery and the posterior ciliary arteries. The latter provides the majority of the blood supply through the short posterior ciliary arteries whereas the retinal arterioles provide partial perfusion of the superficial disc. Anastomoses of posterior ciliary artery branches form the circle of Zinn-Haller, which contributes significant perfusion to the optic nerve head. There are also some additional contributions from choroidal arterioles and recurrent pial arterioles. This blood supply has significant individual variation, and a variety of factors, including the existence of watershed areas between the areas of distribution of the short posterior ciliary arteries, may lead to ischemia in susceptible individuals.

The choroid layer is the vascular layer of the eye sandwiched between the retina and sclera. One set of branches of the posterior ciliary arteries forms the choriocapillaris and provides the major perfusion of the choroid.

Ocular perfusion pressure of the anterior optic nerve is commonly estimated as the difference between the mean arterial pressure (MAP) and intraocular pressure (IOP). Cheng et al. first showed that IOP increased compared with supine awake values in patients undergoing spine surgery during general anesthesia in the prone position, and this was broadly confirmed by an additional patient study performed by Hunt et al. No significant correlation, however, has been shown between IOP and an infarction of the anterior optic nerve as manifested by the onset of either spontaneous AION or perioperative AION.

In both prone studies, it was postulated that the increase in IOP was due to an increase in episcleral venous pressure, but there was no clear correlation to fluid administration. Lam and Douthwaite state that the episcleral venous pressure should be the same in the supine and prone postures and that other factors may be responsible for the increase in IOP. Postulating venous engorgement as a significant factor in the increase in IOP in the prone position, however, two authors conducted positional studies and showed that using 10 degrees of reverse Trendelenburg (RT) attenuated the increase in IOP, and recommendations for these elevations were implied.

The majority of spine surgeons use a one-piece, radiolucent table, which does not allow for segmental elevation, to perform major lumbar surgeries requiring instrumentation and fusion. A 10-degree elevation in a one-piece table is equivalent to 37-cm head versus foot height, which theoretically may cause increased venous pooling at the lumbar surgical site. One preliminary study on awake volunteers showed that an increase in table inclination of only 4 degrees (15 cm) would attenuate the increase in IOP over 1 h whereas a pilot study on two awake volunteers over 5 h showed a trend but not a significant difference. With the exception of the pilot study, no volunteer study in the prone position, evaluating this degree of head elevation and eliminating the effects of anesthetics and fluid administration, has been conducted beyond 1 h. The thickness of the choroid layer also increased significantly over time but not significantly with table position. The increase in the size of this vascular layer may provide further evidence of the increase in vascular congestion of the globe because of pooling in the dependent position for a prolonged period and may lead to an increase in episcleral venous pressure.

The posterior optic nerve is the portion of the nerve that lies in the orbit behind the globe and is perfused by the pial circulation. The branches of the opthalmic artery either directly perfuse the pia or indirectly perfuse it through recurrent branches of the short posterior ciliary arteries or a branch of the central retinal artery. Anatomic variations can result in either a decrease or absence of anastomoses in this circulation, creating end arteries leading to a watershed zone. One of the factors proposed as contributing to PION is increased orbital venous pressure and in combination with a blood supply with fewer anastomoses may lead to a significant decrease in perfusion and increased susceptibility to ischemia. In the previously mentioned pilot study, ultrasound imaging also showed a significant increase in the diameter of the posterior optic nerve over 5 h in the prone position in two awake volunteers.

Therefore, the purpose of this study was to evaluate the effect of the prone position and a 4-degree increase in table inclination over a 5-h period on IOP as well as ultrasound imaging of the choroid layer and optic nerve diameter in a larger sample size of awake volunteers. The expected findings of this study were as follows: first, that all three parameters would increase with time in the prone position and that, second, the suggestion of the attenuation of the effects of a mild RT table inclination would become significant.

Materials and Methods

After approval by the office of the institutional review board (University of Medicine and Dentistry of New Jersey [UMDNJ]-Newark Campus, Newark, NJ) for human studies, informed consent was obtained from 10 volunteers (American Society of Anesthesiologists physical status I–II), aged 23–60 yr. Exclusion criteria included allergy to propofol, prilocaine or tropicamide, preexisting eye disease or eye surgery, and the inability to lie prone for 5 h. Baseline supine measurements (heart rate, blood pressure, IOP, choroidal thickness [CT], and optic nerve diameter) were recorded with the volunteer lying on a stretcher. Corresponding baseline and hourly prone measurements were recorded from beneath a Jackson table (Orthopedic Systems, Inc., Union City, CA) with spine frame by using the Dupaco Proneview™ helmet system (Dupaco, Oceanside, CA) with our previously described modified head frame in the horizontal table (HT) inclination. Two volunteers were studied per session. Iden-
tactical measures were repeated on each pair of volunteers at a separate session with the table in a 4-degree RT inclination. The HT inclination indicates that the head of the Jackson table was the same distance from the floor as the foot. In the RT inclination, the head was 15 cm higher than the foot of the table. This measurement technique has also been previously described. An additional set of measurements was added to the protocol in the final eight volunteers. In these subjects, each prone session was followed by a rest period of 30 min in the supine position with the head of the stretcher elevated 30 degrees (post 30) to evaluate any additional changes that may occur in a clinically relevant position routinely used in a postoperative recovery room setting.

Blood pressure measurements were taken using a disposable blood pressure cuff recorded on a Philips MP70 monitor (Boeblingen, Germany) or Propaq monitor (Welch Allyn, Beaverton, OR). Heart rate was measured using the Masimo (Irvine, CA) oxygen saturation probe recorded on either of the above described monitors.

The IOP measurements were performed using the handheld Tono-pen XL® applanation tonometer (Medtronic Solan, Jacksonville, FL) with latex tip cover after installation of local anesthetic and insertion of a soft contact lens in the right eye in the baseline supine and subsequent positions. Contact lens use was selected to prevent corneal abrasions in subjects undergoing repeated measures of IOP. The validity of measuring IOP by a soft contact lens has been well documented. The tonometer averages four successful blood pressure cuff recordings on a Philips MP70 monitor (Boeblingen, Germany) or Propaq monitor (Welch Allyn, Beaverton, OR). Heart rate was measured using the Masimo (Irvine, CA) oxygen saturation probe recorded on either of the above described monitors.

Ultrasound imaging of the left eye was performed with standard ultrasound gel through a closed eyelid by using the Sonomed B-1000 (Sonomed, Inc., Lake Success, NY). The I3 System-ABD ultrasound with B-scan probe (Innovative Imaging, Inc., Sacramento, CA) was substituted in the latter half of the studies after the Sonomed B-1000 probe was damaged. Transcutaneous B-scan provides the advantage of obtaining safe images through a closed eyelid, eliminating the risk of corneal abrasion. Frozen images of the choroid at the macula, and the optic nerve approximately 3 mm posterior to the lamina cribrosa, were used for the measurement of the thickness of the choroid layer and retrobulbar optic nerve diameter, respectively. The macula is located by an experienced ultrasonographer by first locating the optic nerve and rotating the probe slightly temporally. The thickness of the choroid layer is then measured from the inner gray surface to outer gray surface (fig. 1A). For the optic nerve measurement, the 3-mm marker was placed by the ultrasonographer in real time (fig. 1B). Studies have shown that the sheath is widest at 3 mm behind the globe and varies along the length of the nerve as it travels posteriorly. All measurements were performed by the same ophthalmic ultrasonographer with over 9 yr of ultrasound experience (approximately 2,000 B-scans per year). Identical table positions were used for ultrasound imaging and IOP measurements in eight of the volunteers, but only three prone positions were used in the first two volunteers (prone 0, prone 2.5, and prone 5). After observing significant changes in the choroid thickness and optic nerve diameter between prone 0 and prone 5 in the first two volunteers, we performed additional ultrasound measurements including baseline supine at all the time points at both table inclinations for the remaining eight volunteers. No baselines had been obtained for the
first two volunteers, and thus, the ultrasound data were compared with baseline supine for only the last eight volunteers. Intraobserver reproducibility was established during a separate session by the ophthalmic ultrasonographer. Choroid layer thickness and optic nerve diameter were measured alternately between two volunteers in the supine position over a 45-min period for a total of 10 measurements of each parameter in each volunteer. Measurements were displayed on the screen and recorded by a separate investigator.

Visual acuity was measured at the beginning and conclusion of each study with a near card and appropriate visual correction.

Statistical Analysis
MAP, IOP, choroid thickness, and optic nerve diameter were calculated as percentage of baseline (supine), and the effects of time and table position from prone 0 through prone 5 were evaluated using ANOVA. ANOVA, post hoc analysis, was used to compare data at post 0 and post 30 with baseline. Data are reported as mean ± SD and analyzed using the SPSS system (SPSS, Inc., Chicago, IL); P < 0.05 was considered significant.

Results

Demographic
Five men and five women, ages ranging between 23 and 60 yr, heights ranging from 155 to 198 cm, weights ranging from 56 to 147 kg, and body mass indices from 21.3 to 37.6 kg/m² were studied for five continuous hours in the prone position. No volunteer had a history of hypertension, diabetes, or anemia. Only one volunteer was taking chronic medications (prednisone and azulfidine) for rheumatoid arthritis. The height of the volunteer with a body mass index of 37.6 was 198.1 cm. Because of his height, his weight was well distributed, and he did not exhibit the body habitus of obesity. The values of the ocular measurements for this volunteer were not different from that of his paired volunteer with a body mass index of 23.8.

Vital Signs
Mean heart rates ranged from 68 to 75 beats/min in the HT inclination and 67–75 beats/min in the RT inclination. There were no significant differences from baseline at any of the time points or any differences between table inclinations for heart rate.

Supine values for MAP were 82 ± 12 SD mmHg in the HT inclination and 83 ± 12 SD mmHg in the RT. Figure 2 is a graphical representation of MAP as a percentage of baseline and illustrates the upward trend over time in the prone position. Using ANOVA, there was no significant change with prone time or effect of table inclination on MAP.

Ocular Measures
Intraocular Pressure. Supine values for IOP were 16 ± 3 SD mmHg in the HT and 17 ± 4 SD mmHg in the RT. Figure 3 is a graphical representation of IOP as a percentage of baseline supine. There was a significant effect of time on the increase in IOP in the prone position (ANOVA, P < 0.05), and the increase in IOP was greater in RT than in HT
(P < 0.01). IOP returned to baseline (i.e., no difference from baseline) at post 30 at both the RT and HT sessions.

**Intraocular CT.** Supine values for CT were 1.3 ± 0.3 SD mm in the HT and 1.6 ± 0.3 SD mm in the RT. Figure 4 is a graphical representation of CT as a percentage of baseline supine. There was a significant effect of time on the increase in CT (ANOVA, P < 0.001), and the increase in CT was greater in the HT than RT (P < 0.05). CT decreased but did not reach baseline at post 30 (i.e., statistically different from baseline) at either session.

**Retrobulbar Optic Nerve Diameter.** Supine values for optic nerve diameter (OND) were 5.5 ± 1.1 SD mm and 6.2 ± 1.2 SD mm in the RT. Figure 5 is a graphical representation of OND as percentage of baseline supine. There was a significant effect of time on the increase in OND in the prone position (ANOVA, P < 0.001), but there was no difference between the HT and RT positions. OND decreased but did not reach baseline at post 30 (i.e., statistically different from baseline) at either session.

**Intraobserver Reproducibility.** CT and OND values were 1.6 ± 0.1 SD mm and 5.5 ± 0.1 SD mm, respectively, in volunteer 1 and 1.6 ± 0.0 SD mm and 6.1 ± 0.1 SD mm in volunteer 2 during a third supine measurement session.

**Visual Acuity.** There were no changes recorded in visual acuity in any of the subjects after either session compared with the baseline obtained before any measurements.

**Discussion**

The current study is the first to measure IOP and ultrasound imaging in volunteers for 5 h in the prone position and the first to compare these prone measurements in the HT inclination with a 4-degree RT inclination, which is applicable to lumbar spine surgery. Of particular note is that this is the first study that evaluates the anatomy of the posterior optic nerve in the prone position using ultrasonography.

The results show a clear increase in IOP, choroid layer thickness, and optic nerve diameter in the prone position compared with the supine position, which increases further with time over 5 h. Although the changes in MAP showed an upward trend, these changes were not significant. It is interesting to note that the graphs for all four parameters describe a similar pattern with a change in the rate of increase and a peak. The peak occurs at prone 5 for all the parameters except IOP in the HT position. This similarity in pattern of ocular parameters supports the hypothesis that at least part of the increase in IOP could be related to orbital venous congestion and its effect on episcleral venous congestion. There was a trend to return to baseline in all the parameters after 30 min in head of stretcher elevation of 30 degrees with significance achieved in both table positions for IOP (i.e., no difference from baseline).

This study confirms the increase in IOP that has been shown to occur in the prone position\(^9,^{10,15}\) but demonstrated more of an unanticipated increase with time by using a small elevation in table inclination. The choroid layer thickness showed an improvement with the mild RT inclination, and there was no effect on optic nerve diameter. Thus, we were unable to show an attenuation of IOP with a 4-degree (15 cm) RT table inclination as was shown for an immediate
change in table inclination in two previous studies for a 10-degree elevation\textsuperscript{15,16} and over 1 h at a 4-degree elevation.\textsuperscript{18} However, in the second patient study,\textsuperscript{16} this immediate attenuation could not be translated into differences when either horizontal or RT (10 degrees) were used for the duration of the surgery. Thus, if a difference could not be shown over time for a 10-degree elevation, it is likely that a 4-degree elevation is too small to show consistent comparative improvement in these parameters over a prolonged period. The attenuation of the increase in the choroid layer may indicate that there are less transient factors besides an increase in episcleral venous pressure contributing to the rise in IOP in the prone position as suggested by Lam and Douthwaite.\textsuperscript{14} In one study, the authors showed no immediate change in optic nerve diameter comparing supine, Trendelenburg (30 degrees), and RT (30 degrees) positions in healthy adults during 1-min position changes using ultrasound.\textsuperscript{26} However, to our knowledge, no one has previously studied the effects of the prone position or prolonged positional changes on optic nerve diameter.

The cause of ION is unclear, but hypoperfusion of the optic nerve has been associated with multiple risk factors, including obesity, hypertension, diabetes, low preoperative hematocrit, operation of long duration, large blood loss, prone position, hypotension, and blood replacement strategies, which increase the tissue fluid compartment while decreasing the hematocrit.\textsuperscript{3,4,8} Each of these factors seems to contribute to an upstream decrease in perfusion or a downstream increase in resistance to perfusion of the optic nerve.

Much attention has been given to the concept of ocular perfusion pressure estimated by the difference between MAP and IOP.\textsuperscript{6–8} However, this concept estimates the perfusion pressure of the intraocular nerve head,\textsuperscript{7} and IOP has no effect on the intraorbital optic nerve.\textsuperscript{13} In addition, Hayreh et al.\textsuperscript{11} found an association between hypotension and spontaneous AION on awakening but no association with elevated IOP. The reports describing cases of perioperative ION, specifically PION, have shown normal IOPs on postoperative examination.\textsuperscript{27} However, as we have shown in this study, IOP approaches baseline very quickly after return to the supine position, and thus an increased IOP intraoperatively may not be detected postoperatively. However, no significant association has been shown, and elevated IOP is considered an unlikely cause of perioperative AION and most certainly not the cause of PION.\textsuperscript{13} However, it may still be an important marker for venous congestion affecting the orbit because some of the same factors that affect IOP may increase intraorbital venous pressure.

Gerling et al. compared the diameters of the retrobulbar (intraorbital) optic nerve by using ultrasonography in patients with optic neuritis and unilateral AION. The diameters of the optic nerve in patients with optic neuritis with and without disc swelling were significantly larger than in patients with unilateral AION. There was no difference be-
tween eyes in the patients with AION, and the numbers were not different from normal controls. In AION, the disease process occurs in the laminar or intraocular optic nerve, whereas optic neuritis can occur anywhere along the course of the nerve. Thus, in AION, one would not expect to see an increase in the retrobulbar optic nerve diameter. In our study, we believe that we are measuring the retrobulbar optic nerve sheath complex rather than the isolated optic nerve and that either a dependent increase in subarachnoid fluid or venous congestion is causing the increase in prone diameters. We do not believe that intrinsic nerve swelling is occurring as described for optic neuritis.

ION results from an infarction of the optic nerve and PION specifically from an infarction of the intraorbital optic nerve. An arterial infarction occurs as a result of decreased oxygen delivery, which can occur in one of three ways: a decrease in arterial perfusion pressure, an increase in resistance to blood flow, or a decrease in blood oxygen-carrying capacity. Increased orbital venous pressure can lead to a decrease in arterial perfusion pressure and may be involved in the pathogenesis of PION. In addition, venous congestion may cause secondary constriction of small arterioles through the venoarteriolar response, leading to a venous infarct, an evolving concept in the pathogenesis of ischemic optic neuropathies.

The prone position may contribute to increased orbital venous pressure or venous congestion or both, although this has not been easily quantified. A recent case report documents reversible enlargement of superior ophthalmic veins in a case of bilateral perioperative PION after prolonged spine surgery in the prone position. Significant enlargement of these veins was documented 19 h after surgery by magnetic resonance imaging and was normalized at 5 months. This case lends credence to the hypothesis that an increase in orbital venous pressure may be associated with the development of PION. Our findings of an increase in optic nerve diameter in the prone position over time may be suggestive of an increase in orbital venous congestion and associated pressure.

**Study Limitations**

Using awake volunteers does not provide surgical controls, but isolating the effects of the prone position without surgery, anesthesia, or fluids provides valuable information regarding the ocular effects over time. It is remarkable that the diameters of the optic nerve and the thickness of the choroid layer increase markedly without a fluid infusion. This leads to an interesting debate as to whether limiting crystalloid infusion has a significant impact on a process that occurs from the position alone.

Our baseline supine measurements for optic nerve diameter were higher than those published in other studies, and baselines were different for the two study sessions (5.5 and 6.2 mm, respectively). In the study by Ger-
ling et al., the diameters of the optic nerve of their controls were also significantly different compared with those found in other studies. The authors suggested that technical details including exact probe placement requirement that each laboratory establish its own norms. In addition, we corrected for these differences by comparing percentages of baseline. We do not attempt to establish normal reference values with our findings, but we do suggest that ultrasonography may show an upward trend in the prone position with time compared with baseline. In addition, we believe that the low standard deviations accomplished during the repeated supine measurements on two additional volunteers established reasonable intraobserver reproducibility.

The majority of cases of ION after spine surgery as reported in the American Society of Anesthesiologists Postoperative Visual Loss Registry was associated with an anesthetic duration greater than 6 h. We used 5 h as our maximum time in the prone position as a compromise for subject comfort. Our volunteers began to complain of chest discomfort and symptoms of facial and sinus congestion during the last hour. Symptoms were short lived, and none lasted greater than 24 h in any subject.

Summary

In summary, we have shown a marked increase in ocular parameters, which are presumed to be signs of vascular congestion including IOP and CT as well as optic nerve diameter over a 5-h period in the prone position. Table elevation of 4 degrees provided a significant attenuation of the increase in only one of the parameters. We also showed a significant return to baseline in one of the parameters with a slower trend in the other two after a 30-degree supine head elevation, which may have some significance for postoperative stretcher position. Although the ultrasound findings are unique and remarkable, they do not allow us to predict what measurement thresholds would herald optic nerve ischemia in a given individual. They do, however, provide an additional piece of the puzzle and a beginning framework to noninvasively evaluate the ocular system of patients undergoing prolonged prone surgery.

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**ANESTHESIOLOGY REFLECTIONS**

**Hales’ 1733 Haemastaticks**

In 1733 the Reverend Stephen Hales (1677–1761) recorded in his *Haemastaticks* volume of *Statical Essays* how, years earlier, he had conducted the first direct measurement of arterial blood pressure. The English physiologist and clergyman wrote, “I caused a mare to be tied down alive on her back; she was . . . neither very lean, nor yet lusty. Having laid open the left crural Artery about three inches from her belly, I inserted into it a brass Pipe, whose bore was one-sixth of an inch in diameter; and to that, by means of another brass Pipe which was fitly adapted to it, I fixed a glass Tube, of nearly the same diameter, which was nine feet in Length. Then untying the Ligature on the Artery, the blood rose in the Tube eight feet three inches perpendicular above the level of the left Ventricle of the Heart.” (Copyright © the American Society of Anesthesiologists, Inc. This image appears in color in the *Anesthesiology Reflections* online collection available at www.anesthesiology.org.)

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