Coronal Axis Measurement of the Optic Nerve Sheath Diameter Using a Linear Transducer

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Objectives—The true optic nerve sheath diameter cutoff value for detecting elevated intracranial pressure is variable. The variability may stem from the technique used to acquire sonographic measurements of the optic nerve sheath diameter as well as sonographic artifacts inherent to the technique. The purpose of this study was to compare the traditional visual axis technique to an infraorbital coronal axis technique for assessing the optic nerve sheath diameter using a high-frequency linear array transducer.

Methods—We conducted a cross-sectional study at an academic medical center. Timed optic nerve sheath diameter measurements were obtained on both eyes of healthy adult volunteers with a 10–5-MHz broadband linear array transducer using both traditional visual axis and coronal axis techniques. Optic nerve sheath diameter measurements were obtained by 2 sonologists who graded the difficulty of each technique and were blinded to each other’s measurements for each participant.

Results—A total of 42 volunteers were enrolled, yielding 84 optic nerve sheath diameter measurements. There were no significant differences in the measurements between the techniques on either eye (P = .23 [right]; P = .99 [left]). Additionally, there was no difference in the degree of difficulty obtaining the measurements between the techniques (P = .16). There was a statistically significant difference in the time required to obtain the measurements between the traditional and coronal techniques (P < .05).

Conclusions—Infraorbital coronal axis measurements are similar to measurements obtained in the traditional visual axis. The infraorbital coronal axis technique is slightly faster to perform and is not technically challenging.

Key Words—emergency ultrasound; measurement; ocular ultrasound; optic nerve; optic nerve sheath diameter; point-of-care ultrasound
Published cutoff values for detection of elevated intracranial pressure range from 4.0 to 4.5 mm in children and 5.0 to 5.9 mm in adults.\textsuperscript{14–16} In addition, test characteristics of these cutoff values are variable, with sensitivity ranging from 61\% to 90\% and specificity ranging from 22\% to 100\%.\textsuperscript{6,14–16} It is possible that the variability of sonographic optic nerve sheath diameter measurements stems from the traditional visual axis approach used to acquire them. The visual axis approach has been questioned to falsely increase measurements secondary to shadowing from the lamina cribrosa.\textsuperscript{17} Numerous scanning techniques have been described in the literature. An axial approach is obtained when the transducer is centered on the cornea and ultrasound beams are directed through the lens and toward the optic nerve. A longitudinal approach is obtained when the transducer is placed temporal to the cornea and ultrasound beams are directed toward the optic nerve, thereby avoiding the cornea and lens. Last, the vertical transverse approach is obtained when the transducer is placed temporal to the cornea and the ultrasound beams are directed medial and posterior to create a coronal cross section of the optic nerve or obtain relative perpendicularity to the optic nerve.\textsuperscript{18}

Studies have been performed to evaluate alternative imaging techniques to decrease imaging artifacts and improve accuracy. Hall et al\textsuperscript{11} evaluated anterior transbulbar and lateral transbulbar approaches to optic nerve sheath diameter imaging in patients with ventriculoperitoneal shunts. That study revealed a poor correlation between optic nerve sheath diameter measurements and ventriculoperitoneal shunt failure and demonstrated no difference between the two imaging techniques. Another study suggested that a coronal axis approach with an intracavitary transducer can provide a more accurate optic nerve sheath diameter measurement because it may overcome the shadowing artifact that may result from papilledema.\textsuperscript{19} This approach to coronal axis imaging is cumbersome because it is challenging to place the intracavitary transducer in the lateral canthus and maneuver the transducer to obtain optimal images. Furthermore, the reliability of the coronal axis technique has not been extensively investigated. Establishing a universal optic nerve sheath diameter cutoff value for elevated intracranial pressure may require additional research in alternative approaches to measurement.

In this study, we evaluated an infraorbital approach to coronal axis measurements of the optic nerve sheath diameter using a linear array transducer. The purpose of this study was to compare the traditional visual axis technique to an infraorbital coronal axis technique using a high-frequency linear array transducer. We hypothesized that there would be no difference between optic nerve sheath diameter measurements obtained in visual and coronal axes.

**Materials and Methods**

**Study Design and Setting**

This cross-sectional study was conducted at an academic medical center in the Clinical and Professional Skills Laboratory. This study was reviewed by the Institutional Review Board and arbitrated as not systematic research. Informed consent from participants was not required per our Institutional Review Board. Data were collected from April 2013 to January 2014.

**Study Population**

Participation in this study was voluntary and involved medical student volunteers with no history of optic nerve disease. Recruitment for participation in the investigation was conducted by e-mail invitation.

**Study Protocol**

All sonographic examinations were performed by 2 independent sonologists with fellowship training in emergency ultrasound and prior experience with ocular sonography. The sonologists were blinded to each other in a single session for each participant. The ocular sonographic examinations were performed with a Sparq ultrasound system (Philips Healthcare, Andover, MA) using a 10–5-MHz broadband linear array transducer. The optic nerve sheath diameter measurements were obtained at the bedside, and images were initially saved on the ultrasound system. All images were subsequently transferred from the ultrasound system to a Web-based image archival system (Q-path; Telexy Healthcare, Maple Ridge, British Columbia, Canada). No further review of sonograms was performed.

Ocular imaging was performed on both eyes of each volunteer using both the traditional visual axis technique as well as an infraorbital coronal technique simultaneously. The traditional visual axial technique was performed by placing the transducer anteriorly over the closed eye with the indicator directed nasally and with the volunteer fixed in a primary visual gaze; the ultrasound beams were directed posteriorly to image the optic nerve sheath in the long axis (Figure 1A). The infraorbital coronal axis technique was performed on recumbent volunteers by placing the linear transducer inferior to the closed eye while resting on the maxillary and zygomatic bones. With the volunteer fixed in a primary visual gaze, the indicator was directed nasally, and the ultrasound beams were directed posteriorly and superiorly to obtain a coronal axis image of the optic nerve.
sheath. The images acquired were the widest circular coronal sections of the optic nerve sheath, immediately behind the globe where it is most accurately measured. To bring the posterior aspect of the eye and optic nerve into the scanning plane, the volunteers were asked to lift their chins superiorly and direct their gaze downward (Figure 1C).

The traditional visual axis views were obtained by author L.A.S., and the coronal axis views were obtained by author R.A. simultaneously. Three measurements were taken in each eye using the traditional visual axis technique, and 3 measurements were taken in each eye using the coronal axis technique. In the visual axis view, calipers were used to designate 3 mm posterior to the globe, and measurements were taken from medial to lateral (Figure 1B). In the infraorbital coronal axis view, images acquired were circular coronal sections of the optic nerve sheath immediately behind the globe. These circular coronal sections were measured from the lateral to the medial borders of the optic nerve sheath (Figure 1D). The average of 3 measurements for each technique was used for final analysis. At the completion of the imaging protocol for each volunteer, the sonologists were asked to rate the difficulty of image acquisition on a Likert scale from 1 to 10.

Data Analysis

Data were analyzed with Stata release 12 statistical software (StataCorp LP, College Station, TX). Continuous data were presented as means with standard deviations. An a priori power calculation estimated a need for 32 ocular sonograms to detect a 0.5-mm discrepancy between optic nerve sheath diameter measurements obtained with the two approaches ($\alpha = .05; \beta = .8$). A paired t test was used for comparison of paired samples between techniques. The Bland-Altman graphic approach was used to assess the agreement between the sonographic techniques. The statistical significance was set at $P < .05$. Since multiple measurements were taken for each eye, the reliability of the measurements was evaluated by computing the intraclass correlation coefficient (ICC) for each rater.

Results

A total of 42 volunteers were enrolled, yielding 84 ocular sonograms. The recruited participants were a convenience sample from a population with an average age of 24 years and of whom 52% were male and 48% were female. None of the participants had a history of optic nerve disease.

The optic nerve sheath diameter measurements, time to completion, and degree of difficulty are shown in Table 1. No significant differences were found between the measurements between the techniques on either eye. There was a statistically significant difference between the times required to diameter measurement using the infraorbital coronal axis technique compared to the traditional visual axis technique. There was no difference in the degree of difficulty obtaining the measurements between the traditional visual axial technique and the infraorbital coronal axis technique (Table 2).

**Table 1.** Values for Outcomes Obtained by Traditional Visual Axis and Infraorbital Coronal Axis Techniques ($n = 44$)

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Visual Axis</th>
<th>Coronal Axis</th>
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<tbody>
<tr>
<td>Right optic nerve sheath diameter, mm</td>
<td>4.73 (0.73)</td>
<td>4.55 (0.79)</td>
</tr>
<tr>
<td>Left optic nerve sheath diameter, mm</td>
<td>4.48 (0.62)</td>
<td>4.48 (0.64)</td>
</tr>
<tr>
<td>Time to completion, s</td>
<td>200 (44)</td>
<td>152 (44)</td>
</tr>
<tr>
<td>Technical difficulty</td>
<td>3.38 (1.78)</td>
<td>2.79 (1.97)</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD).
Discrepancies in measurements between the techniques are displayed in the Bland-Altman plots (Figure 2). There was moderate to good reliability of the measurements obtained by the sonologists. The ICCs for the rater who used the traditional visual axis technique were 0.71 for the left eye and 0.72 for the right eye. The ICCs for the rater who used the infraorbital coronal axis technique were 0.76 for the left eye and 0.79 for the right eye.

**Discussion**

Visual axis imaging may create artifacts emanating from the cornea, lens, or lamina cribrosa, which can lead to errors in optic nerve sheath diameter measurements. In addition, papilledema can cause optic disc cupping, which can create an edge artifact and shadowing, resulting in an overestimation of the optic nerve sheath diameter.17,19,22 Our study findings suggest that optic nerve sheath diameter measurements can be obtained by using a coronal technique with the linear transducer that is commonly used in emergency medicine and critical care practice. Coronal axis imaging has been suggested to be the optimal scanning technique; however, few studies have investigated how coronal axis imaging compares to visual axis imaging.3,18 The infraorbital coronal axis imaging approach implemented in this study avoids imaging through the lens or cornea and may eliminate potential artifacts associated with visual axis techniques. It can also avoid overmeasuring optic disc artifacts in patients with papilledema.19 Last, because coronal axis imaging yields circular cross sections, it may decrease the potential for measurement error, as the optic nerve sheath diameter is more clearly delineated.

Few studies have compared imaging techniques for optic nerve sheath diameter measurements. Hall et al11 conducted a study using a linear transducer in which the investigators compared an anterior transbulbar technique to a lateral transbulbar technique and found no significant difference between the techniques. Although our study also did not show statistically significant differences between visual and infraorbital coronal axis techniques, the infraorbital technique, unlike the lateral transbulbar technique, decreases artifacts by avoiding intraocular structures, the optic disc, and the lamina cribrosa. Blehar et al19 evaluated optic nerve sheath diameter measurements using an intracavitary transducer measuring the coronal axis and traditional visual axis in 24 healthy patients, and they found that the coronal axis measurements were on average smaller than the visual axis measurements. Although our results show adequate statistical correlation between the techniques, the small differences in measurements between the techniques could be clinically meaningful.

**Table 2. Comparisons Between Outcomes Obtained by Traditional Visual Axis and Infraorbital Coronal Axis Techniques**

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>P</th>
<th>Bland-Altman Plot Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right optic nerve sheath diameter</td>
<td>.23</td>
<td>Yes</td>
</tr>
<tr>
<td>Left optic nerve sheath diameter</td>
<td>.99</td>
<td>Yes</td>
</tr>
<tr>
<td>Time to completion</td>
<td>&lt;.05</td>
<td>NA</td>
</tr>
<tr>
<td>Technical difficulty</td>
<td>.16</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA indicates not applicable.

Figure 2. Bland-Altman plots showing agreement between visual axis and coronal axis techniques. **A**, Optic nerve sheath diameter (ONSD) measurements from the left eye. **B**, Optic nerve sheath diameter measurements from the right eye.
On average, the coronal axis technique was approximately 1 minute faster per participant than the traditional visual axis technique. This finding may be attributed to the fact that the traditional technique requires first measuring a distance of 3 mm below the retina before measuring the optic nerve sheath diameter. With our coronal axis technique, the optic nerve is visualized with well-defined circular margins at a location nearest the retina. When this step is accomplished, the optic nerve sheath diameter is measured within the range recommended by Hansen and Helmke (2.1–4.8 mm from the globe). As a result, we chose to bypass the need to use calipers twice, which is similar to the technique described by Green and Byrne. Additionally, it may be easier for a sonologist to identify a circular cross-sectional structure (Figure 1D). Although the coronal axis technique is faster, a 1-minute difference may not be meaningful in the clinical setting.

In our study, the sonologists reported that the degree of difficulty between the coronal axis technique and the traditional technique was identical. Although the infraorbital coronal axis technique involves imaging of the eye with angles that can be obstructed by facial bones or deeply set eyes, this factor did not increase the difficulty experienced by the operator. Furthermore, imaging was successfully performed on all 42 volunteers without failed attempts. Unlike the study performed by Blehar et al., in which an intracavitary transducer was used to measure the coronal axis of the optic nerve sheath, it is possible to use a linear transducer to image the optic nerve sheath diameter in the coronal axis. Furthermore, a linear transducer is used more frequently by emergency physicians, is easier to maneuver than the endocavitary transducer, and is readily available.

Although it is intuitive that a coronal measurement of a cylindrical structure would avoid a cylinder tangent effect and would be more accurate, there is no study to date evaluating how it compares to intracranial pressure as measured by lumbar puncture or invasive pressure monitoring. Although our assessment did not show differences between the techniques, our investigation did not include participants with elevated intracranial pressure. It is possible that the infraorbital coronal axis technique is more reproducible and more accurate in pathologic states. The infraorbital approach with a linear transducer may also provide an additional option in situations in which it is technically challenging to obtain optic nerve sheath diameter measurements using the traditional technique or suboptimal visualization of optic nerve with the traditional visual axis technique. In addition, infraorbital coronal axis measurements with a linear transducer may be useful for optic nerve and optic nerve sheath measurements in patients with pseudotumor cerebri, in whom the optic nerve can more easily be differentiated from the optic nerve sheath.

This study had several limitations. It was designed only to assess the correlation between optic nerve sheath diameter values measured between the traditional visual axis technique and the coronal axis technique. There was no reference-standard measurement to determine which technique was more accurate. Additional studies should evaluate the accuracy of the coronal axis technique compared to magnetic resonance imaging, computed tomography, and lumbar puncture opening pressures. Another limitation to this study was that all volunteers were individuals without a history of abnormal optic nerve sheath diameter measurements, which limits the applicability of our findings. Furthermore, each sonographer was assigned to only one imaging technique without crossover, which creates the potential that one author may have overmeasured and one may have underestimated the optic nerve sheath diameter, thereby affecting our results. This factor was not corrected during data analysis. Additionally, an independent reviewer did not analyze images for optimal quality or measurement accuracy. Last, an ICC was calculated, that demonstrated variability within the same rater in each eye.

In conclusion, infraorbital coronal axis optic sheath diameter measurements obtained with a linear transducer are similar to measurements obtained in the traditional visual axis. The infraorbital coronal axis technique is slightly faster to perform and is not technically challenging.

References


