

# A Unique Model for Ultrasound Assessment of Optic Nerve Sheath Diameter

Frederick A. Zeiler, Bertram Unger, Andreas H. Kramer, Andrew W. Kirkpatrick, Lawrence M. Gillman

**ABSTRACT: Background:** Ultrasonic assessment of optic nerve sheath diameter (ONSD) as a non-invasive measure of intracranial pressure (ICP) has been evaluated in the literature as a potential valid technique for rapid ICP estimation in the absence of invasive intracranial monitoring. The technique can be challenging to perform and little literature exists surrounding intra-operator variability. **Objectives:** In this study we describe the creation of a novel model of ONSD to be utilized in ultrasound training of this technique. We demonstrate the realistic ultrasonographic images created utilizing this novel model. **Methods:** We designed ocular models composed of gelatin spheres and variable three dimensional printed cylinders, which simulate the globe of the eye and variable ONSD's respectively. These models were suspended in a gelatin background and ultrasound of the ONSD was conducted using standard techniques described in the literature. **Results:** This model produces clear and accurate representation of ONSD that closely mimics *in vivo* images. It is affordable and easy to produce in large quantities, portending its use in an educational environment. **Conclusions:** Utilizing the standard linear array ultrasound probe for ONSD measurements in our model provided realistic images comparable to *in vivo*. This provides an affordable and exciting means to test intra- and inter- operator variability in a standardized environment. Knowing this, we can further apply this novel model of ONSD to ultrasound teaching and training courses with confidence in its ability and the technique's ability to produce consistent results.

**RÉSUMÉ: Un modèle unique d'évaluation par ultrasonographie du diamètre de la gaine du nerf optique. Contexte :** L'évaluation par ultrasonographie du diamètre de la gaine du nerf optique (DGNO) comme mesure non effractive de la pression intracrânienne (PIC) est considérée selon la littérature comme une technique potentiellement valide d'estimation rapide de la PIC, en l'absence de monitoring intracrânien effractiv. Effectuer la technique peut présenter un défi et il y a peu de publications concernant la variabilité intra-opérateur. **Objectifs :** Nous décrivons un nouveau modèle d'évaluation par ultrasonographie du DGNO que nous avons conçu pour l'enseignement de cette technique. Nous montrons des images ultrasonographiques réalistes créées au moyen de ce nouveau modèle. **Méthode :** Nous avons conçu des modèles oculaires composés de sphères de gélatine et des cylindres imprimés variables à trois dimensions qui simulent respectivement le globe oculaire et différents DGNO. Ces modèles sont suspendus devant une toile de fond de gélatine et l'ultrasonographie du DGNO est ensuite effectuée par la technique standard décrite dans la littérature. **Résultats :** Ce modèle donne une représentation claire et exacte du DGNO qui imite fidèlement les images captées *in vivo*. Il est d'un prix abordable et facile à produire en grande quantité, ce qui laisse présager qu'il sera utilisé pour l'enseignement. **Conclusions :** L'utilisation de la sonde à ultrasons en réseau linéaire pour la mesure du DGNO dans notre modèle a donné des images réaliste, comparables à celles obtenues *in vivo*. C'est donc un moyen abordable et attrayant d'évaluation de la variabilité intra et inter opérateur dans un environnement standardisé. Nous pouvons donc utiliser ce nouveau modèle de DGNO pour l'enseignement et l'entraînement du personnel tout en étant confiant que le modèle et la technique produiront des résultats concordants.

Can J Neurol Sci. 2013; 40: 225-229

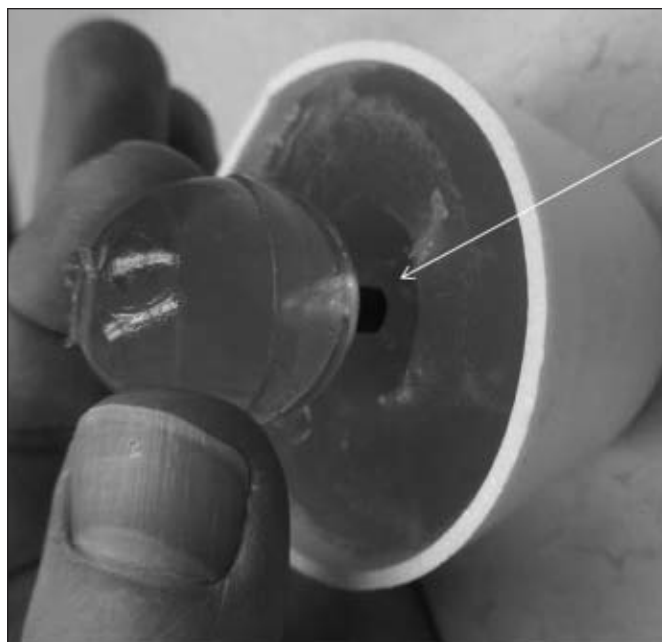
Ultrasound assessment of optic nerve sheath diameter (ONSD) has been proposed as a non-invasive means of intracranial pressure (ICP) determination for over 20 years<sup>1</sup>. More recently, literature is emerging that increasingly confirms its correlation to standard invasive intracranial monitoring in order to better define its role in ICP determination<sup>2-12</sup>. To date, studies have supported the correlation of ONSD to ICP in neurocritically ill patients<sup>4-8</sup>, both adult and pediatric<sup>9</sup>.

Currently, data reflecting normal values for ONSD have been determined from small populations of subjects, both healthy and non-healthy. The majority of normal values are based on non-healthy patients, with intra-cranial pathology, that have normal invasive ICP measurements<sup>6,7,10-12</sup>. Recent meta-analysis

demonstrates normal ONSD ranging from 5.0 to 5.9 mm<sup>2,4,13</sup>, with sensitivity and specificity for intracranial hypertension ranging from 70.8% to 100% and 63% to 100%<sup>13</sup>, respectively.

From the Section of Neurosurgery (FAZ), Section of General Surgery (LMG), Department of Surgery, Section of Critical Care Medicine, Department of Internal Medicine (BU, LMG), Department of Medical Education (BU), University of Manitoba, Winnipeg, Manitoba; Section of General Surgery, Department of Surgery (AWK), Regional Trauma Services (AWK), Critical Care (AHK, AWK), Department of Clinical Neurosciences (AHK), University of Calgary, Calgary, Alberta, Canada.

RECEIVED JULY 19, 2012. FINAL REVISIONS SUBMITTED SEPTEMBER 19, 2012.  
Correspondence to: Frederick A. Zeiler, Section of Neurosurgery, Dept of Surgery, University of Manitoba, GB-1 Health Sciences Center, 820 Sherbrook Street, Winnipeg, Manitoba, R3A 1R9, Canada. Email: umzeiler@cc.umanitoba.ca.



**Figure 1:** Gelatin Globe and 3D Disc Model. Gelatin sphere is formed using a mould. 3D printed discs of 2mm thickness and variable diameters are created and attached to the posterior aspect of the globe with adhesive. Together they form the globe and optic nerve sheath respectively. A Styrofoam cup is used to house the gelatin background that has been carved out to house the globe model.

However, the lack of a standardized ONSD measurement technique leads to confusion within the literature. Furthermore, it is unknown whether ONSD measurements can be reliably correlated to ICP. Inaccurate measurement of ONSD could lead to unnecessary or inappropriate interventions which may have adverse effects (e.g. placement of an ICP monitor, administration of mannitol, sedation, etc.) or (conversely) misplaced reassurance that the ICP is not high when, in fact, it is.

In addition, the technical demands of bedside ultrasound for ONSD determination raises the question of inter/intra-operator variability<sup>14-16</sup> in measurements. To our knowledge there are only two studies that address inter/intra-operator variability with both studies of small volunteer populations (less than 100) and with only two or three operators<sup>14-16</sup>.

The ability of the ultrasound operator and the linear array ultrasound probe to determine ONSD of known dimensions in a standardized environment has not been studied. Heterogeneous patient populations, with varying operator technique and experience are all that exists in the literature so far. A first step in assessing the efficacy of ultrasound for determining ONSD would be to develop a standardized model with known physical parameters. Such a model would ideally provide a validation tool for this technique by creating a reproducible platform of known, independently variable, qualities similar to those of the optic nerve sheath. The use of ONSD on such a standardized ocular and optic nerve sheath model has not been described within the literature to our knowledge. We describe the design and development of such a model and demonstrate that it can be used

to acquire ultrasound images similar to those acquired from *in vivo* sources. Though a model cannot prove the clinical utility of ONSD ultrasound *in vivo*, the model can then be used to assess whether the operator and/or the linear array probe are able to determine the ONSD accurately and reproducibly in a controlled setting.

We describe our novel model of ONSD, its construction, and demonstrate the ultrasound images that can be acquired using such a standardized model.

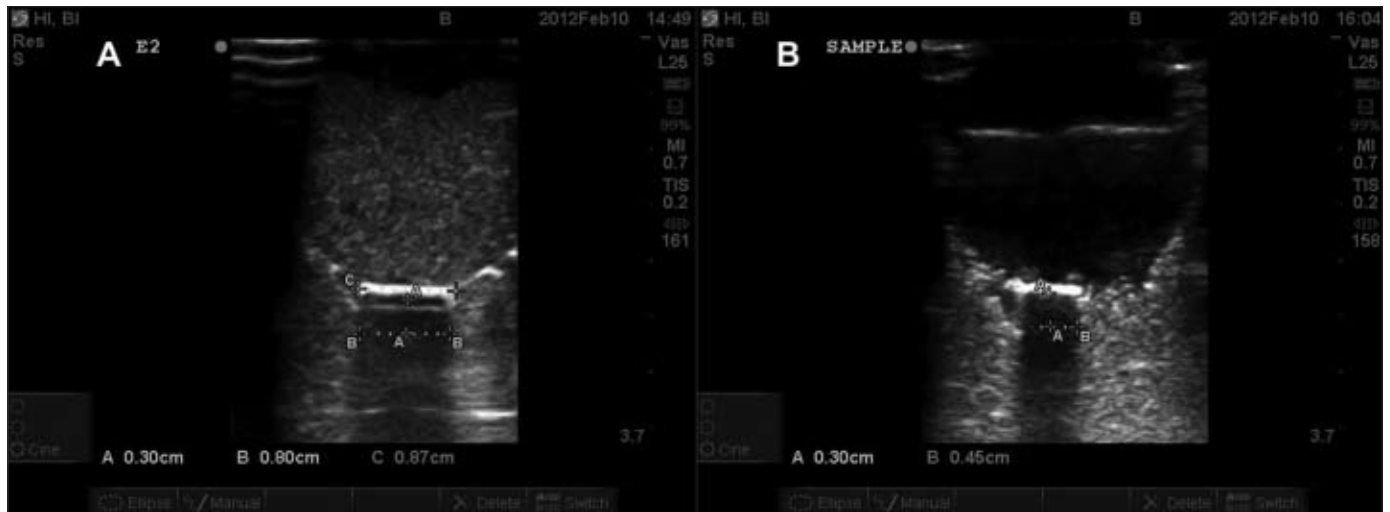
## METHODS

### Model

Ocular models containing an optic nerve sheath phantom were initially produced as two composite and initially separate pieces. First, using a previously described recipe for homemade ultrasound phantoms<sup>17,18</sup>, we combined water, sugar-free



**Figure 2:** Ultrasound Technique with Model Secured in Gelatin Background. The anterior half of the gelatin globe is exposed from the gelatin background in the cup (arrow). It is then coated with ultrasound gel to enhance transmission. The probe is held at an angle perpendicular to the anterior exposed globe surface, directed straight at the 3D printed disc located on the posterior surface of the globe.



**Figure 3:** Ultrasound Images of Large and Small Disc in ONSD Model. A) demonstrates the ultrasound picture of a large 3D printed disc attached to the gelatin globe. B) demonstrates a small 3D printed disc attached to the gelatin globe. Quite distinct acoustic shadows are produced behind the disc, representing the optic nerve sheath. On each image are caliper measurements of the ONSD produced. Of note is measurement “A” on each image is 0.3cm behind the disc (the most common ONSD measurement location described in the literature).

psyllium powder, and unflavored gelatin to create the globe and formed spheres using a 1 inch spherical baking mould (Chicago School of Mold Making, Oak Park, IL) (Figure 1). Second, utilizing a 3D printer (Zprinter 650, 3D Systems, Rock Hill, SC), we produced resin-coated plaster discs of known diameter to represent the optic nerve sheath (Figure 1, arrow). These discs can be printed to the nearest 0.1 mm to an accuracy of 0.089 mm and sizes are confirmed post printing using a digital micrometer. Disc thickness was determined not to be a factor for the ultrasound shadow produced by these discs, thus it was maintained at a constant 2 mm irrespective of the disc diameter. The 3D printed discs were subsequently secured to the posterior aspect of the gelatin spheres using liquid adhesive. After attaching the two phantoms, the composite represented the globe of the eye and the optic nerve sheath respectively (Figure 1).

These models were then placed in a bed of hardened gelatin with a half spherical defect created via sharp dissection (Figure 1, 2). After lining the gelatin bed with a generous amount of ultrasound gel, the ocular models were seated in the gelatin background with the discs pointed into the bed and with the model buried up to its equator having the anterior surface of the globe exposed (Figure 2, arrow). Finally, the anterior surface was coated in ultrasound gel to promote ultrasound conductance.

## RESULTS

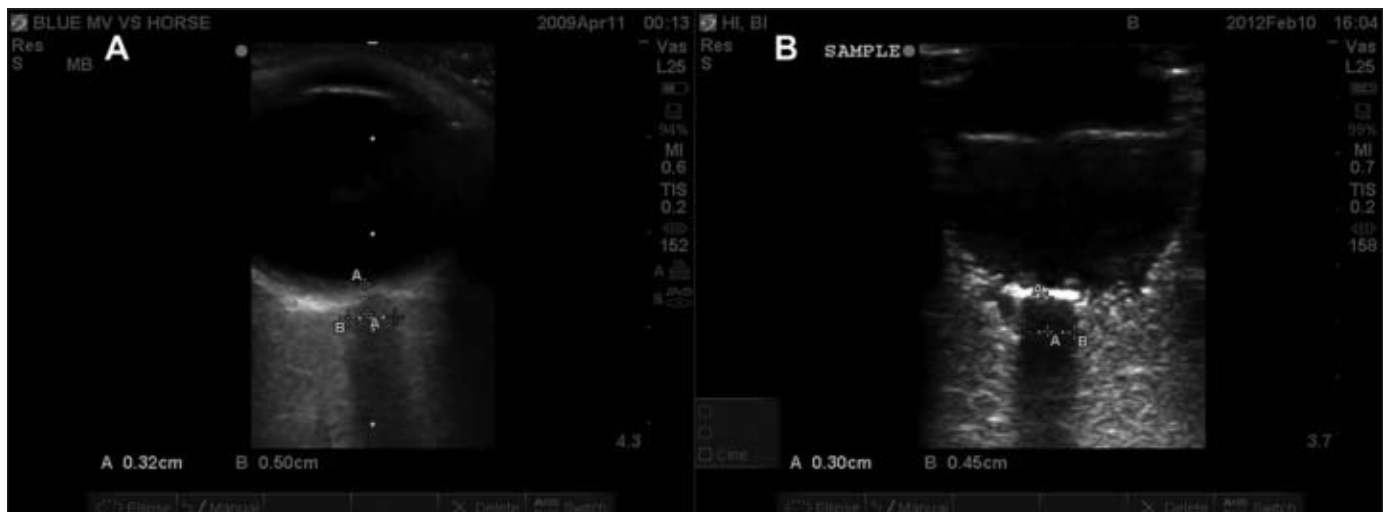
Utilizing a 13.6 MHz linear array ultrasound transducer (L25x transducer, Sonosite Corp, Bothell, WA) and a hand-held ultrasound (Sonosite M-Turbo, SonoSite Inc, Bothell, WA) we measured both large (8 mm) (Figure 3A) and small (3 mm) (Figure 3B) disc ultrasound models to assess the clarity of the images and their likeness to *in vivo* images (Figure 4A). Of note is that the gelatin globe in Figure 3A is made with, while the globe in Figure 3B is made without sugar-free psyllium powder thus changing the acoustic image. Figure 4 demonstrates an *in vivo* ultrasound image acquisition of ONSD.

The exact technique is based on that found in the literature<sup>1-5</sup>. A line perpendicular to the axis of the disc is drawn three millimeters behind the optic disc. At this point, the diameter of the optic nerve sheath is determined. This is demonstrated on both Figure 3A and 3B.

## DISCUSSION

The limitations to using sonography of the optic nerve sheath diameter to routinely and non-invasively provide a determination of the ICP are numerous. Currently, its clinical application is limited due to many unanswered questions. The studies to date are small in number with limited patient sample size. A recent study by Strumwasser et al<sup>3</sup> has also indicated the questionable reliability of ONSD ultrasonography and its accuracy in determining ICP in comparison to standard invasive techniques. Nonetheless, conclusions derived from the literature to date suggest potential promise regarding the use of this technique in the future if concerns regarding its operator-dependent nature can be resolved. The difficulties with this technique for both veteran and novice ultrasound operators in the field makes intra- and inter-operator variability a concern and the reliability of results questionable<sup>14,15</sup>.

Ocular models exist in the literature to represent a variety of disease entities. We utilized pre-existing quick, cheap, and simple techniques to create our model. Rapid-prototyping of the optic disc enables us to precisely reproduce discs of desired diameter. Thus, we are able to mimic a wide variety of normal and pathological ICP states with these discs (as demonstrated in Figure 3A and 3B). The acoustic shadow produced by these models closely mimics *in vivo* images in the literature as may be seen by comparing Figure 3 and 4. The optic nerve sheath shadows are almost identical in appearance when comparing our model to *in vivo* examples. When the psyllium is omitted from the mixture to create the globe, the ultrasonic images more closely mimic the true *in vivo* image. This can be seen by



**Figure 4:** Ultrasound Image of In Vivo Human Eye Compared to Model. A) demonstrates an ultrasound image of a human eye in vivo with measurement of ONSD (measurement B = 0.50 cm). B) demonstrates an ultrasound image of our model with ONSD measurements (B = 0.45 cm).

comparing Figure 4A to Figure 4B. In comparison, including the psyllium (Figure 3A) makes the globe opaque, thus better blinding the operator to the size of the underlying 3D disc.

Our model can potentially be used to train ultrasound operators of all levels. In addition, defining intra- and inter-operator variability with such a model could shed some light on the limitations of the technique in a controlled setting. Previous studies<sup>14,15</sup> of intra- and inter-operator variability were done in human subjects with unknown ONSD, making it impossible to know the correct ONSD measurement. Our model allows for the creation of ONSD of known sizes to the nearest 0.1 mm, allowing for accurate and reproducible assessment of intra- and inter-operator variability and, ultimately, for training and credentialing.

These models are reproducible and have a shelf life of about three weeks. Given the ease of production and quality of images produced, we believe they could be broadly applied in ultrasound teaching institutions in order to expose more operators to this difficult technique.

One may consider just using ultrasound image snap-shots of various ONSD for teaching and evaluating purposes. However, we believe the significant difficulty with technique provides the greatest issue in reliable ONSD determination. Thus, training should involve realistic models and active ultrasound acquisition of ONSD images. Our model provides this opportunity.

There is, however, a limitation to our model. Because we rely on the acoustic shadow of the 3D printed disc to recreate the optic nerve sheath we cannot guarantee the ONSD will be the exact size of the printed disc. This may add some error into the measurements of “known” sizes. We assume this error will be less than 0.1 to 0.2 mm but it is difficult to quantify, as this would require measuring the shadow under ultrasound, which also introduces the error of the operator and the limitations of the ultrasound machine. Sorting out how much each factor contributes to this error would be challenging. However, this

error should be small and consistent across various sizes, thus making it practically irrelevant.

Finally, even if better training is available, the range of normal being 5.0-5.9 mm will remain vulnerable to user variation. The human aspect of caliper use and variability in image acquisition and focal zone selection carry some inter-operator variability. If this inter-operator variability is any more than a few millimeters, the acceptable range of “normal” and “abnormal” values will have to account for this. Subsequently, the use of ONSD ultrasound would only become useful in ruling in/out patients at extreme values and will thus fail as a practical, bedside diagnostic test.

Our future directions include defining both intra- and inter-operator variability with our model, with the goal of instituting it in bedside ultrasound teaching. Furthermore, we plan to analyze the exact shape of the optic nerve sheath using magnetic resonance imaging in order to determine the exact shape of the sheath, round or elliptical, in order to determine the appropriate axis of measurement and to see if optic nerve sheath area may be a more useful correlate for ICP in the future. These future studies will further guide new models, hopefully improve training with this technique, and shed light on new directions with the ONSD ultrasonography.

## CONCLUSIONS

Our novel ONSD model offers simplicity of construction and ultrasound images similar to those found *in vivo*, affording its application for ultrasound teaching of this difficult technique.

## REFERENCES

1. Gangemi M, Cennamo G, Maiuri F, D'Andrea F. Echographic measurement of optic nerve in patients with intracranial hypertension. *Neurochirurgia (Stuttg)*. 1987;30(2):53-5.
2. Rajajee V, Vanaman M, Fletcher JJ, Jacobs TL. Optic nerve ultrasound for the detection of raised intracranial pressure. *Neurocrit Care*. 2011;15(3):506-15.
3. Strumwasser A, Kwan RO, Yeung L, et al. Sonographic optic nerve sheath diameter as an estimate of intracranial pressure in adult trauma. *J Surg Res*. 2011;170(2):265-71.
4. Dubourg J, Javouhey E, Geeraerts T, Messerer M, Kassai B. Ultrasonography of optic nerve sheath diameter for detection of raised intracranial pressure: a systematic review and meta-analysis. *Intensive Care Med*. 2011;37(7):1059-68.
5. Moretti R, Pizzi B. Ultrasonography of the optic nerve in neurocritically ill patients. *Acta Anaesthesiol Scand*. 2011;55(6):644-52.
6. Kimberly HH, Shah S, Marill K, Noble V. Correlation of optic nerve sheath diameter with direct measurement of intracranial pressure. *Acad Emerg Med*. 2008;15(2):201-4.
7. Tayal VS, Neulander M, Norton HJ, Foster T, Saunder T, Blaivas M. Emergency department sonographic measurement of optic nerve sheath diameter to detect findings of increased intracranial pressure in adult head injury patients. *Ann Emerg Med*. 2007;49(4):508-14.
8. Blaivas M, Theodoro D, Sierzenski PR. Elevated intracranial pressure detected by bedside emergency ultrasonography of the optic nerve sheath. *Acad Emerg Med*. 2003;10(4):376-81.
9. Newman WD, Hollman AS, Dutton GN, Carachi R. Measurement of optic nerve sheath diameter by ultrasound: a means of detecting acute raised intracranial pressure in hydrocephalus. *Br J Ophthalmol*. 2002;86:1109-13.
10. Geeraerts T, Merceron S, Benhamou D, Vigue B, Duranteau J. Non-invasive assessment of intracranial pressure using ocular sonography in neurocritical care patients. *Intensive Care Med*. 2008;34:2062-7.
11. Goel RS, Goyal NK, Dharap SB, Kumar M, Gore MA. Utility of optic nerve ultrasonography in head injury. *Int J Care Injured*. 2008;39:519-24.
12. Wantanabe A, Kinouchi H, Horikoshi T, Uchida M, Ishigame K. Effect of intracranial pressure on the diameter of the optic nerve sheath. *J Neurosurg*. 2008;109:255-8.
13. Moretti R, Pizzi B. Ultrasonography of the optic nerve in neurocritically ill patients. *Acta Anaesthesiol Scand*. 2011;55:644-52.
14. Ballantyne SA, O'Neill G, Hamilton R, Hollman AS. Observer variation in the sonographic measurement of optic nerve sheath diameter in normal adults. *Eur J Ultrasound*. 2002;15:145-9.
15. Potgieter DW, Kippin A, Ngu F, McKean C. Can accurate ultrasonographic measurement of the optic nerve sheath diameter (a non-invasive measure of intracranial pressure) be taught to novice operators in a single training session? *Anaesth Intensive Care*. 2011;39(1):95-100.
16. Bauerle J, Lochner P, Kaps M, Nedelmann M. Intra- and interobserver reliability of sonographic assessment of the optic nerve sheath diameter in healthy adults. *J Neuroimaging*. 2012 Jan;22(1):42-5. Epub 2010 Dec 1.
17. Bude RO, Adler RS. An easily made, low-cost, tissue-like ultrasound phantom material. *J Clin Ultrasound*. 1995;23:271-3.
18. Jafri F, Runde D, Saul T, Lewiss RE. An inexpensive and easy simulation model of ocular ultrasound that mimics normal anatomy as well as abnormal ophthalmologic conditions. *J Ultrasound Med*. 2011;30:569-73.