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Ultrasonographic Measurement of Optic Nerve Sheath Diameter

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Abstract:

Intracranial pressure (ICP) monitoring is crucial in critically ill patients, particularly those with traumatic brain injury, intracranial hemorrhage, or other neurological emergencies. Invasive ICP monitoring remains the gold standard; however, it carries risks such as infection, hemorrhage, and technical complications. Ultrasonographic measurement of optic nerve sheath diameter (ONSD) has emerged as a rapid, bedside, noninvasive, and reliable surrogate marker for detecting raised ICP. The optic nerve sheath is anatomically continuous with the intracranial subarachnoid space, allowing transmission of cerebrospinal fluid pressure changes to the optic nerve sheath. Therefore, measurement of ONSD using bedside ultrasound may provide valuable information regarding elevated ICP.

Keywords: Optic nerve sheath diameter; Intracranial pressure; Ultrasonography; Noninvasive monitoring; Critical care; Neurocritical care.

Introduction:

Elevated intracranial pressure (ICP) is a critical neurological emergency associated with traumatic brain injury, intracranial hemorrhage, brain tumors, hydrocephalus, and other acute neurological conditions. Early detection of increased ICP is essential to prevent cerebral ischemia, herniation, and irreversible neurological damage. Although invasive ICP monitoring remains the gold standard, it is associated with potential complications including infection, hemorrhage, and technical failure, in addition to limited availability in resource-constrained settings. Consequently, there is increasing interest in reliable, rapid, and noninvasive methods for ICP assessment in emergency and critical care practice **(1).**

The optic nerve sheath is anatomically continuous with the intracranial subarachnoid space, allowing cerebrospinal fluid pressure changes to be transmitted to the optic nerve sheath. Ultrasonographic measurement of optic nerve sheath diameter (ONSD), typically performed 3 mm posterior to the globe, has emerged as a practical bedside tool for detecting raised ICP. Recent systematic reviews and meta-analyses have demonstrated a strong correlation between increased ONSD and elevated ICP, supporting its diagnostic accuracy and clinical utility in neurocritical care settings **(2).** Accordingly, bedside ocular ultrasonography represents a promising noninvasive modality for early identification of intracranial hypertension.

1. Technical Overview

Ultrasonographic measurement of optic nerve sheath diameter (ONSD) has emerged as a valuable non-invasive technique for estimating intracranial pressure (ICP). This method utilizes the principles of ultrasound imaging to visualize and measure the optic nerve sheath, providing a rapid and relatively accessible means of assessing ICP at the bedside **(3)**.

1.1 Basics of Ultrasonography

Ultrasonography employs high-frequency sound waves to generate images of internal structures. A transducer,

containing piezoelectric crystals, converts electrical energy into sound waves and vice versa. When the transducer is placed on the skin, it emits sound waves that travel through the tissues. These sound waves interact with the tissues in different ways, depending on the tissue's density and acoustic properties. Some waves are reflected back to the transducer, while others are scattered or absorbed **(3)**.

The reflected sound waves, also known as echoes, are detected by the transducer and converted back into electrical signals. These signals are then processed by the ultrasound machine to create a real-time image on a monitor. The image displays the anatomical structures based on their echogenicity, which refers to their ability to reflect sound waves. Hyperechoic structures, such as bone, appear bright on the image, while hypoechoic structures, such as fluids, appear dark **(3)**.

In the context of ONSD measurement, ultrasonography allows for visualization of the optic nerve sheath. As ICP increases, CSF pressure within the optic nerve sheath also rises, leading to distension of the sheath. By measuring the diameter of the optic nerve sheath using ultrasound, clinicians can indirectly assess ICP **(4)**.

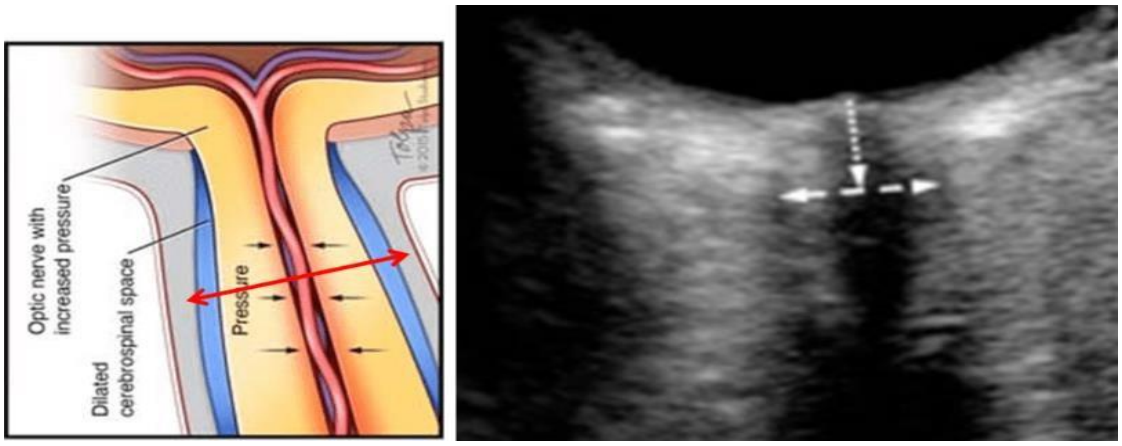

Figure 1: Enlarged Optic Nerve Sheath Diameter (ONSD) due to the intracranial hypertension (4)

1.2 Steps for Probe Placement and Image Acquisition

1. Patient Positioning

Proper patient positioning is crucial for obtaining optimal images of the optic nerve sheath. The patient is typically positioned supine with the head slightly elevated to reduce venous pressure and minimize orbital congestion. The eyelids are gently closed to prevent pressure on the globe and distortion of the optic nerve sheath. Place the ultrasound machine on the patient's right side so you can scan with your right hand and manipulate ultrasound buttons with your left hand **(4)**.

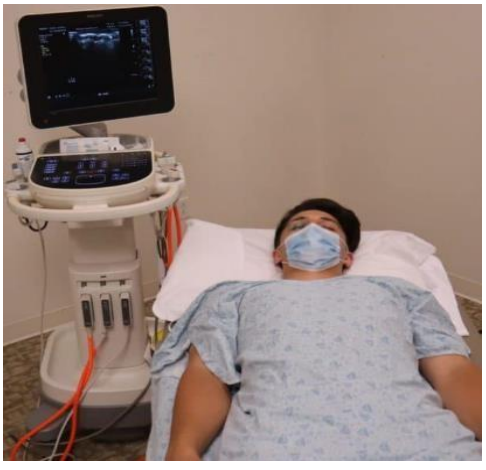

Figure 2: Patient and Machine Positioning (5)

2. Transducer Selection

A high-frequency linear array transducer (7.5-10 MHz) is typically preferred for ONSD measurement. The high frequency provides better resolution for visualizing the optic nerve sheath, which is a relatively small structure. The linear array configuration allows for a wider field of view, facilitating identification of anatomical landmarks **(5)**.

3. Probe Placement

In addition to a generous amount of gel, it is important to anchor your probe to decrease the amount of pressure applied to the patient's eyes. Grasp the linear probe and anchor your fingers on a bony surface of the patient's face. For the Right eye, anchor your right pinky finger on the patient's nose. For the Left eye, anchor your right pinky finger or palm on the zygomatic arch **(6)**.

Figure 3: Right Eye: Anchor on Nose - Left Eye: Anchor on Zygomatic Arch (6)

The transducer is placed on the closed eyelid, with the probe oriented parallel to the long axis of the orbit. This orientation ensures that the ultrasound beam is perpendicular to the optic nerve sheath, minimizing measurement errors due to oblique angles. The probe is then gently moved until a clear image of the optic nerve sheath is obtained **(6)**.

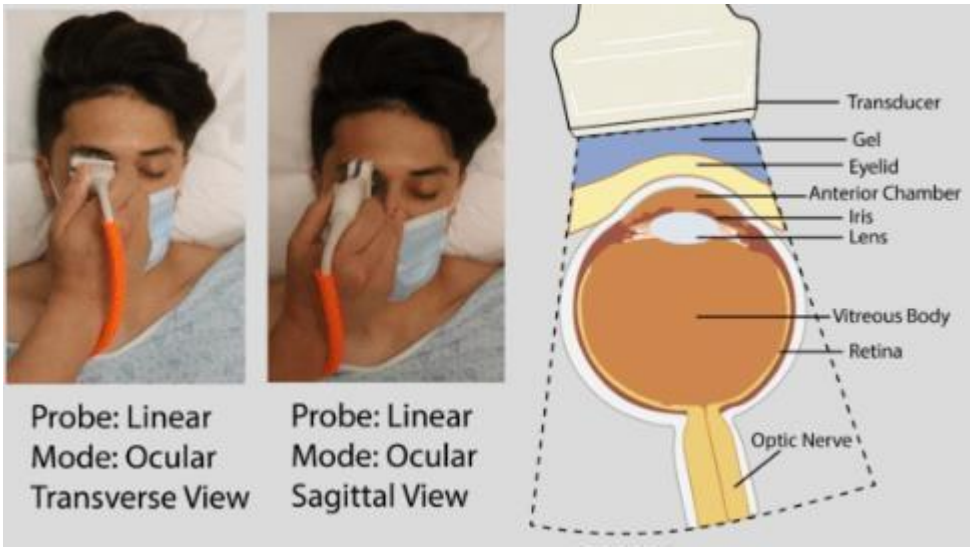

Figure 4: Assess for Extraocular Movements (7)

Next, ask the patient to look left and right to evaluate for extraocular movements. This is important when patients have severe periorbital edema from facial trauma.In the transverse view, you are looking for MEDIAL and LATERAL (or Left and Right) movements of the eye. Increase the gain slowly to better detect intraocular pathologies such as mobile findings of retinal detachment, posterior vitreous detachment, or vitreous hemorrhage **(7)**.

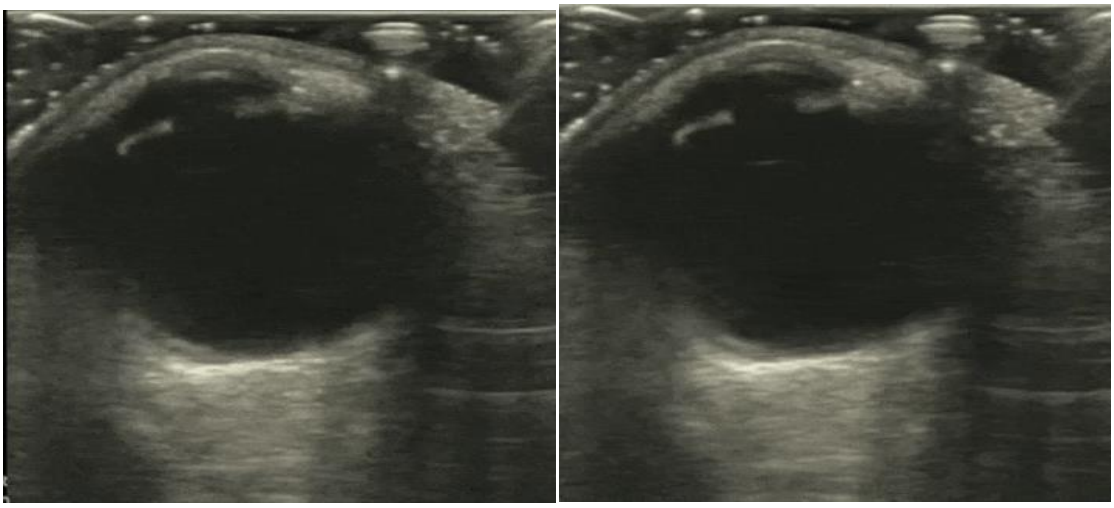

Figure 5: Extraocular Ocular Movement on Ultrasound (8)

4. Image Optimization

The gain, focus, and depth settings of the ultrasound machine are adjusted to optimize the image quality. The gain controls the amplification of the returning echoes, while the focus adjusts the sharpness of the image. The depth setting determines the range of tissue visualized on the screen. The optic nerve sheath should be clearly visualized as a hypoechoic structure surrounding the hyperechoic optic nerve **(8)**.

5. ONSD Measurement

Accurate measurement of the ONSD is crucial for reliable ICP estimation. The ONSD is typically measured 3 mm behind the globe, perpendicular to the long axis of the optic nerve sheath. This standardized measurement point helps to minimize variability and improve reproducibility. The measurement is taken at the widest point of the sheath, ensuring that the maximum diameter is captured **(9)**.

In the transverse view, rock the probe about 10-15° laterally to visualize where the hypoechoic optic nerve radiates away from the base of the globe. If you do not see the ocular nerve immediately, tilt the probe up and down until it comes into view. Once you have a good view, freeze the image **(9)**.

Figure 6: ONSD measurement in transverse view (9)

Use the caliper function to measure 3 mm (.3cm) posterior to where the optic nerve sheath attaches to the retina. This is the location where you will use to measure your optic nerve sheath diameter. Next, use the calipers again to measure the outermost lateral borders of the optic nerve sheath (anechoic border). The figure below measures the ONSD diameter to be 4.68mm (.468cm). To obtain better accuracy, you can obtain a few measurements and take the average of the ONSD values **(10)**.

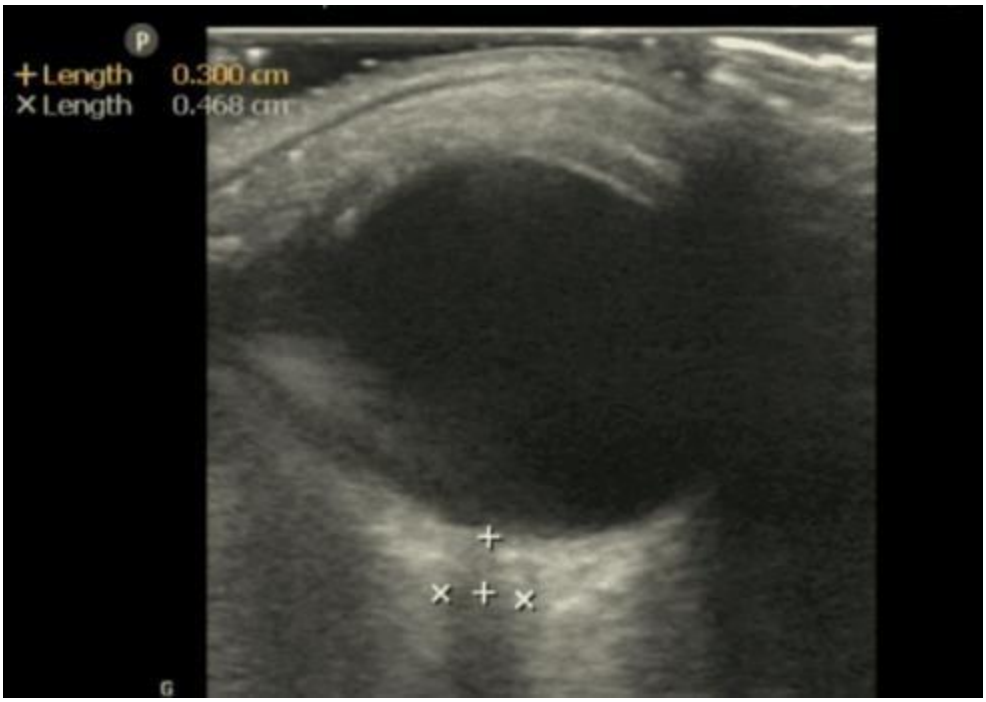

Figure 7: Normal ONSD Measurement (10)

6. Image Recording

The ultrasound image, along with the ONSD measurement, is recorded for documentation and future reference. The images can be stored electronically or printed for inclusion in the patient's medical record **(10)**.

Tips for Optimal Image Acquisition

Use ample acoustic gel to ensure good contact between the transducer and the eyelid, minimizing air gaps that can interfere with sound wave transmission. Apply gentle pressure with the transducer to avoid distorting the optic nerve sheath and causing discomfort to the patient. Adjust the gain and focus settings to optimize image quality, ensuring that the optic nerve sheath is clearly visualized. Measure the ONSD at the widest point of the sheath, perpendicular to its long axis, to obtain the most accurate measurement. Record multiple images and measurements to ensure accuracy and reproducibility, especially if there is any uncertainty about the initial measurement **(11)**.

1. Protocols and Thresholds

Standardizing the technique for optic nerve sheath diameter (ONSD) measurement is crucial to ensure accuracy and reproducibility, particularly given the potential impact of anatomical variations and operator experience **(11)**.

2.1 Landmarks for Probe Placement

Accurate probe placement is essential for obtaining reliable ONSD measurements. The following landmarks aid in consistent probe positioning **(12)**:

- The lateral canthus serves as a starting point for probe placement.
- The probe is placed on the closed upper eyelid, approximately 1 cm above the lateral canthus.
- The probe should be aligned with the orbital rim, ensuring that the ultrasound beam is directed along the axis of the orbit.

2.2 Probe Angles

The angle of the probe can influence the ONSD measurement. In transverse Plane, the probe should be held perpendicular to the long axis of the optic nerve, ensuring a cross-sectional view of the optic nerve sheath. On slight Medial Angulation, A slight medial angulation (approximately 5-10 degrees) may be necessary to optimize visualization of the optic nerve sheath, particularly in patients with deep-set eyes **(12)**.

2.3 Established ICP Thresholds

Several studies have established ONSD thresholds for identifying elevated ICP.2 While these thresholds may vary slightly depending on the patient population and the specific ultrasound technique used, a general guideline is as follows: (1) ONSD ≥ 5 mm: An ONSD of 5 mm or greater is often considered suggestive of elevated ICP, particularly in adults. (2) ONSD ≥ 5.5 - 6 mm: ONSD values in this range are highly suggestive of elevated ICP and warrant close monitoring and potential intervention. (3) ONSD<5 mm: ONSD values below 5 mm are generally considered normal and do not indicate elevated ICP **(13)**.

2.4 Pediatric Considerations

ONSD thresholds differ for pediatric patients due to age-related variations in optic nerve sheath size. Age-specific thresholds have been proposed, with ONSD values generally decreasing with age **(13)**.

2.5 Limitations of ONSD Thresholds

While ONSD thresholds provide a useful guide for identifying elevated ICP, they have limitations. Anatomical variations in optic nerve sheath size and morphology can influence ONSD measurements, leading to potential discrepancies between individuals. Additionally, ONSD measurements may not always correlate perfectly with invasive ICP measurements, leading to potential false positives or false negatives. Furthermore, ICP is a dynamic parameter that can fluctuate rapidly, and ONSD measurements provide only a snapshot in time, potentially missing transient changes in ICP **(13)**.

2. Validation Studies: Evidence for ONSD as a Non-invasive ICP Marker

A growing body of research has focused on validating the use of optic nerve sheath diameter (ONSD) measurements as a non-invasive surrogate for intracranial pressure (ICP) monitoring. These studies have employed various methodologies and patient populations to assess the accuracy and reliability of ONSD in comparison to the gold standard of invasive ICP monitoring techniques, such as external ventricular drains (EVDs) and intraparenchymal monitors **(14)**.

3.1 Correlation between ONSD and ICP

A cornerstone of validating ONSD as an ICP marker lies in establishing a strong correlation between the two measurements. Several studies have demonstrated a statistically significant positive correlation between ONSD and invasive ICP readings. This correlation indicates that as ICP rises, ONSD tends to increase proportionally, supporting the physiological basis for using ONSD as an indirect measure of ICP **(14)**.

The strength of this correlation has been reported to vary across studies, likely due to differences in patient populations, ultrasound techniques, and statistical methods employed. However, the consistent finding of a positive correlation reinforces the notion that ONSD reflects changes in ICP, particularly in the context of elevated ICP **(15)**.

3.2 Accuracy in Detecting Elevated ICP

Beyond correlation, the accuracy of ONSD in detecting elevated ICP is a critical aspect of its validation. Studies have evaluated the sensitivity and specificity of ONSD in identifying patients with elevated ICP, often defined as an ICP value above a certain threshold (e.g., 20 mmHg) **(15)**.

The reported sensitivities and specificities for ONSD in detecting elevated ICP have generally been favorable, ranging from 70% to 90%. This suggests that ONSD can reliably identify a significant proportion of patients with elevated ICP, although false positives and false negatives can occur. The accuracy of ONSD may be influenced by several factors, including the chosen ICP threshold, the specific ultrasound technique used, and the patient population studied. For instance, ONSD may be more accurate in detecting severe elevations of ICP compared to mild elevations **(15)**.

3. Limitations in Predicting Absolute ICP Values

While ONSD demonstrates good accuracy in detecting elevated ICP, its ability to predict absolute ICP values is more limited. This limitation stems from several factors **(15)**:

4.1 Inter-individual Variability

The anatomical variability in optic nerve sheath size and morphology among individuals can influence ONSD measurements. This variability can lead to discrepancies between ONSD and invasive ICP readings, making it challenging to predict precise ICP values based solely on ONSD **(16)**.

4.2 Dynamic Nature of ICP

ICP is a dynamic physiological parameter that can fluctuate rapidly in response to various stimuli, such as coughing, straining, or changes in posture. ONSD measurements, while providing a snapshot of ICP at a particular moment, may not capture these transient fluctuations, potentially leading to inaccuracies in predicting absolute ICP values **(16)**.

4.3 Potential for Continuous Monitoring

Recent advancements in ultrasound technology have opened up the possibility of continuous ONSD monitoring. Specialized ultrasound probes can be secured in place for extended periods, allowing for continuous tracking of ONSD changes. This approach holds promise as a non-invasive alternative to continuous invasive ICP monitoring, particularly in settings where invasive monitoring is impractical or carries unacceptable risks **(16)**.

However, continuous ONSD monitoring is still in its early stages of development, and further research is needed to validate its accuracy and reliability. Studies are ongoing to assess the feasibility and clinical utility of continuous ONSD monitoring in various patient populations **(17)**.

References:

1. Amini, A., Eghtesadi, R., Feizi, A. M., et al. (2024). Diagnostic accuracy of optic nerve sheath diameter for detection of raised intracranial pressure: Updated evidence. Critical Care, 28, 112.
2. Lochner, P., Coppo, L., Cantello, R., et al. (2023). Role of optic nerve sheath diameter in intracranial hypertension assessment. Journal of Clinical Medicine, 12(14), 4567.
3. Chen, L. M., Wang, L. J., Hu, Y., Jiang, X. H., Wang, Y. Z et al. 2019. Ultrasonic measurement of optic nerve sheath diameter: a non-invasive surrogate approach for dynamic, real-time evaluation of intracranial pressure. Br J Ophthalmol, 103, 437-441.
4. Bhargava, V., Tawfik, D., Tan, Y. J., Dunbar, T., Haileselassie, B. & Su, E. 2020. Ultrasonographic Optic Nerve Sheath Diameter Measurement to Detect Intracranial Hypertension in Children With Neurological Injury: A Systematic Review. Pediatr Crit Care Med, 21, e858-e868.
5. Martínez-Palacios, K., Vásquez-García, S., Fariyike, O. A., Robba, C. & Rubiano, A. M. 2024. Using Optic Nerve Sheath Diameter for Intracranial Pressure (ICP) Monitoring in Traumatic Brain Injury: A Scoping Review. Neurocrit Care, 40, 1193-1212.
6. Ji, X., Xiao, W., Ye, H., Chen, R., Wu, J., Mao, Y., et al. 2021. Ultrasonographic measurement of the optic nerve sheath diameter in dysthyroid optic neuropathy. Eye (Lond), 35, 568-574.
7. Yic, C. D., Pontet, J., Mercado, M., Muñoz, M. & Biestro, A. 2023. Ultrasonographic measurement of the optic nerve sheath diameter to detect intracranial hypertension: an observational study. Ultrasound J, 15, 4.
8. Danieli, L., Montali, M., Remonda, L., Killer, H. E., Colosimo, C. & Cianfoni, A. 2018. Clinically Directed Neuroimaging of Ophthalmoplegia. Clin Neuroradiol, 28, 3-16.
9. Hirzallah, M. I., Lochner, P., Hafeez, M. U., Lee, A. G., Krogias, C., Dongarwar, D., et al. 2024. Optic Nerve Sheath Diameter Point- of-Care Ultrasonography Quality Criteria Checklist: An International Consensus Statement on Optic Nerve Sheath Diameter Imaging and Measurement. Crit Care Med, 52, 1543- 1556.
10. Graziano, M., Sannino, C. & Mottola, F. F. 2023. Standardized Ultrasonographic Measurement of Optic Nerve Sheath Diameter in Traumatic Brain Injury Patients. *Neurol India,* 71, 792.
11. Hoch, M. J., Bruno, M. T. & Shepherd, T. M. 2017. Advanced MRI of the Optic Nerve. J Neuroophthalmol, 37, 187-196.
12. Montgomery, S. P., Moore, B., Hampton, S. M., Macy, G., Li, W. & Bronshteyn, Y. S. 2023. Optic Nerve Sheath Point of Care Ultrasound: Image Acquisition. J Vis Exp.
13. Barkatullah, A. F., Leishangthem, L. & Moss, H. E. 2021. MRI findings as markers of idiopathic intracranial hypertension. Curr Opin Neurol, 34, 75-83.
14. Schott, C. K., Hirzallah, M. I., Heyman, R., Lesky, D. N., Brant, E. B. & Callaway, C. W. 2020. Ultrasound measurement of optic nerve sheath diameter pre- and post-lumbar puncture. Ultrasound J, 12, 26.
15. Jasien, J. V., Laurie, S. S., Lee, S. M. C., Martin, D. S., Kemp, D. T., Ebert, D. J., et al. 2022. Noninvasive indicators of intracranial pressure before, during, and after long-duration spaceflight. J Appl Physiol (1985), 133, 721-731.
16. Padayachy, L., Brekken, R., Fieggen, G. & Selbekk, T. 2016. Pulsatile Dynamics of the Optic Nerve Sheath and Intracranial Pressure: An Exploratory In Vivo Investigation. Neurosurgery, 79, 100-7.