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OPTIC NERVE SHEATH DIAMETER AND INTRACRANIAL PRESSURE: MOLECULAR PATHOPHYSIOLOGY AND MULTIDISCIPLINARY APPLICATIONS IN OPHTHALMOLOGY, RADIOLOGY, AND GENERAL SURGERY

Dr. Aliya Shabir[1], Dr. Junaid Nabi Wani[2*], Dr. Muzaffar Hussain Sherwani[3], Dr. J.K. Bansal[4], Dr. Jatin Bansal[5], Dr. Vibhor Upadhyay[6]

[1]Consultant Radiologist, Private Radiology Practice, Kathua, Jammu & Kashmir, India, Former Senior Resident, Department of Radiodiagnosis, Government Medical College Baramulla, Kashmir University, Jammu & Kashmir, India, Orcid Id: 0009-0000-2141-1704, Email Id: manansherwani9@gmail.com
[2*]Assistant Professor, Department of General Surgery, Govt Medical College Kathua J&K, Jammu University, Orcid Id: 0009-0009-4178-7325, Email Id: Junaid9wani@gmail.com
[3]Professor, Department of Ophthalmology, Dr. B. S. Kushwah Institute of Medical Sciences, Lakhanpur, Kanpur, Uttar Pradesh, India, Affiliated to Atal Bihari Vajpayee Medical University, Orcid Id: 0009-0002-3277-453X, Email Id: muzaffarsherwani9@gmail.com
[4]Director and Head, Department of Ophthalmology, Sumitra ECMC Lucknow, UP-226003, India, Email Id: sumitraclinic@gmail.com
[5]Resident, Pacific Institute of Medical Sciences, Umarda, Udaipur, Email Id: Jatin10bansal@gmail.com
[6]Senior Consultant, Neurology, Apollomedics Hospital, Lucknow, Neurology, Apollomedics, Hospital, Lucknow -226006, India, Orcid Id: 0009-0006-0675-5393, Email Id: docvibhor@gmail.com
*Corresponding Author: Dr. Junaid Nabi Wani, Email Id: Junaid9wani@gmail.com

ABSTRACT
Raised intracranial pressure is a major cause of secondary neurological injury, yet invasive monitoring is not always feasible, creating demand for reliable noninvasive indicators. This review examines optic nerve sheath diameter as a surrogate marker of intracranial pressure, with emphasis on its molecular basis and multidisciplinary clinical applications. The objective is to integrate current evidence on pressure transmission through the perioptic subarachnoid space, sheath distensibility, cerebral edema, blood–brain barrier dysfunction, neuroinflammation, and altered cerebrospinal fluid dynamics. Key outcomes indicate that ultrasonography, computed tomography, and magnetic resonance imaging can detect optic nerve sheath enlargement associated with intracranial hypertension, although diagnostic thresholds vary across populations, techniques, and clinical settings. Ophthalmological applications include papilledema and idiopathic intracranial hypertension assessment, whereas radiological and surgical applications extend to traumatic brain injury, perioperative monitoring, pneumoperitoneum, Trendelenburg positioning, and critical care surveillance. These findings imply that optic nerve sheath diameter is most useful when interpreted alongside neurological examination, fundoscopy, imaging signs, and physiological monitoring rather than as a standalone measurement. Standardized acquisition protocols, population-specific cutoffs, automated analysis, and multicenter validation are required. In conclusion, optic nerve sheath diameter offers a rapid, accessible, and repeatable approach to intracranial pressure assessment across diverse healthcare environments. The principal takeaway is that its greatest value lies in multidisciplinary, multimodal clinical decision-making.

KEYWORDS: Optic nerve sheath diameter, Intracranial pressure, Intracranial hypertension, Transorbital ultrasonography, Neuroimaging

1. INTRODUCTION
ICP is a result of the dynamic balance of the brain tissue, CSF, and ICPB contained in the limited space of the cranium. Early recognition and prompt treatment are paramount in emergency and critical care situations with acute increase in ICP, as it can quickly diminish cerebral perfusion, induce ischemia, cause herniation, and exacerbate neurological outcomes (Kareemi et al., 2023). While invasive ventricular and intraparenchymal monitoring continues to be the gold standard technique, these methods have risks of hemorrhage, risk of infection, and require specialized expertise or may not be appropriate or available in many patients (Zhang et al., 2017). Thus, a clinical evaluation, neuroimaging, and a physiological assessment of the patient are still important components of the initial work-up for suspected intracranial hypertension, especially when definitive monitoring is not set up immediately (Patel et al., 2023).
The drawbacks of invasive monitoring have led to the search for ways to monitor raised ICP and provide triage and serial evaluation that are not invasive. New techniques such as transcranial Doppler ultrasonography, tympanic membrane displacement, pupillometry, venous ophthalmic measurements and deformation-based cranial techniques have been developed, but their accuracy, feasibility and reproducibility are variable and dependent on the clinical context (Ballestero et al., 2023). In recent years, there have been several innovations to enhance continuous or bedside assessment, but none of the noninvasive modalities has been able to completely overcome the direct measurement of ICP, which is most likely

affected by anatomical variations, operator skill, disease state, and equipment characteristics (Nag et al., 2019). Of this, optic nerve sheath diameter (ONSD) has received great focus as the optic nerve is surrounded by meningeal layers that are connected to the intracranial subarachnoid space. The distortion of the sheath secondary to an increasing ICP can be measured and is called CSF transmission into the perioptic compartment.

Diagnosis of ONSD can be performed by transorbital ultrasonography, computed tomography, or magnetic resonance imaging. In unstable patients who cannot be safely transported, bedside ultrasound of the heart is particularly appealing due to its speed, repeatability, low cost, and the ability to be performed easily. There are reports of age-, ethnicity-, plane-, resolution-, timing-, and reference-standard-dependent thresholds for ONSD enlargement, suggesting that this is associated with an increase in ICP (Lochner et al., 2019). The presence of these sources of heterogeneity, which restrict the use of a single universal cutoff and which suggest a multimodal interpretation, Today, critical care practice has evolved to consider ONSD as the most useful when combined with a neurological exam, hemodynamic parameters, imaging, and other noninvasive parameters rather than as a standalone test (Bianchini et al., 2025).

The ophthalmological significance of ONSD goes beyond emergencies of acute neurological disorders. Idiopathic intracranial hypertension can cause papilledema, visual-field defects, headache, and progressive optic nerve dysfunction, necessitating collaborative evaluation by the neurologist, ophthalmologist, and radiologist. Consensus is that structured diagnosis, visual monitoring, weight management, medical therapy, and timely escalation of treatment when the vision is threatened should be emphasized (Bsteh et al., 2025). ONSD measurement could add to the information available from fundoscopy, optical coherence tomography and formal perimetry, and may be used in conjunction.

Emerging concepts of glymphatic transport are also of relevance for the connection between ocular structures and CSF. In experimental and translational studies, pressure gradients have been shown to affect the flow of fluid along the optic nerve pathways, and to play a role in changes to the eye in abnormal intracranial pressure states (Wostyn et al., 2022). Additionally, the brain-oedema effect of cephalad fluid shifts, the changes in intracranial dynamics, the optic disc oedema, globe flattening, choroidal folding and visual impairment have been associated in spaceflight research, further expanding the clinical relevance of perioptic pressure transmission (Zhang & Hargens, 2018).

This review will discuss the anatomical, molecular and physiological pathways between ICP and ONSD and their role in ophthalmology, radiology, general surgery, anaesthesia, emergency medicine and critical care. Special emphasis is placed on the methods of measurement, diagnostic sensitivity, the effects of surgery on the measurement, especially pneumoperitoneum and Trendelenburg position, and lack of standardization. It also reflects on the potential of automated image analysis and population-specific reference values to enhance reproducibility, reduce operator dependency, and enable easier application in a variety of clinical settings around the globe. The main idea is that ONSD is a clinically applicable and non-invasive surrogate in a multi-disciplinary and multi-modal decision-making process and not as a standalone marker for invasive monitoring.

Objectives of the review:

1. To explain the molecular and physiological basis linking ONSD with intracranial pressure.
2. To evaluate ONSD measurement methods and diagnostic performance.
3. To examine multidisciplinary applications across ophthalmology, radiology, and surgery.

2. Anatomy of the Optic Nerve, Optic Nerve Sheath, and Perioptic Subarachnoid Space

The optic nerve consists of an extension of the CNS enclosed by the dura mater, arachnoid mater, and pia mater. It contains a subarachnoid space that communicates with the intracranial CSF compartment, and hence any changes in ICP will travel along the retrobulbar optic nerve. This continuity of anatomy is the reason why a widening of the optic nerve sheath is a good, non-invasive indicator of elevated ICP. The lamina cribrosa divides the intraocular compartment from the retrolaminar compartment, establishing a translaminar pressure gradient that is influenced by intraocular pressure, intra-CSF pressure, tissue resistance and compliance (Kaskar et al., 2019).

The perioptic subarachnoid space is not a continuous pathway. Cerebrospinal fluid movement and pressure transmission can be altered by Septa, Trabeculae, Sheath Elasticity, and Local Narrowing. Impaired CSF circulation in the orbit may result in stagnation, impaired nutrient exchange, and chronic mechanical stress to the optic nerve, as has been associated with glaucomatous optic neuropathy (Killer, 2020). Some of these structural characteristics could account for some of the variations in sheath enlargement at identical ICP.

Astrocytic water transport is also critical to maintenance of fluid homeostasis in the optic nerve and surrounding tissues. Aquaporin-4 is expressed in astrocytic end-feet and involved in regulating water exchange between neural and vascular barriers, and edema formation in cerebrovascular injury (Chu et al., 2016). The dysregulated aquaporin-4 expression may have a greater effect on the amplification of cytotoxic or vasogenic swelling, which in turn affects intracranial compliance and perioptic pressure dynamics (Tang & Yang, 2016). However, the ONSD is not just the result of pressure but rather the product of a combination of meningeal structure, CSF continuity, distensibility of the sheaths, and water transport. The anatomical and physiological basis of changes in ONSD is shown in Figure 1.

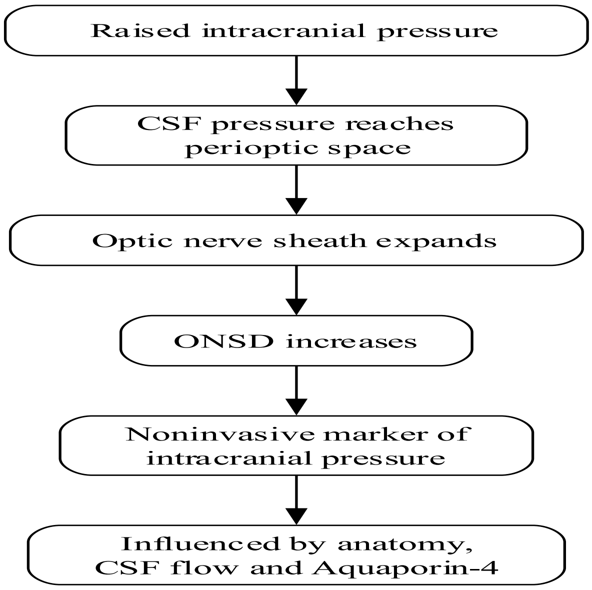

Figure 1. Anatomical and Physiological Basis of Optic Nerve Sheath Diameter Changes

3. Molecular and Cellular Pathophysiology of Intracranial Hypertension

Intracranial hypertension is an increase in intracranial pressure (ICP) due to an overloading of compensatory mechanisms of the fixed cranial vault, which can be caused by brain tissue, cerebrospinal fluid, or blood volume. The cellular mechanisms of the causes of cytotoxic edema include ischemia, trauma, inflammation, and metabolic failure, which alter the ion gradients, causing sodium to accumulate and water to enter the astrocytes and neurons. The role of aquaporin channels (particularly aquaporin-4) in regulating the movement of water across the membranes can either promote or facilitate the formation of edema, depending on the phase of injury, site of injury, and severity of disease (Kokkoris et al., 2025). Altered expression of aquaporin will not only exacerbate tissue swelling but also decrease intracranial compliance (Czyżewski et al., 2024) due to the combination of damage to the blood–brain barrier, neuroinflammation, oxidative stress, and impairment of glymphatic transport.

These processes lead to an increase in pressure in the CSF compartment, and mechanical forces are conveyed towards the perioptic subarachnoid space. The continuous elevation of pressure causes the optic nerve sheath to become distended, changes the axoplasmic flow, affects the venous drainage, and also helps to cause optic disc edema. Megacystia of glaucoma, another condition associated with spaceflight, is caused by cephalad flow redistribution, changes in venous pressure, and disturbances in cerebrospinal fluid dynamics associated with these changes, which could lead to optic nerve head change, choroidal folds, and flattening of the globe (Aleci & Dutto, 2025).

Posture and tiny structures in the optic nerve subarachnoid space also influence pressure transmission. It has been suggested by mathematical models that the movement and pressure gradients of CSF change around the optic nerve as a result of trabeculae, septa, local narrowing, and body position (Holmlund et al., 2022). Thus, the diameter of the optic nerve sheath is not just a reflection of the ICP at one time and one place but a reflection of several molecular, vascular, biomechanical, and hydrodynamic mechanisms. Figure 2 shows the molecular mechanisms that link intracranial hypertension with OSD.

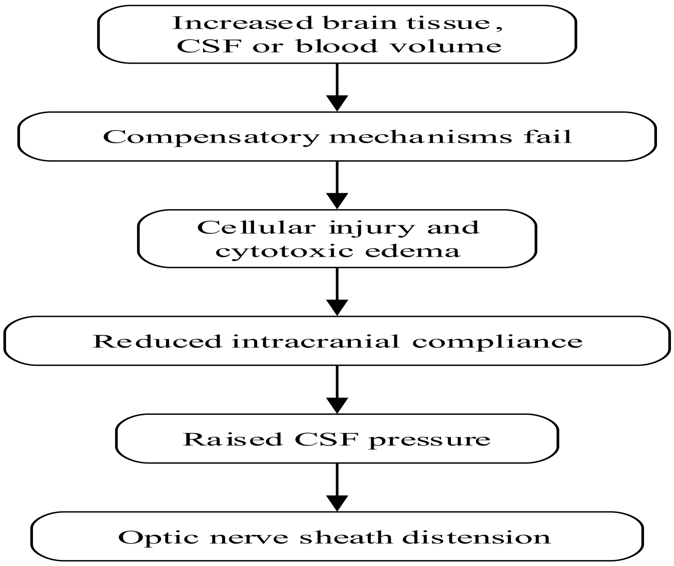

Figure 2. Molecular Pathophysiology Linking Intracranial Hypertension to Optic Nerve Sheath Distension

4. Transmission of Intracranial Pressure to the Optic Nerve Sheath

The CSF column that extends from the space adjacent to the meninges in the cranium through the optic canal into the perioptic space transmits intracranial pressure to the optic nerve. Distention of the optic nerve sheath occurs when pressure waves travel along this pathway, with a greater degree of distention seen in the retrobulbar portion of the optic nerve. Experimental modelling indicates that there could be significant mechanical stress on the sheath and its surrounding microvasculature during rapid cerebrospinal fluid pressure rise, which could be a factor in vulnerable infants with optic nerve sheath bleeding (Stewart et al., 2024).

The amount of expansion of the sheaths and the timing of the expansion are related to the pressure amplitude, duration, elasticity of the tissue, venous outflow, and structural resistance from the arachnoid trabeculae and septa. These variables are different for each person, and optic nerve sheath diameter is not necessarily numerically equivalent to ICP. It acts rather as a pressure-sensitive biomarker which needs to be interpreted along with clinical, radiological, and physiological data (Robba et al., 2016).

Technical standardization is also an important aspect of accurate assessment. Several factors such as probe orientation, measurement depth behind the globe, image quality, caliper placement, and experience of the operator can significantly affect values recorded. Consensus-based quality criteria are then crucial to enhance the level of reliability and comparability between research and clinical contexts (Hirzallah et al., 2022).

There are further difficulties in pediatrics as the size of the sheath changes as a function of developmental age. Transorbital ultrasonography is reported as having good repeatability, but there are significant limitations in observer variability and also in population-specific reference ranges, especially when compared to invasive monitoring (Padayachy et al., 2016).

The overall concept of optic nerve sheath distension is a dynamic pressure transmission, which is modified by anatomy, compliance, age, and also technique. Based on the available anatomical and molecular literature, the following is suggested as the anatomical and molecular basis of ONSD distension (Table 1).

Table 1. Anatomical, Molecular, and Physiological Basis of Optic Nerve Sheath Distension

Domain	Principal components	Mechanism relevant to intracranial pressure	Clinical significance	Citation
Optic nerve anatomy	Dura mater, arachnoid mater, pia mater, perioptic subarachnoid space	Continuity with the intracranial subarachnoid compartment permits transmission of cerebrospinal fluid pressure to the retrobulbar optic nerve sheath.	Provides the anatomical basis for using optic nerve sheath diameter as a surrogate marker of raised intracranial pressure	(Kaskar et al., 2019)
Cerebrospinal fluid compartmentalization	Trabeculae, septa, local narrowing, perioptic fluid pathways	Structural resistance may produce uneven pressure transmission, localized stagnation, and interindividual differences in sheath expansion	Explains why identical intracranial pressure values may not produce equivalent optic nerve sheath diameter measurements	(Killer, 2020)
Aquaporin-mediated water transport	Aquaporin-4 in astrocytic end-feet	Regulates water movement across neural and vascular interfaces and contributes to cytotoxic and vasogenic edema	Links cellular fluid imbalance with reduced intracranial compliance and pressure elevation	(Chu et al., 2016)
Cerebral edema	Astrocytic swelling, blood–brain barrier disruption, extracellular fluid accumulation	Tissue expansion increases intracranial volume and promotes pressure transmission toward the perioptic compartment.	Supports the molecular relationship between brain injury and optic nerve sheath enlargement	(Tang & Yang, 2016)
Acute brain injury	Neuroinflammation, oxidative stress, ion imbalance, glymphatic dysfunction	Combined cellular and vascular abnormalities amplify tissue swelling and cerebrospinal fluid pressure.	Indicates that optic nerve sheath diameter reflects several interacting pathophysiological processes	(Kokkoris et al., 2025)
Traumatic brain injury	Altered aquaporin expression, endothelial	Increased brain water and reduced	Supports bedside optic nerve sheath diameter	(Czyżewski et al., 2024)

	injury, impaired fluid clearance	intracranial compliance facilitate intracranial hypertension.	monitoring in neurotrauma	
Postural and microstructural effects	Body position, optic nerve sheath microstructures, cerebrospinal fluid pathways	Posture and perioptic structures modify pressure gradients and fluid movement around the optic nerve.	Limits direct conversion of optic nerve sheath diameter into an exact intracranial pressure value	(Holmlund et al., 2022)

5. Techniques for Measuring Optic Nerve Sheath Diameter

Transorbital ultrasonography, computed tomography, and magnetic resonance imaging are methods that can be used to measure optic nerve sheath diameter, with their own advantages and disadvantages. Bedside ultrasound is most accessible due to its many advantages — it is fast, repeatable, non-radiating, and can be used on unstable patients. Typically, the measurement of the sheath is made around 3 mm behind the globe in a transverse or sagittal plane, in which distention is most sensitive to changes in ICP. Three-dimensional (3D) freehand ultrasound may be valuable in providing better spatial coverage, less reliance on a single imaging plane, and possibly more reproducible volumetric assessment of the perioptic compartment (Riemer et al., 2025).

There is still a lot of variation due to methodological inconsistencies. Multiple factors may change the reported values and make it difficult to compare data across studies, such as differences in probe frequency, insonation angle, gain settings, caliper placement, eye position, and measurement plane (Stevens et al., 2021). However, serial ultrasonographic measurements can also detect dynamic changes in ICP and can assist with management of ICP for bedside monitoring if it cannot be measured invasively, and/or is contraindicated (Maissan et al., 2015).

Computed tomography allows retrospective measurement in the course of routine neuro-imaging; it also allows the detection of associated findings like globe flattening and optic nerve tortuosity. Magnetic resonance imaging (MRI) is ideal for soft tissue contrast and detailed imaging of the optic nerve, sheath and perioptic CSF, but is not as useful in an emergency. The current meta-analytic evidence suggests that ultrasound can be a clinically useful tool for the diagnosis of raised ICP, but there is some variation in threshold and heterogeneity of the studies that would make it hard to standardise the adoption of a threshold by universal consensus (Aletreby et al., 2022). Standardized acquisition and bilateral measurements, repeated evaluations, and association with clinical and radiological findings are therefore necessary for interpretation. The ONSD measurement techniques and considerations are summarized in Table 2.

Table 2. Optic Nerve Sheath Diameter Measurement Techniques and Methodological Considerations

Technique	Measurement approach	Main advantages	Principal limitations	Recommended application	Citation
Two-dimensional transorbital ultrasonography	Bilateral sheath measurement, commonly approximately 3 mm behind the globe	Rapid, portable, repeatable, radiation-free, and suitable for unstable patients	Operator dependence, variable insonation angle, gain settings, caliper placement, and image quality	Point-of-care screening and serial bedside monitoring	(Stevens et al., 2021)
Three-dimensional freehand ultrasonography	Volumetric reconstruction of the optic nerve and surrounding sheath	Greater spatial coverage and reduced dependence on a single imaging plane	Requires specialized equipment, reconstruction software, and further clinical validation	Research applications and future automated volumetric assessment	(Riemer et al., 2025)
Serial ultrasonography	Repeated measurements before and after physiological or therapeutic changes	Detects dynamic trends and may reflect rapid alterations in intracranial pressure	Measurements may be influenced by operator variability and transient physiological factors.	Monitoring responses to osmotherapy, ventilation, positioning, or surgery	(Maissan et al., 2015)
Computed tomography	Axial or reformatted measurement of the retrobulbar sheath	Widely available in emergency and trauma settings and allows retrospective evaluation	Radiation exposure, variable slice thickness, and limited sensitivity to small soft-tissue	Trauma, acute neurological deterioration, and opportunistic assessment on routine imaging	(Freddi & Ottaiano, 2022)

			differences		
Magnetic resonance imaging	High-resolution visualization of the optic nerve, sheath, perioptic fluid, and globe	Superior soft-tissue contrast and identification of associated neuro-ocular abnormalities	Longer acquisition time, higher cost, limited emergency availability, and motion sensitivity	Idiopathic intracranial hypertension, chronic disease, and detailed neuro-ophthalmic evaluation	(Cejvanovic et al., 2024)
Automated ultrasound segmentation	Deep learning-based identification and quantification of optic nerve sheath boundaries	May improve consistency, reduce manual caliper error, and support less experienced operators	Dataset heterogeneity, image artifacts, device variability, and incomplete external validation	Future standardized point-of-care measurement systems	(Marzola et al., 2023)
Automated structural quantification	Algorithmic measurement of optic nerve and sheath morphology	Enables reproducible characterization of multiple anatomical parameters	Requires diverse training datasets and prospective clinical validation	Artificial intelligence-assisted monitoring and multicenter research	(Yang et al., 2025)

6. Diagnostic Accuracy and Thresholds for Detecting Raised Intracranial Pressure

The diagnostic value of optic nerve sheath diameter is dependent on the patient population, the method of measurement, the reference standard, and the situation in which intracranial hypertension is suspected. In children, ONSD could be used with useful sensitivity and specificity to detect raised ICP, but there is variation in age and thresholds which makes it hard to apply a single threshold to all children (Rajendran et al., 2024). Pooled data also confirm that ONSD sonography is a fast screening tool when invasive methods of monitoring cannot be performed or are delayed, but with varying degrees of accuracy depending on the severity, timing, and skill of the operator (Xu et al., 2024).

Therefore, interpretation of the threshold should take into account bilateral measurements and the quality of the image, depth of measurement, and serial change, and not only one absolute value. Sheath enlargement may be related to a physiological variation or chronic pressure exposure or may be due to technical error; rapid sheath enlargement may better reflect the escalation of pressure. ONSD must also be read in conjunction with an ophthalmic assessment. Optical coherence tomography can also describe the changes in the retinal nerve fiber layer that occur with papilledema, and measure the effects of treatment, in addition to the sheath diameter (Auinger et al., 2015).

There are limitations to the use of OCT, such as segmentation errors, limited ability to differentiate severe edema from axonal loss, and decreased specificity when used in combination with optic disc anomalies (Costello & Hamann, 2024). Therefore, the combination of ONSD with fundoscopy, OCT, neuroimaging and neurological examination, and, as appropriate, invasive pressure measurement, is most useful for diagnostic purposes. It is necessary to validate population-specific thresholds, standardized acquisition protocols, and multicenter validation for reliable clinical use in all age groups and care settings. A summary of the multimodal diagnostic assessment of ONSD is given in Figure 3.

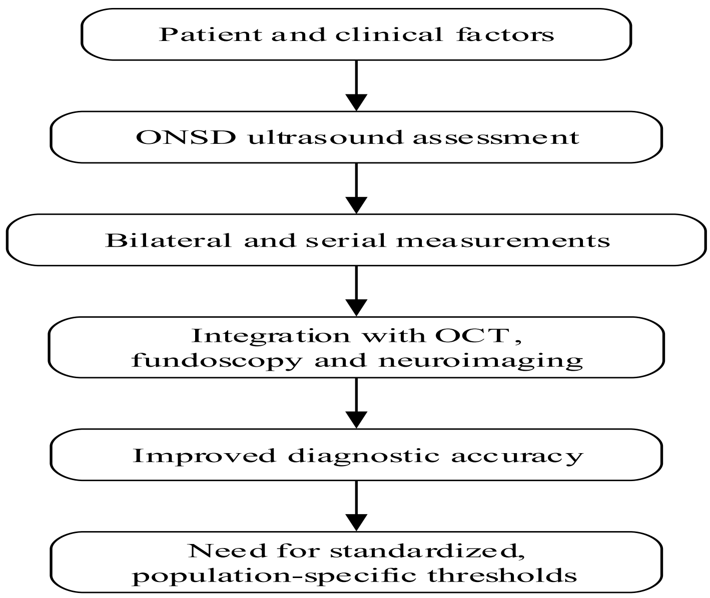

Figure 3. Diagnostic Assessment and Multimodal Interpretation of Optic Nerve Sheath Diameter

7. Ophthalmological Applications

The evaluation of optic nerve sheath diameter is clinically relevant in ophthalmology practice, especially for papilledema, optic disc swelling, and visual dysfunction caused by intraocular pressure. Measurement of ONSD can be used alongside fundus examination, visual-field testing, and optical coherence tomography to offer information about the distension that occurs in the sheath behind the eye in idiopathic intracranial hypertension, when the CSF pressure is raised. Optical coherence tomography is particularly valuable to quantify the thickness of peripapillary retinal nerve fibres (RNF), the volume of the optic nerve head (ONH), and changes in the macula ganglion cell (MGC) when making a diagnosis and following up patients (Malhotra et al., 2020).

It is important to do serial ophthalmic evaluations as there may be deterioration in visual function despite improvements in headache or neurological symptoms. Combined neuro-ophthalmological examination with optical coherence tomography can show the decrease and/or resolution of papilledema, retinal structure, and visual function in patients with venous sinus stenting before and after intervention (Hendrix et al., 2022). ONSD may consider adding a noninvasive measure of pressure response, but not as a substitute for the actual assessment of vision.

In the presence of optic disc abnormalities because of structural causes, interpretation is more complex and can be confused with papilledema. Peripapillary hyperreflective ovoid mass-like structures may change the appearance of the optic nerve head and may be confused with true peripapillary pressure-related edema, but they are congenital or structural changes, which can be differentiated by multimodal imaging (Heath Jeffery & Chen, 2023). Further supportive features can be identified using neuroimaging, including posterior globe flattening, optic nerve tortuosity, empty sella, and prominence of the perioptic CSF (Cejvanovic et al., 2024). For this reason, ophthalmological use of ONSD is best when performed in a multimodal approach which combines visual function, retinal imaging, fundoscopy and neuroimaging. This holistic approach enhances the accuracy of diagnosis, follow-up and timely prevention of permanent vision loss.

8. Radiological Applications

When ultrasonography is not available or technically limited, or the presence of pressure-related changes needs confirmation, radiological assessment of optic nerve sheath diameter is a non-invasive method used for the identification of pressure-related changes. Computed tomography (CT) and magnetic resonance imaging (MRI) allow direct visualization of the optic nerve, perioptic cerebrospinal fluid, posterior globe and adjacent orbital structures. Patel et al., 2021, suggest that abnormal globe shape, such as posterior scleral flattening, should be used in conjunction with other neuroimaging features rather than on its own and may be a sign of elevated intracranial pressure.

Cross-sectional imaging can also aid in the differential diagnosis of intracranial hypertension, optic nerve tumor, inflammatory neuropathy, ischemic injury, congenital abnormalities, and orbital disease. Magnetic resonance imaging provides better contrast between soft tissues, and computed tomography is faster and more available for emergency and trauma settings. In order to be able to interpret accurately, it is important to know normal anatomy, sheath morphology, enhancement patterns, and the characteristics of signals (Freddi & Ottaiano, 2022).

The use of radiological evaluation is especially important during laparoscopy, laparoscopy, and robotic surgery, where pneumoperitoneum and positioning of the body can affect cerebral venous drainage, increasing the ICP. Optic nerve sheath imaging has the potential to be a useful perioperative marker of pressure change, as prospective observations show that carbon dioxide insufflation and Trendelenburg positioning can cause an increase in the diameter of the optic nerve sheath. Optic nerve sheath imaging may serve as a useful marker of pressure change, as observed in the prospective case; the diameter of the optic nerve sheath increases with carbon dioxide insufflation and Trendelenburg positioning in the operating room. Ventilation, hemodynamics, duration, and baseline neurological function also influence individual responses, as is demonstrated by multimodal noninvasive assessments, which also show pressure elevation during these operative conditions (Robba et al., 2016).

Therefore, radiological ONSD measurements are best standardized and interpreted bilaterally and in conjunction with the globe configuration, venous findings, clinical status, and the operative context. Over time, serial imaging can help to understand what is happening, whether it is progressive or reversible, and how it was affected by treatment.

9. Applications in General Surgery, Trauma, and Perioperative Care

Optic nerve sheath diameter monitoring is becoming increasingly relevant in general surgery and perioperative medicine as factors during the surgery may affect the ICP transiently. Carbon dioxide pneumoperitoneum raises intra-abdominal and intra-thoracic pressure, reduces cerebral venous return, and can cause an increase in the levels of arterial carbon dioxide, all of which contribute to an increase in ICP. These effects may be aggravated by cephalad venous congestion as occurs with Trendelenburg positioning. Further evidence in prospective studies in gynecologic surgery demonstrates that ultrasonographic ONSD increases during the combined Trendelenburg and pneumoperitoneum positioning, which justifies its use for real-time assessment of the effects of pressure change (Ruan et al., 2025).

Adjustments in positioning can help to minimize this physiological burden. Applying reverse Trendelenburg before pneumoperitoneum during laparoscopic cholecystectomy, when performed, can be beneficial for reducing excessive ONSD enlargement, which may represent simple perioperative modifications that can help improve cerebral pressure control (Demirgan et al., 2021). This can be especially significant in patients who had a traumatic brain injury, had an intracranial lesion, had impaired venous drainage, or had decreased intracranial compliance.

Airway, ventilation, and sedation must also be taken into consideration when making decisions regarding perioperative management. Avoiding hypoxemia, hypercapnia, coughing, and insufficient sedation may lead to increased cerebral blood volume, leading to increased intracranial hypertension, whereas controlled ventilation and adequate anesthetic depth may lead to a decrease in secondary neurological stress (Rajajee et al., 2017). Lung and brain ultrasound is a workable strategy

for optimizing pulmonary recruitment and cerebral protection during situations of positive airway pressures (Corradi et al., 2018).
Thus, ONSD monitoring can be implemented to assist with individual surgical positioning, ventilation, and hemodynamic management. It should be used in addition to, not instead of, neurological exam, capnography, systemic monitoring, or formal neuroimaging studies when clinically indicated. The factors that can influence ICP and ONSD perioperatively are shown in Figure 4.

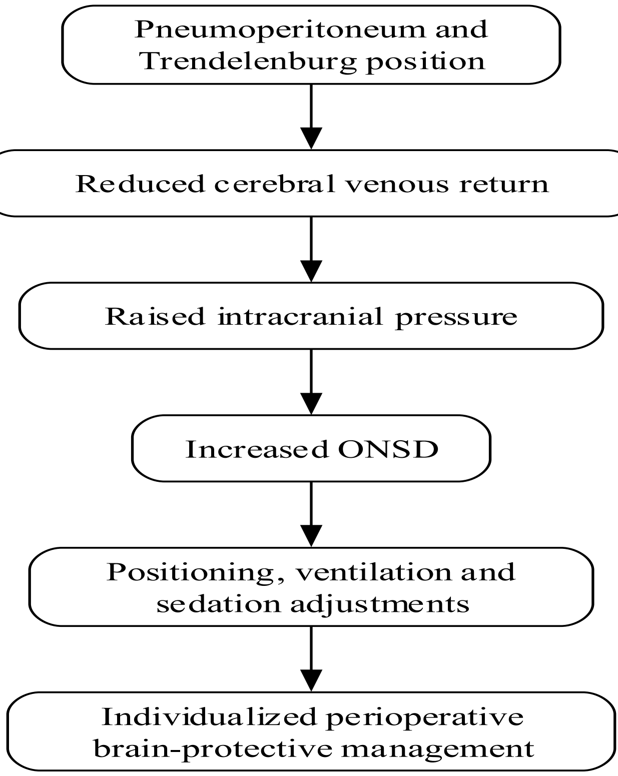

Figure 4. Perioperative Factors Influencing Intracranial Pressure and Optic Nerve Sheath Diameter

10. Critical Care, Anesthesia, and Emergency Medicine Applications
Evaluating the diameter of the optic nerve sheath (ONS) is becoming a more common tool in critical care, anesthesia, and emergency medicine for an immediate bedside assessment of possible intracranial hypertension. Mechanical ventilation is often necessary in patients with neurocritical care, but positive airway pressure, hypercapnia, hypoxemia, coughing, and ventilator asynchrony can also lead to an increase in cerebral blood volume and a decrease in venous drainage. Ventilation thus needs to be tightly regulated in order to maintain cerebral blood flow and compliance of the cranium (Dibu, 2022).
Point-of-care transorbital ultrasonography is especially useful when examination of the neurologic system is limited by sedation, intubation, or altered consciousness. Measurement of ONSD can be useful in the early detection of raised ICP in patients with non-traumatic headache and may aid in prioritising neuro-imaging, specialist assessment or invasive ICP monitoring as appropriate (Tlaiss et al., 2025). Obtaining serial measurements also can help determine how a patient reacts to the changes in ventilation, osmotherapy, positioning, or sedation.
Bedside ONSD assessment could be more reliable using automated image analysis. AI algorithms based on multi-center ultrasound data have shown promise for optic nerve localization and sheath morphology in minimizing the need for manual placement of calipers and operator expertise (Marzola et al., 2023). More recent models can reliably measure structures of the optic nerve and optic sheath at different image qualities and anatomies (Yang et al., 2025). But dataset heterogeneity, device variations, image artifacts, and incomplete external validation are still issues with automation (Escamilla-Ocañas et al., 2025).
Therefore, ONSD should be used as an add-on to multimodal neurological monitoring. Clinical, capnographic, hemodynamic, cerebral imaging, and cerebral ultrasound are other modalities that could benefit from integration with clinical examination in order to enhance brain-protective management in a variety of emergency, operative, and intensive care settings and to enhance triage and longitudinal surveillance. Table 3 points out a few clinical applications in a multidisciplinary approach.

Table 3. Multidisciplinary Clinical Applications of Optic Nerve Sheath Diameter

Specialty or setting	**Clinical scenario**	**Role of optic nerve sheath diameter**	**Complementary assessments**	**Major considerations**	**Citation**
Ophthalmology	Idiopathic	Supports	Fundoscopy,	Should not	(Malhotra

	intracranial hypertension and papilledema	assessment of retrobulbar pressure-related sheath distension and longitudinal monitoring	visual-field testing, optical coherence tomography, and visual acuity	replace direct evaluation of visual function or optic nerve damage	et al., 2020)
Neuro-ophthalmology	Monitoring before and after venous sinus stenting	May provide a noninvasive marker of pressure response following intervention	Retinal nerve fiber layer thickness, optic nerve head volume, and visual-field testing	Structural improvement may not parallel symptom resolution	(Hendrix et al., 2022)
Radiology	Suspected intracranial hypertension on CT or MRI	Adds quantitative assessment to associated signs such as posterior globe flattening and perioptic fluid prominence	Empty sella, venous sinus abnormalities, optic nerve tortuosity, and globe contour	Imaging findings should be interpreted collectively rather than independently.	(Patel et al., 2021)
General surgery	Laparoscopic and robotic procedures	Detects intracranial pressure-related changes caused by pneumoperitoneum and operative positioning	End-tidal carbon dioxide, hemodynamic monitoring, ventilation variables, and patient position	Effects depend on insufflation pressure, duration, carbon dioxide retention, and baseline compliance.	(Ruan et al., 2025)
Gynecological surgery	Prolonged Trendelenburg positioning	Serial measurement may identify progressive perioperative sheath enlargement.	Capnography, airway pressure, blood pressure, and cerebral oxygenation	Trendelenburg positioning may impair cerebral venous drainage	(Sahay et al., 2018)
Laparoscopic general surgery	Reverse Trendelenburg before pneumoperitoneum	May demonstrate reduction in excessive pressure-related sheath expansion	Standard anesthetic and ventilatory monitoring	Position modification may be useful in neurologically vulnerable patients	(Demirgan et al., 2021)
Neurocritical care	Mechanical ventilation in patients with acute brain injury	Supports surveillance when clinical examination is limited by intubation or sedation	Intracranial pressure monitoring, transcranial Doppler, blood gases, and cerebral perfusion pressure	Positive pressure, hypercapnia, hypoxemia, and coughing can affect measurements	(Dibu, 2022)
Emergency medicine	Non-traumatic headache with suspected raised intracranial pressure	May assist triage and prioritization for neuroimaging or specialist evaluation	Neurological examination, fundoscopy, CT, MRI, and lumbar puncture when appropriate	Best used as a screening adjunct rather than a definitive diagnostic test	(Tlaiss et al., 2025)

11. Limitations and Future Directions

Existing evidence is limited due to inconsistent measurement protocols, individual probe orientations, varying distances behind the globe, heterogeneous patient populations, and differing reference standards for ICP. Reported cutoff values are thus not generally applicable and may be influenced by age, anatomy, operator experience, ventilation, positioning, and orbital disease. Having said that, optic nerve sheath diameter cannot accurately measure ICP and should not be used instead of ICP monitoring.

A focus of future research should be the development of a standard protocol for acquisition and reporting, multicenter prospective validation, and setting thresholds for adults and children. A single ICP reading is not sufficient for assessing serial measurements, but rather should be compared to dynamic ICP values. Automated segmentation, 3D ultrasonography, and AI have the potential to increase reproducibility and operator independence. Prediction could be improved by incorporating more data, such as optical coherence tomography, transcranial Doppler, neuroimaging, biomarkers, and clinical scoring systems. Emphasis also needs to be placed on the assessment of perioperative decision thresholds, monitoring of treatment response, cost-effectiveness, and implementation in the emergency, surgical, critical-care, and resource-limited environments.

12. CONCLUSION

Optic nerve sheath diameter has become a useful non-invasive marker to detect elevation of ICP in various specialist fields such as ophthalmology, radiology, general surgery, anaesthesia, emergency and critical care. The clinical value is based on the anatomical continuity of the intracranial and perioptic subarachnoid space, and its behavior is also influenced by the dynamics of the cerebrospinal fluid, vascular congestion, tissue compliance, water transport through aquaporins, and neuroinflammation. Unlike computed tomography and magnetic resonance imaging, which provide complementary structural information, ultrasonography may be used to assess the patient rapidly at the bedside and may also be used to assess any associated neuro-ocular signs. To date, there is a consensus that ONSD may be a valuable screening and monitoring tool in the following clinical settings: TBI, idiopathic intracranial hypertension (IIH), positioning during surgery, pneumoperitoneum, mechanical ventilation, and acute neurological deterioration. It has its drawbacks as it is operator-dependent, has variable thresholds, is anatomically heterogeneous, and cannot accurately quantify ICP. It is important, therefore, that ONSD is viewed as a component of a multimodal approach, and cannot be considered an alternative to invasive monitoring. To enhance reliability, increase clinical uptake and improve patient-centred decision-making safely and securely across different resource and clinical settings globally, standardized protocols, automated image analysis, population-specific reference values and multicenter validation are essential.

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