International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 05 | May - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Non-Invasive ICP Monitoring in Case of Traumatic Brain Injury by Serial Measuring Optic Nerve Sheath Diameter & Pupillometry

Kazi MD Refayetullah [1], Sakib Alam Halder [1]
kazisafwon1111@gmail.com , haldersakib205@gmail.com

[1] Assistant Professor, Institute of Leadership, Entrepreneurship and Development (iLEAD)

INTRODUCTION :

Intracranial pressure (ICP) is a critical physiological parameter that reflects the pressure within the skull. Accurate monitoring of ICP is essential for managing neurological conditions such as traumatic brain injury (TBI), hydrocephalus, intracranial hemorrhage, and other disorders that may lead to increased ICP. Traditionally, ICP monitoring has relied on invasive methods, such as ventricular catheters or intra-parenchymal sensors, which, although accurate, carry risks of infection, hemorrhage, and other complications.

Early work done by Guillaume and Janny in 1951, followed by Lundberg's magnum opus in 1960 laid the foundation for subsequent developments in intracranial pressure (ICP) monitoring
.The association between raised ICP and poor neurological outcome has been widely reported, with distinct clinical and therapeutic implications. Though some reports have questioned the merits of monitoring ICP, the diagnostic and therapeutic role of invasive monitoring techniques, especially in traumatic brain injury (TBI), has been well supported. The benefits of reliably and non-invasively assessing ICP, however, have also been described, and while invasive ICP monitoring remains the gold standard, the development of accurate, non-invasive alternatives is ongoing. Perhaps the most benefit of a reliable non-invasive technique lies in early detection, especially where the clinical presentation of raised ICP may be subtle. (1)

Intracranial pressure (ICP) refers to the pressure generated by the contents of the cranial cavity [brain tissue, blood, and cerebrospinal fluid (CSF)] on the wall of the cranial cavity. ICP is usually measured in millimetre of mercury and centimetre water column, and normal ICP in supine adults is 7–15, 5–15, or 0–15 mmHg in the literature. Intraocular pressure (IOP) is the pressure exerted by the eye's contents on the wall and the interaction between the contents of the eyeball. IOP is usually measured in millimetre of mercury. The normal IOP range is from 10–21 mmHg. IOP and ICP are 2 sets of pressure systems that are interrelated and relatively independent. Through the circulation of the aqueous humour and CSF, ICP and IOP are relatively stable. (2)

Non-invasive ICP monitoring offers a safer, less invasive alternative to assess ICP. These techniques utilize advanced imaging, physiological signals, and bioengineering principles to estimate ICP without breaching the skull or dura mater. They are particularly valuable in situations where invasive monitoring is contraindicated, unavailable, or unsuitable, such as in resource-limited settings, outpatient care, or during routine screenings.

While non-invasive methods may not yet match the precision of invasive techniques, their portability, repeatability, and safety make them a vital tool in modern neurology, neurosurgery, and critical care. Emerging advancements in technology continue to refine their accuracy and broaden their clinical applications, bridging the gap between safety and precision in ICP monitoring.

A mainstay of neurocritical care, intracranial pressure (ICP) monitoring has been used for decades to treat a variety of neurological disorders. While management of ICP is of clear benefit, there is no consensus in the literature about whether ICP monitoring provides any clinic benefit, compared with management based only on the patient's neurological examination, imaging findings and the clinician's judgment. While some studies have shown that ICP monitoring is associated with improved survival rates, others have suggested that this not only is fruitless but also may, in fact, lead to worse clinical outcomes, including increased mortality, longer hospitalization, increased complication rates and increased hospitalization costs, compared with a non-ICP monitoring approach in patients with traumatic brain injury (TBI).

In neurocritical care, non-invasive intracranial pressure (ICP) monitoring is a crucial tool, particularly when invasive techniques are either unavailable, prohibited, or utilized in conjunction with invasive methods. These methods estimate ICP indirectly by assessing surrogate markers such as anatomical, physiological, or functional changes associated with raised ICP.
Below are the key non-invasive ICP monitoring techniques:

1. Optic Nerve Sheath Diameter (ONSD) : The optic nerve sheath is contiguous with the duramater and is sensitive to changes in ICP. Cerebrospinal fluid (CSF) builds up in the sheath as a result of elevated ICP, increasing the sheath's diameter.

2. Pupillometry : Pupillometry is a quantitative, automated method to assess the pupillary light reflex, which is sensitive to changes in ICP.

AIM AND OBJECTIVES:

1. Follow up reducing risks associated with invasive monitoring methods, such as infection or bleeding.
2. Tracking ICP changes in young patients with conditions like traumatic brain injury

REVIEW OF LITERATURE :

Shruti A, Francisco A (2024) recently published " Neuromonitoring in children with traumatic brain injury" they have mention that Traumatic brain injury remains a major cause of mortality and morbidity in children across the world. Current management based on international guidelines focuses on a fixed therapeutic target of less than 20 mm Hg for managing intracranial pressure and 40–50 mm Hg for cerebral perfusion pressure across the pediatric age group. To improve outcome from this complex disease, it is essential to understand the pathophysiological mechanisms responsible for disease evolution by using different monitoring tools. In this narrative review, we discuss the neuromonitoring tools available for use to help guide management of severe traumatic brain injury in children and some of the techniques that can in future help with individualizing treatment targets based on advanced cerebral physiology monitoring.(3)

V Rajajee (2024) recently published an article on "Noninvasive intracranial pressure monitoring: Are we yet? ". In their conclusion they have mentioned that there is an urgent unmet need for a reliable noninvasive tool to detect elevations in intracranial pressure (ICP) above guideline-recommended thresholds for treatment. Elevations in ICP transmitted through the subarachnoid space result in distension of the optic nerve sheath. The optic nerve sheath diameter (ONSD) can be measured with ultrasound, and an ONSD threshold can be used to detect elevated ICP. Although many studies suggest this technique accurately detects elevated ICP, there is concern for risk of bias and variations in ONSD thresholds across studies that preclude routine use of this technique in clinical practice. Multiple transcranial Doppler techniques have been used to assess ICP, but the best studied are the pulsatility index and the Czosnyka method to estimate cerebral perfusion pressure and ICP. Although there is inconsistency in the literature, recent prospective studies, including an international multicenter study, suggest the estimated ICP technique has a high negative predictive value (> 95%) but a poor positive predictive value (≤ 30%). Quantitative pupillometry is a sensitive and objective method to assess pupillary size and reactivity. Proprietary indices have been developed to quantify the pupillary light response. Limited data suggest these quantitative measurements may be useful for the early detection of ICP elevation. No current noninvasive technology can replace invasive ICP monitoring. Where ICP monitoring is unavailable, multimodal noninvasive assessment may be useful. Further innovation and research are required to develop a reliable, continuous technique of noninvasive ICP assessment. (4)

Karol Martinez-Palacios , Sebastian Vasquez-Garciav (2024) published on an article "Quantitative Pupillometry for Intracranial Pressure (ICP) Monitoring in Traumatic Brain Injury: A Scoping Review" The neurological examination has remained key for the detection of

worsening in neurocritical care patients, particularly after traumatic brain injury (TBI). New- onset, unreactive anisocoria frequently occurs in such situations, triggering aggressive diagnostic and therapeutic measures to address life-threatening elevations in intracranial pressure (ICP). As such, the field needs objective, unbiased, portable, and reliable methods for quickly assessing such pupillary changes. In this area, quantitative pupillometry (QP) proves promising, leveraging the analysis of different pupillary variables to indirectly estimate ICP. Thus, this scoping review seeks to describe the existing evidence for the use of QP in estimating ICP in adult patients with TBI as compared with invasive methods, which are considered the standard practice. This review was conducted in accordance with the Joanna Briggs Institute methodology for scoping reviews, with a main search of PubMed and EMBASE. The search was limited to studies of adult patients with TBI published in any language between 2012 and 2022. Eight studies were included for analysis, with the vast majority being prospective studies conducted in high-income countries. Among QP variables, serial rather than isolated measurements of neurologic pupillary index, constriction velocity, and maximal constriction velocity demonstrated the best correlation with invasive ICP measurement values, particularly in predicting refractory intracranial hypertension. Neurologic pupillary index and ICP also showed an inverse relationship when trends were simultaneously compared. As such, QP, when used repetitively, seems to be a promising tool for noninvasive ICP monitoring in patients with TBI, especially when used in conjunction with other clinical and neuromonitoring data. (5)

Chiu-Hao Hsu, Lu-Ting Kuo (2023) published an article on "Application of Pupillometry in Neurocritical Patients" they mentioned that pupillometry has become an important tool in the management of intracranial pathology, with increasing evidence supporting the role of automated pupillometry. Although there are currently no guidelines regarding the routine application of pupillometry, automated pupillometry offers several advantages over traditional subjective manual pupil examination. It provides more precise, objective, and quantitative measurements, with better reliability, and reproducibility. Furthermore, automated pupillometry can detect subtle and early changes in pupil size more accurately, which can aid in early diagnosis and intervention. Further research is needed to establish standardized guidelines for the use of pupillometry in clinical practice and to explore its potential for improving patient outcomes in a variety of intracranial pathologies.(6)

Mehdi T , Amirsasan M (2022) published an article on "The role of repeated brain computed tomography based on ultrasound monitoring of optic nerve sheath diameter after moderate traumatic brain injury" they have mentioned This study investigated the value of ONSD obtained on ocular ultrasonography for the need to repeat a brain CT scan in patients with moderate blunt head TBI. Their results indicate that patients with a difference between the first and second ONSD might have a potential for the progression of the brain injury or the development of a new severe brain injury. Therefore, repeat head CT is recommended in these patients. Also, a decrease in GCS should be an indication for repeating the brain CT scan for these patients. The optic nerve is part of the central nervous system. It is surrounded by the subarachnoid

cerebrospinal fluid and duramater. In the case of increased ICP, the size of the ONSD also increases. Ocular ultrasonography of the ONSD is a simple, noninvasive, and safe method for estimating cerebral ICP that can be an excellent alternative to invasive approaches. As a diagnostic method, ONSD measurement in patients with head trauma by ocular ultrasound was introduced years ago. Measurements are performed with a linear probe 3 mm behind the optic disc, in which the presence of a hypoechoic structure with a size of up to 5 mm is normal; nevertheless, a size above 5.7 mm indicates intracerebral hypertension. Changes in ONSD correlate with ICP variations, so increased ICP (in conditions such as cerebral edema) is associated with elevated ONSD. On the other hand, ONSD decreases in situations where ICP is reduced (e.g., hyperventilation). Therefore, in patients with head trauma, the constant monitoring of ONSD by ocular ultrasonography can help monitor ICP and determine the prognosis of these patients. In one study, patients with reduced ONSD had a good prognosis and usually did not need surgery . In addition to predicting ICP changes, ONSD dynamic changes may help predict bleeding volume and even the outcome in intracranial hemorrhage (ICH) patients. In their study, Skoloudik et al. showed that the size of ONSD increases with bleeding volume in ICH patients. Their study showed that an ONSD size greater than 0.66 mm on an ocular ultrasound could predict a cerebral hemorrhage of more than 2.5 cm3 , with a diagnostic accuracy of >90% . In another study, Bender et al. repeatedly measured ONSD by ocular ultrasound in patients with exacerbating clinical conditions, who often underwent brain CT scans. Their study showed that patients with elevated ONSD had worse outcomes. They also found significant

relationships between elevated ONSD and decreased GCS and ICH bleeding volume also declared in their study that ICH patients had greater ONSD values than individuals without cerebral hemorrhage. Considering the correlation between ONSD and ICP changes, ocular ultrasound could be a reliable tool for monitoring patients with cerebral hemorrhage . In our study, we also found a significant relationship between ONSD size in ocular ultrasound and either newly developed lesions or the progression of incremental lesions observed in brain CT scans. This means that the patients who showed signs of new injuries in the brain CT scan also had elevated ONSD on ocular ultrasound, suggesting the need to repeat the brain CT scan. Overall, ONSD monitoring in the ED can be beneficial for the rapid diagnosis of brain injury. In their study, Guzeldag et al. showed a significant inverse correlation between ONSD and GCS, meaning that with decreasing GCS, there was an increase in the size of ONSD. Consistently, we also showed that the patients who developed new brain injuries or revealed deterioration in brain CT scans also had a decline in GCS, which could be a criterion for repeating the scan. Several studies in this field align with our research . The limitations of this study include being a single-center study, not including patients with severe TBI, pregnant women, obese Repeated brain CT in moderate TBI patients based on ONSD patients, and those under 18 years of age, and the fact that some patients' medical proxies did not give consent for participation. In conclusion, ocular ultrasonography of ONSD can help monitor patients with moderate blunt TBI in the ED. In these patients, increased ONSD on ocular ultrasound appears to be an appropriate criterion for repeating a brain CT scan and performing appropriate therapeutic interventions. (7)

Fawaz Al-Mufti, Brendan S (2018) they have mention that elevated intracranial pressure (ICP) following brain injury contributes to poor outcomes for patients, primarily by reducing the calibre of cerebral vasculature, and thereby reducing cerebral blood flow. Careful monitoring of ICP is critical in these patients in order to determine prognosis, implement treatment when ICP becomes elevated, and to judge responsiveness to treatment. Currently, the gold standard for monitoring is invasive pressure transducers, usually an intraventricular monitor, which presents significant risk of infection and hemorrhage. These risks made discovering non-invasive methods for monitoring ICP and cerebral perfusion a priority for researchers. Herein we sought to review recent publications on novel minimally invasive multi-modality monitoring techniques that provide surrogate data on ICP, cerebral oxygenation, metabolism and blood flow. While limitations in various forms preclude them from supplanting the use of invasive monitors, these modalities represent useful screening tools within our armamentarium that may be invaluable when the risks of invasive monitoring outweigh the associated benefits.(8)

Olson, D. M (2016) published an article on "The Use of Automated Pupillometry in Critical Care " they have mentioned that hospitals across the globe are quickly adopting a practice that includes automated pupillometer assessment. Assessment of pupillary function is a non invasive method of providing vital information about patients current neurologic function. Pupil size, shape, and reactivity provides an indication of CN function for CN II and CN III, as well as providing insight into the sympathetic nervous system functional status. When optimally functional, light stimulus to 1 or both pupils causes constriction of both pupils. Given that the bilateral pathways (afferent and efferent) are intact, the normal finding is that the pupils are equal in size, round, and reactive to light. Abnormal findings are associated with specific injury such as CN III damage, and brainstem or transtentorial herniation. (9)

C. Robba, S. Bacigaluppi (2015) published an article on "Non-invasive assessment of intracranial pressure" Monitoring of intracranial pressure (ICP) is invaluable in the management of neurosurgical and neurological critically ill patients. Invasive measurement of ventricular or parenchymal pressure is considered the gold standard for accurate measurement of ICP but is not always possible due to certain risks. Therefore, the availability of accurate methods to non- invasively estimate ICP has the potential to improve the management of these vulnerable patients. This review provides a comparative description of different methods for non-invasive ICP measurement. Current methods are based on changes associated with increased ICP, both morphological (assessed with magnetic resonance, computed tomography, ultrasound, and fundoscopy) and physiological (assessed with transcranial and ophthalmic Doppler, tympanometry, near-infrared spectroscopy, electroencephalography, visual-evoked potentials, and otoacoustic emissions assessment). At present, none of the non-invasive techniques alone seem suitable as a substitute for invasive monitoring. However, following the present analysis and considerations upon each technique, we propose a possible flowchart based on the combination of non-invasive techniques including those characterizing morphologic changes (e.g., repetitive US measurements of ONSD) and those characterizing physiological changes

(e.g., continuous TCD). Such an integrated approach, which still needs to be validated in clinical practice, could aid in deciding whether to place an invasive monitor, or how to titrate therapy when invasive ICP measurement is contraindicated or unavailable. (10)

Kristiansson, H. (2013) they have mention that Elevated intracranial pressure (ICP) is an important cause of secondary brain injury, and a measurement of ICP is often of crucial value in neurosurgical and neurological patients. The gold standard for ICP monitoring is through an intraventricular catheter, but this invasive technique is associated with certain risks. Intra parenchymal ICP monitoring methods are considered to be a safer alternative but can, in certain conditions, be imprecise due to zero drift and still require an invasive procedure. An accurate noninvasive method to measure elevated ICP would therefore be desirable. This article is a review of the current literature on noninvasive methods for measuring and evaluating elevated ICP. The main focus is on studies that compare noninvasively measured ICP with invasively measured ICP. The aim is to provide an overview of the current state of the most common noninvasive techniques available. Several methods for noninvasive measuring of elevated ICP have been proposed: radiologic methods including computed tomography and magnetic resonance imaging, transcranial Doppler, electroencephalography power spectrum analysis, and the audiological and ophthalmological techniques. The noninvasive methods have many advantages, but remain less accurate compared with the invasive techniques. None of the noninvasive techniques available today are suitable for continuous monitoring, and they cannot be used as a substitute for invasive monitoring.They can, however, provide a reliable measurement of the ICP and be useful as screening methods in select patients, especially when invasive monitoring is contraindicated or unavailable. (11)

Hawthorne, C. (2014) published an article on "Monitoring of intracranial pressure in patients with traumatic brain injury" Since Monro published his observations on the nature of the contents of the intracranial space in 1783, there has been investigation of the unique relationship between the contents of the skull and the intracranial pressure (ICP). This is particularly true following traumatic brain injury (TBI), where it is clear that elevated ICP due to the underlying pathological processes is associated with a poorer clinical outcome. Consequently, there is considerable interest in monitoring and manipulating ICP in patients with TBI. The two techniques most commonly used in clinical practice to monitor ICP are via an intraventricular or intraparenchymal catheter with a microtransducer system. Both of these techniques are invasive and are thus associated with complications such as hemorrhage and infection. For this reason, significant research effort has been directed toward development of a non-invasive method to measure ICP. The principle aims of ICP monitoring in TBI are to allow early detection of secondary hemorrhage and to guide therapies that limit intracranial hypertension (ICH) and optimize cerebral perfusion. However, information from the ICP value and the ICP waveform can also be used to assess the intracranial volume–pressure relationship, estimate cerebrovascular pressure reactivity, and attempt to forecast future episodes of ICH.(12)

Sandy Cecil ,Patrick M. Chen (2011) published an article on "Traumatic Brain Injury: Advanced Multimodal Neuromonitoring From Theory to Clinical Practice" Traumatic brain injury accounts for nearly 1.4 million injuries and 52 000 deaths annually in the United States. Intensive bedside neuromonitoring is critical in preventing secondary ischemic and hypoxic injury common to patients with traumatic brain injury in the days following trauma. Advancements in multimodal neuromonitoring have allowed the evaluation of changes in markers of brain metabolism (eg, glucose, lactate, pyruvate, and glycerol) and other physiological parameters such as intracranial pressure, cerebral perfusion pressure, cerebral blood flow, partial pressure of oxygen in brain tissue, blood pressure, and brain temperature. This article highlights the use of multimodal monitoring in the intensive care unit at a level I trauma center in the Pacific Northwest. The trends in and significance of metabolic, physiological, and hemodynamic factors in traumatic brain injury are reviewed, the technical aspects of the specific equipment used to monitor these parameters are described, and how multimodal monitoring may guide therapy is demonstrated. As a clinical practice, multimodal neuromonitoring shows great promise in improving bedside therapy in patients with traumatic brain injury, ultimately leading to improved neurological outcomes. (13)

EQUIPMENTS :

Ultrasound :

Ultrasound machine is a medical imaging device that uses high-frequency sound waves to create images of internal body structures. These images help in diagnosing and monitoring various medical conditions.

How It Works:

Sound Wave Emission: The device uses a transducer (probe) to emit high-frequency sound waves.

Echoes Detection: These sound waves bounce off tissues, organs, and other internal structures, creating echoes.

Image Formation: The machine processes the echoes to create real-time visuals that are shown on a screen.

Key Components:

Transducer (Probe): Emits sound waves and receives echoes. Comes in a range of sizes and forms based on the intended use.

Types: Linear, Convex, Phased Array, and Endocavity.

Control Panel:
includes knobs and buttons to change parameters including frequency, gain, and depth. allows operators the ability to alter image parameters.

Display Screen:
Displays visuals produced in real time by the reflected sound waves. May display additional data like measurements or Doppler readings.

Central Processing Unit (CPU): Interprets information from the transducer. Converts echoes into a visual image.

Printer and Storage:
These components are optional for printing or storing pictures for documentation.

Doppler Technology (if included):
Measures and displays the flow of blood through organs and arteries.

Common Applications:

- Obstetrics and Gynecology:

following the development of the fetus and looking for anomalies. picturing the ovarian and uterine structures.

- Cardiology:

- Abdominal Imaging:

examining organs such as the bladder, pancreas, kidneys, and liver.

- Musculoskeletal Imaging:

identifying anomalies of the tendons, joints, and soft tissues.

- ONSD measurement:

The most common location for measurements of the optic nerve sheath diameter (ONSD) is 3 mm from the posterior globe edge.

- Vascular Imaging:

identifying blood vessel narrowing or obstructions.

- Guided Procedures:

assisting with fluid drainage, catheter implantation, and needle biopsies. Advantages:

- Non-invasive:

Because there is no radiation, it is safe for delicate groups, such as women who are pregnant.

- Real-Time Imaging:

beneficial for dynamic tests like blood flow or heartbeats.

- Portable:

Compact variants are useful at the bedside or in clinics.

Ultrasound Machine

Pupillometry:

A pupilometer is a medical instrument used to measure the size of the eye's pupil using reflected light. Current automated pupillometers may be able to quantify pupillary light reflex in addition to measuring pupil size.

Types of Pupilometers:

- Manual Pupilometer:

makes use of a basic scale or ruler for measuring.
frequently calls for a qualified expert to measure the pupil size in a steady illumination environment.

- Automated /Electronic Pupilometer:

uses digital screens and sophisticated sensors.
provide measurements that are more accurate, reliable, and instantaneous

How It Works :

The pupil is usually illuminated by visible or infrared light in an automated pupilometer. The pupil's size and reaction to light stimuli are measured using sensors.
On a screen, the results are shown along with additional data including latency and constriction velocity.
Applications :
Neurological Assessment: evaluates a pupil's size and light sensitivity. uses pupillary reflex anomalies to identify neurological conditions including stroke or brain injury.

- Ophthalmology and Optometry: evaluates pupil size in various lighting scenarios for LASIK procedures or contact lens prescriptions.

- Critical Care and Emergency Medicine: uses the pupil light reflex (PLR) in critical care situations to track neurological health. monitors shifts in student reactivity throughout trauma evaluations.

- Research and Psychology: used in pupil dilation-based research on emotional reactions, cognitive load, and attention. Advantages of Pupilometers :

gives measurements that are repeatable and objective. minimizes the error margin brought on by human interpretation. helpful when precision is crucial particularly in low light.

Pupillometry

MATERIALS & METHODS:

LOCATION OF STUDY – The study was conducted on all traumatic brain injury patients admitted in ITU at a tertisry hospital located at Kolkata over a period of 6 months. (june 2024 to November 2024)

Inclusion Criteria:

1. patient with alleged history of Traumatic Brain Injury - The study's expected outcome is that the ONSD/PUPILLOMETRY ratio will increase in TBI cases and mirror the rise in ICP, determining TBI severity. We anticipate a strong correlation between the ONSD/ PUPILLOMETRY ratio, which could serve as an adjunct parameter. Additionally, the ONSD/ PUPILLOMETRY ratio combined with the QPi's may provide a congruent review of clinical severity at presentation with progression reflected by the GCS.

Procedure :

- Optic Nerve Sheath Diameter (ONSD)

Non-invasive intracranial pressure (ICP) monitoring, typically assessed through various methods, can be measured using a technology called Optic Nerve Sheath Diameter (ONSD**)**.This method evaluates variations in the optic nerve sheath diameter, which are correlated with variations in intracranial pressure, using ultrasonography.

O

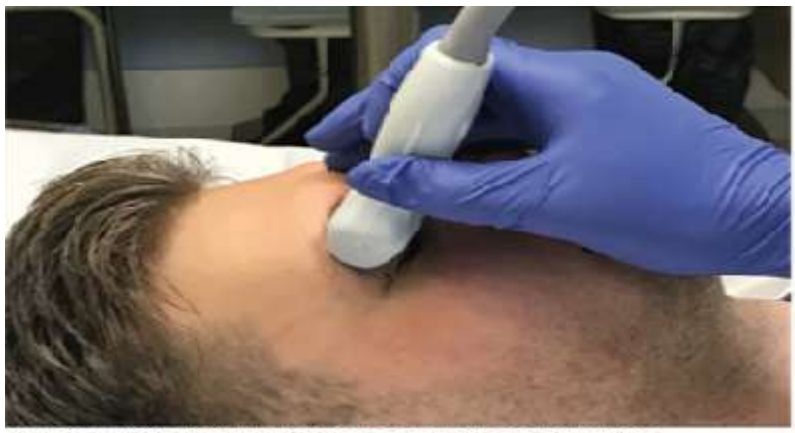


Figure 1. Measurement of the optic nerve sheath diameter

Optic Nerve Sheath Diameter (ONSD)

- Anatomical Basis:

Cerebrospinal fluid (CSF) surrounds the optic nerve, and variations in intracranial pressure (ICP) impact the CSF compartment's volume and pressure. Ultrasound can show the distention of the optic nerve sheath caused by a rise in intracranial pressure.

- Measurement Technique:

A linear probe (Philips) was used for ONSD evaluation. The probe was placed on the closed upper eyelid, and ONSD was evaluated 3 mm behind the retinal papilla. Two measurements were obtained from each optic nerve: the first in the transverse plane and the second in the sagittal plane (14). Non invasive intracranial pressure measured by ONSD was derived from a mathematic formula described elsewhere in the literature (15,16). ICP values >20 mmHg were again considered indicative of intracranial hypertension (17).

- Advantages of ONSD Monitoring:

Non-invasive: ONSD measurement eliminates the need for invasive procedures, in contrast to conventional ICP monitoring techniques such lumbar puncture or intraventricular catheterization.

Real-time Assessment: In some therapeutic contexts, it can be carried out quickly and repeatedly, enabling continuous ICP monitoring.

Portable and Accessible: Ultrasound devices are often portable and widely available, which makes ONSD measurement suitable for emergency or intensive care settings.

Clinical Application:

Patients with traumatic brain injury (TBI), stroke, or other disorders that may result in intracranial pressure benefit from it when ongoing ICP monitoring is required.

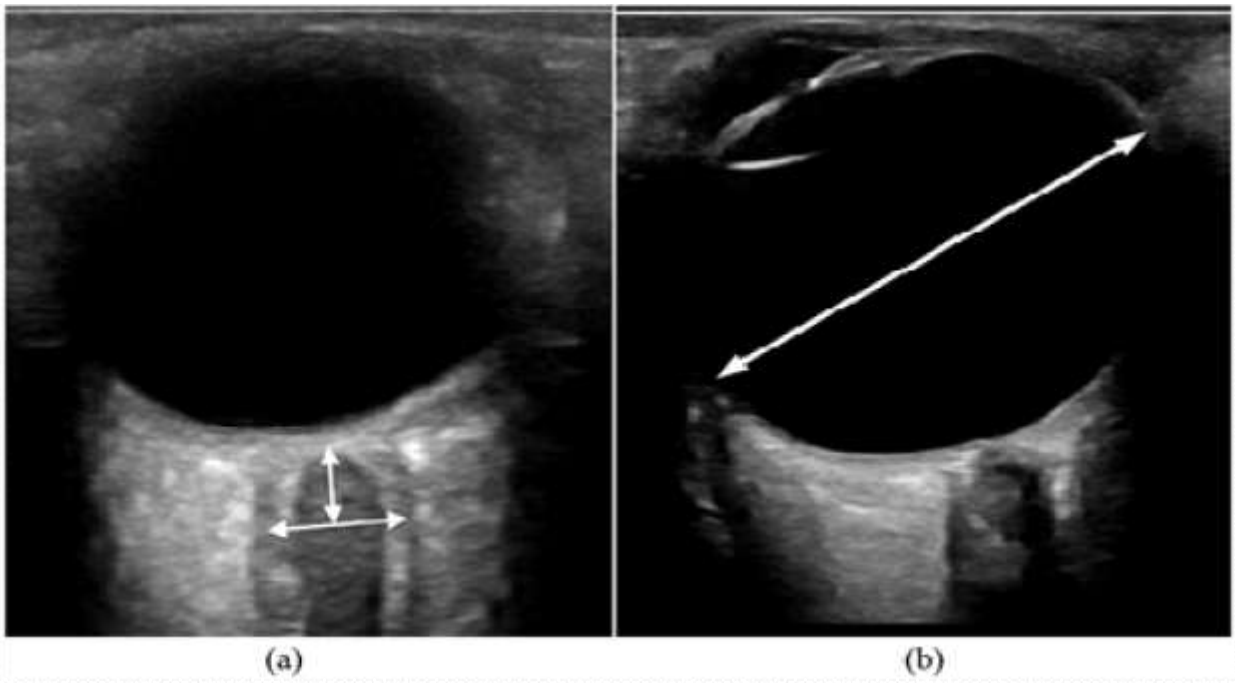
To increase diagnostic accuracy, ONSD measurement is frequently employed in conjunction with other clinical evaluations and monitoring tools, even though it can be a trustworthy indication of ICP changes.

Limitations:

The relationship between ONSD and ICP may not be linear, and factors such as age, body position, or pre-existing optic nerve conditions can affect results.

Patients with low ICP or those with other underlying disorders that impair the optic nerve may have less reliable ONSD measurements.

Ultrasound assessment of ONSD offers a non-invasive and efficient means of estimating changes in ICP, which makes it a useful tool in clinical settings, especially for continuous monitoring or in situations where invasive approaches are impractical.



Ultrasound images showing of ONSD measurement

- Pupillometry

Pupillometry is another non-invasive method used to monitor intracranial pressure (ICP). It involves measuring the size and reactivity of the pupil in response to light. Changes in ICP can affect the autonomic control of the eye, including pupil size and reactivity, which is why pupillometry can be useful in detecting elevated ICP.

A classical approach to the neurological trauma examination includes two parts: the Glasgow Coma Scale score and the pupil examination. Although the Glasgow Coma Scale score can be replicated with reasonable consistency, several studies have demonstrated that the same cannot be said for the manual evaluation of the patient's pupillary light refexes (PLRs), whose measurement may be biased by subjective estimations of pupillary size and reactivity, as well as other factors, such as diferent degrees of ambient light during the examination. Tis leads to wide measurement discrepancies, with only 33.3% of pupils scored as nonreactive by health care practitioners also being scored as nonreactive by quantitative pupillometry (QP) (18,19)
The standard pupil examination involves assessing pupil size, shape, symmetry, and the PLR. The PLR is a strong predictor of outcome and survival after brain injury, such as traumatic brain injury (TBI) [20] or subarachnoid hemorrhage [21].

Mechanism of Action:

ICP and Pupil Function: The autonomic pathways that control the pupils (including the oculomotor nerve) are vulnerable to changes in intracranial pressure. Increased ICP can lead to pressure on the brainstem, which affects the pupillary light reflex, causing changes in pupil size and reactivity.

When ICP rises, there can be a loss of normal pupillary constriction in response to light, resulting in abnormal pupil responses. Specifically, it can lead to unequal pupil sizes (anisocoria), slow reaction times, or a fixed, dilated pupil in extreme cases.

How Pupillometry Works:

Pupillometry measures and logs the pupil's reaction to light stimulation using specialized equipment.It measures parameters like:

Pupil Diameter:the pupil's size under typical illumination conditions.

Pupil Response to Light:the rate and magnitude of dilatation and constriction following a light stimulation.

Latency and Velocity of Response:The pupil's rate of dilation or contraction in response to light.

To evaluate variations in ICP, these measurements are made objectively and can be made repeatedly.
Clinical Use in ICP Monitoring:

To keep an eye out for early indications of elevated ICP, pupillometry is commonly utilized in emergency rooms and critical care units.

Slow or unresponsive pupils could be a sign of an elevated ICP. For example, unusual pupil size or reactivity may suggest that further investigation or treatment is necessary for increased ICP.

Continuous Monitoring: Some advanced pupillometry systems allow for continuous or repeated assessments, offering a way to track changes in pupil response over time. This can be valuable for managing patients with fluctuating ICP.
Advantages of Pupillometry :

1. Non-invasive :

Pupillometry is less dangerous because it doesn't involve any surgery or the implantation of equipment like intraventricular pressure monitors.

2. Fast and Convenient:

Pupillometry is a simple procedure that can be carried out in emergency departments, intensive care units, or on patients who have limited access to other monitoring equipment. It can give prompt feedback on changes in ICP.

3. Real-time Monitoring:

It provides frequent or continuous measurements, which is useful for identifying minute variations in ICP before they become serious.

4. Objective Data:

Automated pupillometry reduces the subjectivity of clinical evaluation by providing accurate, repeatable

measurements.

Limitations of Pupillometry

1. Sensitivity and Specificity:

Pupillometry is not totally specific to increased ICP, although it might be a useful technique. Pupil responses may also be impacted by additional variables, such as drug usage, neurological conditions, or ocular injuries.

2. Not a Standalone Tool:

Pupillometry is usually used to confirm or rule out elevated ICP in combination with other diagnostic procedures and clinical assessments. Using pupil size or reactivity alone to diagnose excessive ICP is not always enough.
A useful non-invasive method for tracking intracranial pressure, particularly in critical care situations, is pupillometry. It offers objective, up-to-date information on pupil size and reactivity in real time, which can reveal variations in ICP. Although it is a helpful supplement to other diagnostic techniques, it is crucial to take into account its drawbacks and employ it in conjunction with a thorough patient monitoring strategy.

Data/statistical analysis :

We meticulously added each data point to our study database using the Statistical Package for Jeffreys's Amazing Statistics Program (JAPS) version 0.18.3.0. A descriptive analysis used frequency (number percent) as the expression for categorical characteristics. We used analytical statistics, the chi-square test was used to check the significance of difference between frequency distribution of data in different groups and the p-value to assess significance after calculating the means for continuous variables. We calculated the GCS, ONSD, PUPILLOMETRY (Qpi,size variation, anisocoria) and ONSD/Qpi ratios to ascertain their sensitivity, specificity, and positive and negative predictive values. We computed the average or mean ONSD and pupillometry of both eyes. We primarily correlated the ONSD/PUPILLOMETRY (left & right Qpi) ratio with the radio-pathological severity and prognosis provided by GCS to establish its potential role as an adjunct surrogate for raised ICP. The correlation analysis encompassed these variables, along with gender and age. We used the chi-square test to determine significance, accepting a p-value of less than 0.05 as the threshold for statistical significance.

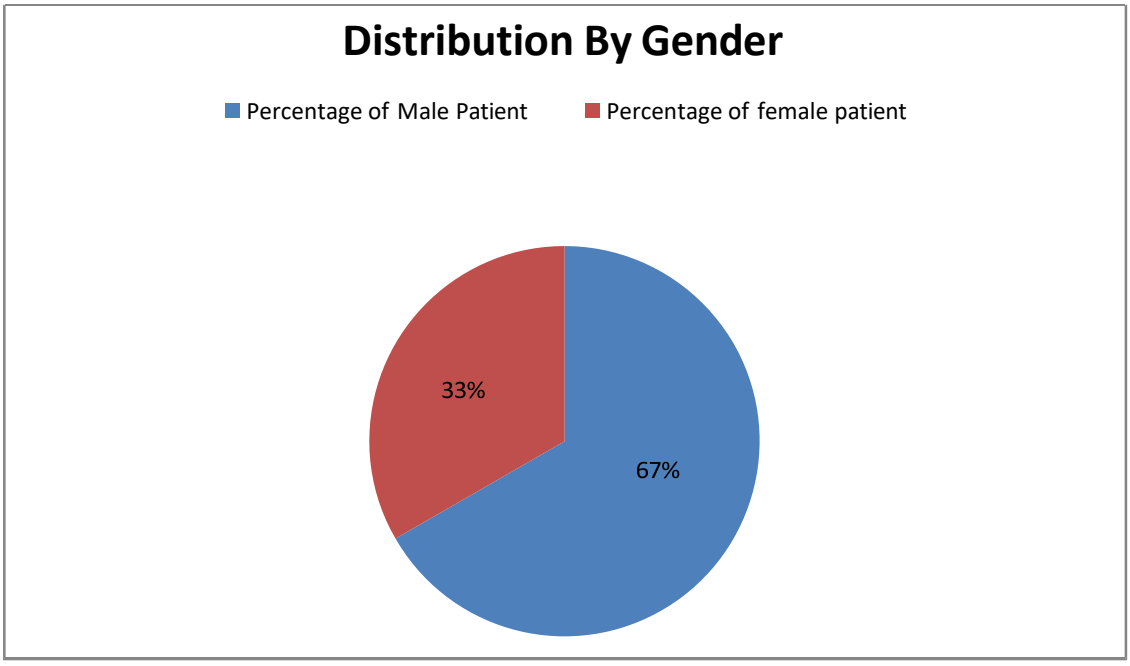
Machine &Instruments :

.Pupillometer :Neurolight portable pupillometer (SM 2024 – 379)

Ultrasound : Venue Go (SM – VC0009303)

INTERPRITATION OF THE RESULTS:

This study included 51 patients and comprised 34 male patients (66.67%) and 17 female patients (33.33%).



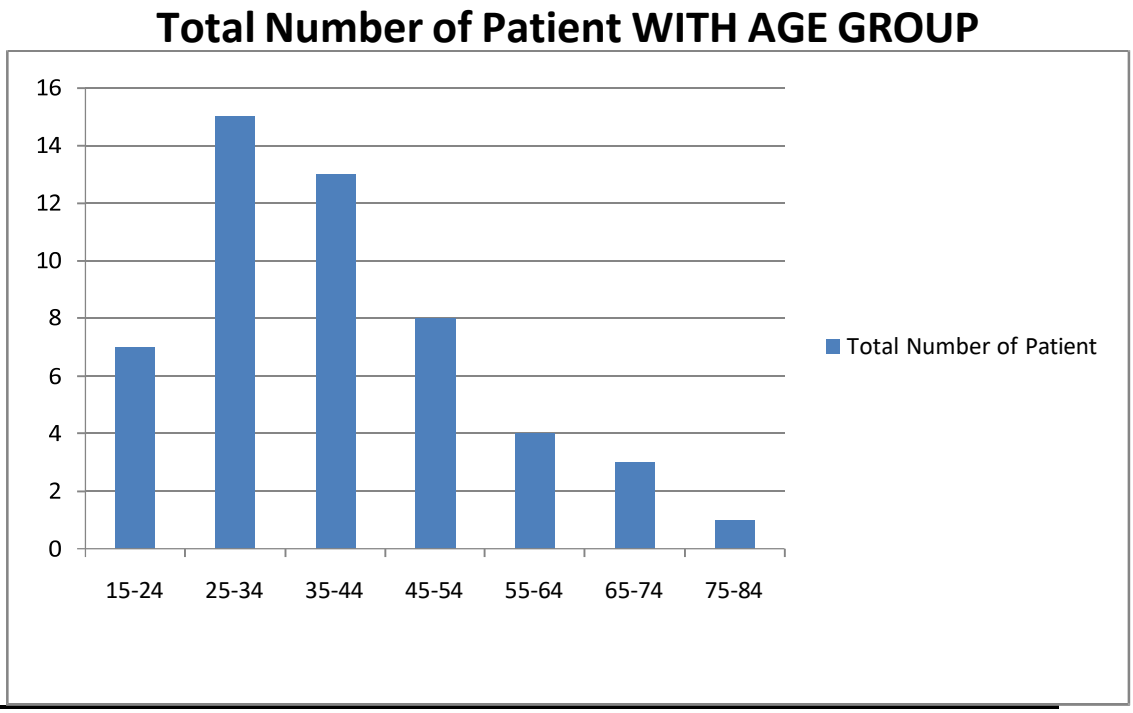
Graphical Presentation of Distribution of Gender in Study Population

The study population's baseline features revealed significant differences in essential measurements and demographic data.

The age distribution was as follows :

PATIENTS AGE	NUMBER OF PATIENT	MALE	FEMALE
15-24	7	5	2
25-34	15	8	7
35-44	13	10	3
45-54	8	6	2
55-64	4	2	2
65-74	3	2	1
75-84	1	1	0
TOTAL	**51**	**34**	**17**

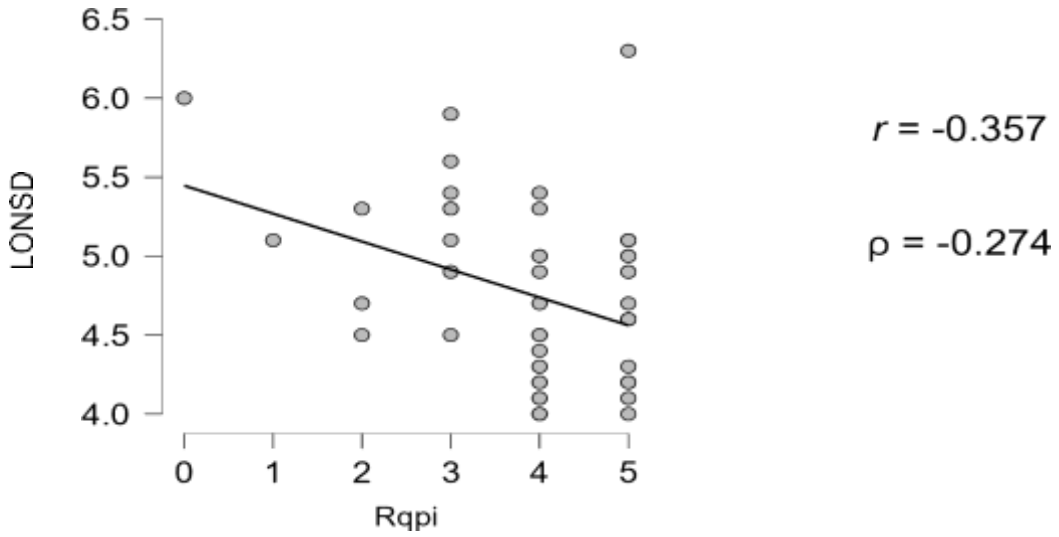
Age group with gender of patient



Graphical Presentation of Distribution of Age in Study Population

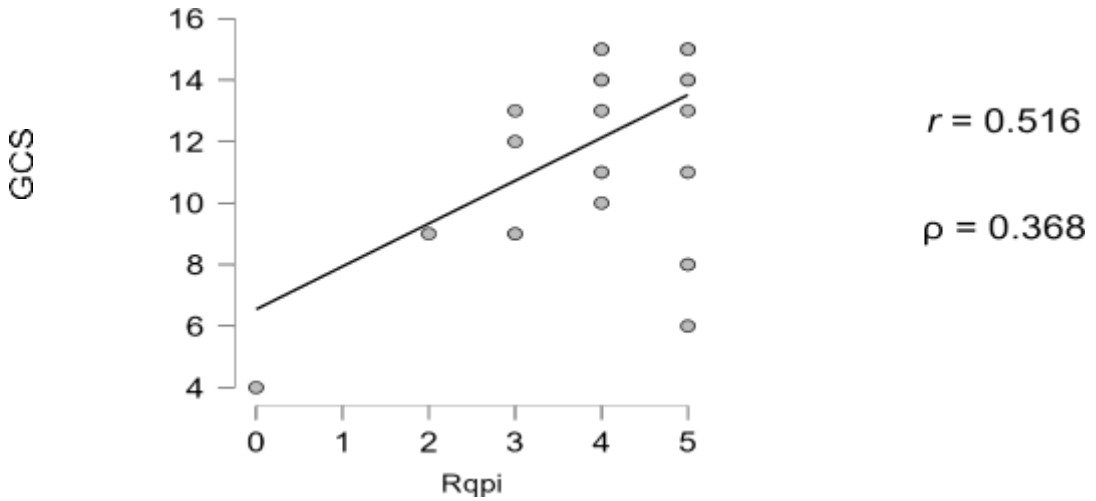
correlations -

1. Correlation between Right Qpi (Quantitative Pupillometry Index) and left ONSD (optic nerve sheath diameter): Decrease RQpi and left onsd will increased (ICP elevated) ;
Significant P value (P) = 0.01



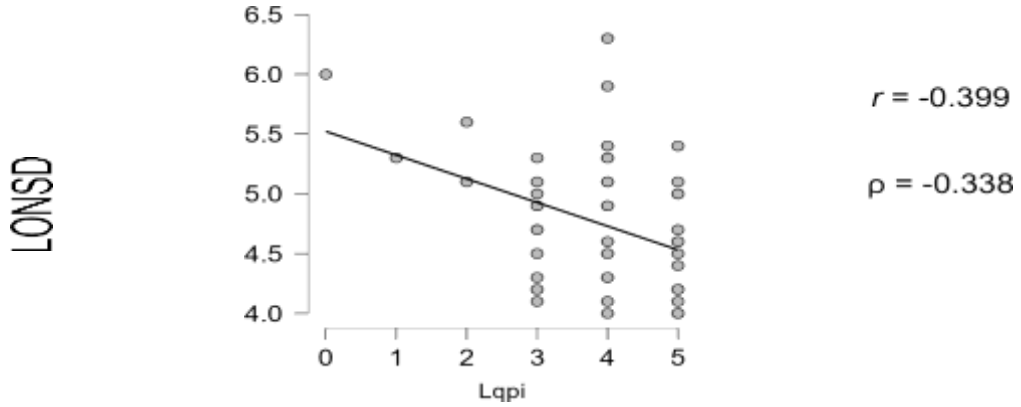
[LONSD – left optic nerve sheath diameter; RQpi –Right Quantitative Pupillometry Index; ICP - intracranial pressure ; r -pearson correlation coefficient (-0.357) ; ρ - Spearman correlation coefficient (-274)]

Correlation between GCS (Glasgow Coma Scale) and Right Qpi (Quantitative Pupillometry Index) : decrease GCS and RQpi increase (ICP elevated) ; Significant P value (P) = 0.002



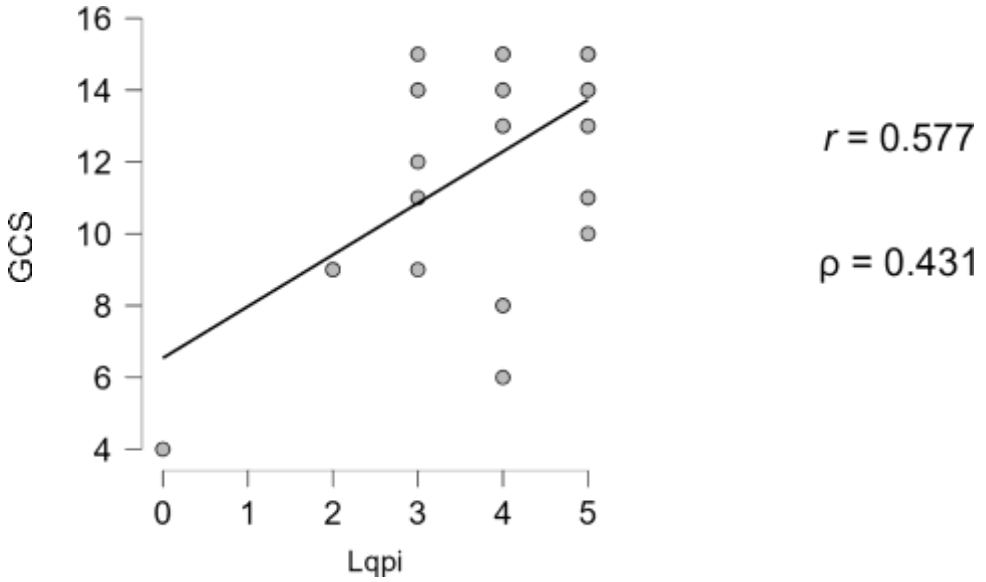
[GCS - Glasgow Coma Scale ; R Qpi – Right Quantitative Pupillometry Index ; r - pearson correlation coefficient (0.516) ; ρ - Spearman correlation coefficient (0.368)]

2. Correlation between Left Qpi (Quantitative Pupillometry Index) and Left ONSD (optic nerve sheath diameter): decrease LQpi , increase LONSD then increase ICP : Significant P value (P) = 0.004



[LONSD – left optic nerve sheath diameter: LQpi – left Quantitative Pupillometry Index: - r - pearson correlation coefficient (-0.399) ; ρ - Spearman correlation coefficient (-0.338)]

3. Correlation between GCS (Glasgow Coma Scale) and Left qpi (Quantitative Pupillometry Index) : decrease GCS, increase left Qpi then increase ICP; Significant P value (P) = 0.001



[GCS - Glasgow Coma Scale : LQpi – Left Quantitative Pupillometry Index ; **- r - pearson correlation coefficient (0.577) ; ρ - Spearman correlation coefficient (0.431)]**

PARAMETERS	VALID	MISSING	MEAN	STANDER DEVIATION	MINIMUM	MAXIMUM
AGE	51	0	38.745	13.467	16.000	72.000
RQPi	51	0	3.961	1.131	0.000	5.000
LQPi	51	0	3.922	1.129	0.000	5.000
RSIZE	51	0	4.063	0.837	2.300	6.070
LSIZE	51	0	4.127	1.103	0.050	6.120
RVAR	51	0	33.627	9.792	8.000	48.000
LVAR	51	0	0.335	0.096	0.100	0.490
ANISOCORIA	51	0	0.446	0.425	0.000	2.600
RONSD	51	0	4.670	0.574	4.000	6.400
LONSD	51	0	4.745	0.560	4.000	6.300
TOTAL GCS	51	18	12.333	2.955	4.000	15.00

DEMOGRAPIC PARAMETERS

Discussion :

ICP assessment plays an important role in the monitoring and early warning of neurological diseases and in determining the occurrence, development, and prognosis of many diseases. The non-invasive, safe, and accurate measurement of ICP has been clinicians' focus for many years. Because of the optic nerve's anatomic characteristics, most non-invasive ICP detection methods are focused on the optic nerve and its surroundings. ICP detection has 2 aspects. The first is the increase of ICP, which is suitable for tumor, trauma, hemorrhage, and other brain and spinal cord diseases. The second is that low ICP can be used to evaluate glaucoma in ophthalmology. Also, ophthalmic signs of low ICP have been found in patients with low CSF pressure/ volume syndromes, such as spontaneous intracranial hypotension and CSF leaks. For the measurement of the optic nerve, the ONSD is the most commonly used method. (22)

Increased ICP is a common finding in TBI patients. In fact, increased ICP measured with both ONSD and PUPILLOMETRY was very common, and a large portion of patients exhibited altered papillary reactivity.

TBI patients noninvasive ICP monitoring may be essential for the early detection of patients. The incongruity between

the results of the two noninvasive methods might be explained by differences in pathophysiological sensitivity and specificity for ICP assessment between the two both techniques can present important methodological limitations (intra-interobserver, variability, and low accuracy in estimating ICP as a number). Although we found no correlation between altered neuromonitoring findings and the occurrence of neurological complications, we strongly recommend the use of these methods in TBI patients. In general, in ICU patients undergoing mechanical ventilation for the early detection of neurological complications. Noninvasive neuromonitoring tools are safe, quick, low-cost, and easily available and can provide relevant data at the patient's bedside.

In most cases, the increase of ICP will lead to the transfer of CSF to ONS and increase the ONSD. Similarly, when the ICP decreases, CSF returns to the subarachnoid space, and ONSD decreases accordingly. However, the process mentioned above needs to follow the elastic conservation so that the ONS can return to the original diameter after expansion, which is suitable for the application of ONSD to estimate ICP (23). However, in some cases, such as the rupture of intracranial aneurysms, ICP can suddenly rise, which will cause acute irreversible expansion of the ONS. At this time, the ONSD cannot accurately reflect ICP changes (24). Also, when ICP is elevated for the long term, the ONS will lose its elasticity due to long-term expansion, and the optic nerve edema will continue well after the ICP returns to normal; optic nerve atrophy after the optic nerve edema subsidies will also make the ICP estimation inaccurate. Therefore, the application of the ONSD to evaluate ICP has its limitations (25).

This study is the first to use the ONSD-to- pupillometry (Quantitative Pupillometry Index} ratio as a tool correlating with the GCS. We found a robust and independent correlation between the ONSD/QPi ratio and both GCS who had suffered TBI. A sequential increase in the ONSD/Qpi ratio, low GCS scores were critical predictors of TBI outcomes. In total, 51 patients met the inclusion criteria. The ONSD values of >5.5 mm respectively, were significantly linked with elevated ICP.

the ONSD are set at 5.5 mm to indicate normal and elevated ICP respectively. These values align with the findings of Vaiman et al., who reported that in healthy individuals, the ONSD ranges from 3.65 mm to 5.5 mm (26)

We recommend the USG measurement of the ONSD/QPi ratio due to its safety, no ionizing radiation, ability to provide immediate results in the ICU and ER at the point of care. However, USG has disadvantages, such as dependency on skilled personnel and potential delays in diagnostics due to human resource logistics.

Different authors use different techniques for measuring ONSD; some measure 3 mm from the eyeball. (27)

The ONSD are independent parameters that predict outcomes in TBI, and they are much less variable than the ONSD for ICP monitoring. In this regard, we aimed to evaluate the ONSD/QPi ratio measurement on the sequential in correlation with the GCS. A timely diagnosis of raised ICP secondary to a TBI suggests a poor prognosis and is crucial for management.

Conclusions:

Neurological complications are common in TBI patients and are associated with longer hospital and ICU stay. The duration of mechanical ventilation is strongly associated with the development of neurological complications. Noninvasiveneuromonitoring during ICU stay may be helpful to detect cerebrovascular alterations earlier. Further studies, including a larger number of patients, may provide new insights on the role of noninvasiveneuromonitoring in TBI patients admitted to ITU.

Using QPi to find the ONSD-to-GCS ratio seems like a practical, non invasive way to measure ICP in people who have had a TBI. Based on known severity markers such as the GCS and QPi, our results show statistically significant connections between the ONSD/QPiratio. A steady rise in the ONSD/QPi ratio, low GCS scores, are all signs that critical ICP is developing in trauma settings. While a high ONSD/QPi ratio is associated with poor outcomes, it is crucial to note that it does not necessarily preclude the possibility of favorable outcomes. Furthermore, it integrates the

ONSD/QPi ratio with other clinical, radiological, and laboratory parameters for comprehensive patient evaluation and management. Future research should focus on multicenter validation analyses and investigations of applications in various clinical settings to demonstrate the role and benefit of the ONSD/QPi ratio in improving triage, monitoring, and outcome prediction for TBI patients.

No current noninvasive technology can replace invasive ICP monitoring. Where invasive monitoring is unavailable, however, multimodal assessment with noninvasive techniques may be useful. Further innovation and research are required to develop a reliable, continuous technique of noninvasive ICP assessment.

REFERENCE :

1. Smith M (2008) Monitoring intracranial pressure in traumatic brain injury.AnesthAnalg 106(1):240–248

2. Ficarrotta KR, Passaglia CL. Intracranial pressure modulates aqueous humour dynamics of the eye. J Physiol 2020;598:403-13

3. ShrutiAgrawal , Francisco Abecasis, Ibrahim Jalloh· Neuromonitoring in Children with Traumatic Brain Injury. Neurocrit Care. 2024 Feb;40(1):147-158. doi: 10.1007/s12028- 023-01779-1

4. VenkatakrishnaRajajee. Noninvasive Intracranial Pressure Monitoring: Are We There Yet?.Neurocrit Care https://doi.org/10.1007/s12028-024-01951-1

5. Karol Martinez-Palacios , Sebastian Vasquez-Garciav. et al. Quantitative Pupillometry for Intracranial Pressure (ICP) Monitoring in Traumatic Brain Injury: A Scoping Review. Neurocrit Care. 2024 Aug;41(1):255-271.doi: 10.1007/s12028-023-01927-7

6. Chiu-Hao Hsu, Lu-Ting Kuo, Application of Pupillometry in Neurocritical Patients, J Pers Med 2023 Jul 5;13(7):1100. doi: 10.3390/jpm13071100

7. Mehdi T ,Amirsasan M et al. The role of repeated brain computed tomography based on ultrasound monitoring of optic nerve sheath diameter after moderate traumatic brain injury. ClinExpEmerg Med 2023;10(1):68-73 https://doi.org/10.15441/ceem.22.340

8. Al-Mufti, F., Smith, B., Lander, M., Damodara, N., Nuoman, R., El-Ghanem, M., … Gandhi, C. D. (2018). Novel minimally invasive multi-modality monitoring modalities in neurocritical care. Journal of the Neurological Sciences, 390, 184–192. doi:10.1016/j.jns.2018.03.032

9. Olson, D. M., &Fishel, M. (2016). The Use of Automated Pupillometry in Critical Care. Critical Care Nursing Clinics of North America, 28(1), 101–107. doi:10.1016/j.cnc.2015.09.003

10. Robba, C., Bacigaluppi, S., Cardim, D., Donnelly, J., Bertuccio, A., &Czosnyka, M. (2015). Non-invasive assessment of intracranial pressure. ActaNeurologicaScandinavica, 134(1), 4–21. doi:10.1111/ane.12527

11. Kristiansson, H., Nissborg, E., Bartek, J., Andresen, M., Reinstrup, P., &Romner, B. (2013). Measuring Elevated Intracranial Pressure through Noninvasive Methods. Journal of Neurosurgical Anesthesiology, 25(4), 372–385. doi:10.1097/ana.0b013e31829795ce

12. Hawthorne, C., & Piper, I. (2014). Monitoring of Intracranial Pressure in Patients with Traumatic Brain Injury. Frontiers in Neurology, 5. doi:10.3389/fneur.2014.00121

13. Cecil, S., Chen, P. M., Callaway, S. E., Rowland, S. M., Adler, D. E., & Chen, J. W. (2010). Traumatic Brain Injury: Advanced Multimodal NeuromonitoringFrom Theory to Clinical Practice. Critical Care Nurse, 31(2), 25–37. doi:10.4037/ccn2010226

14. Olson DM, Stutzman S, Saju C, Wilson M, Zhao W, Aiyagari V. Interraterreli- ability of pupillary assessments. Neurocrit Care. 2016;24(2):251– 7.https://doi.org/10.1007/s12028-015-0182-1

15. Boulter JH, Shields MM, Meister MR, Murtha G, Curry BP, Dengler BA. The expanding role of quantitative pupillometry in the evaluation and man-agement of traumatic brain injury. Front Neurol. 2021;12: 685313. https:// doi.org/10.3389/fneur.2021.685313.

16. Klein, S.P.; Depreitere, B. What Determines Outcome in Patients That Suffer Raised Intracranial Pressure after Traumatic Brain Injury. In Intracranial Pressure &Neuromonitoring XVI; Springer: Berlin/Heidelberg, Germany, 2018; pp. 51–54.

17. Lieberman, J.D.; Pasquale, M.D.; Garcia, R.; Cipolle, M.D.; Mark Li, P.; Wasser, T.E. Use of Admission Glasgow Coma Score, Pupil Size, and Pupil Reactivity to Determine Outcome for Trauma Patients. J. Trauma Inj. Infect. Crit. Care 2003, 55, 437–443. [CrossRef] [PubMed]

18. Robba C, Santori G, Czosnyka M, Corradi F, Bragazzi N, Padayachy L, et al. Optic nerve sheath diameter measured sonographically as non-invasive estimator of intracranial pressure: a systematic review and meta-analysis. Intensive Care Med. (2018) 44:1284–94. doi: 10.1007/s00134-018-5305-7

19. Robba C, Cardim D, Tajsic T, Pietersen J, Bulman M, Donnelly J, et al. Ultrasound non-invasive measurement of intracranial pressure in neurointensive care: a prospective observational study. PLoS Med. (2017) 14:e1002356. doi: 10.1371/journal.pmed.1002356

20. Zafar SF, Suarez JI. Automated pupillometer for monitoring the critically ill patient: a critical appraisal. J Crit Care.(2014) 29:599–603.doi: 10.1016/j.jcrc.2014.01.012

21. Giacobbe DR, Battaglini D, Ball L, Brunetti I, Bruzzone B, Codda G, et al. Bloodstream infections in critically ill patients with COVID-19. Eur J Clin Invest. (2020) 50:e13319. doi: 10.1111/eci.13319

22. Vaiman M, Gottlieb P, Bekerman I: Quantitative relations between the eyeball, the optic nerve, and the optic canal important for intracranial pressure monitoring. Head Face Med. 2014, 10:32. 10.1186/1746- 160X-10-32

23. Kimberly HH, Noble VE: Using MRI of the optic nerve sheath to detect elevated intracranial pressure .Crit Care. 2008, 12:181. 10.1186/cc7008

24. Zoerle T, Caccioppola A, D'Angelo E, Carbonara M, Conte G, Avignone S, Zanier ER, Birg T, Ortolano F, Triulzi F, Stocchetti N. Optic Nerve Sheath Diameter is not Related to Intracranial Pressure in Subarachnoid Hemorrhage Patients. Neurocrit Care 2020;33:491-8.

25. Rajajee V, Fletcher JJ, Rochlen LR, Jacobs TL. Comparison of accuracy of optic nerve ultrasound for the detection of intracranial hypertension in the setting of acutely fluctuating vs stable intracranial pressure: post-hoc analysis of data from a prospective, blinded single center study. Crit Care 2012;16:R79.

26. Raffiz M, Abdullah JM. Optic nerve sheath diameter measurement: a means of detecting raised ICP in adult traumatic and non-traumatic neurosurgical patients. Am J Emerg Med 2017;35:150-3.

27. Hsu, C.-H.; Kuo, L.-T.Application of Pupillometry in Neurocritical Patients.J. Pers. Med. 2023, 13, 1100. https://doi.org/0.3390/jpm13071100

ABBREVIATIONS :

TBI	Traumatic brain injury
ICP	Intracranial pressure
IH	Intracranial hypertension
ONSD	Optic Nerve Sheath Diameter
CSF	Cerebrospinal fluid
QPi	Quantitative Pupillometry Index
IOP	Intraocular pressure
GCS	Glasgow coma scale
VAR	Variation