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Article

Ultrasound-Based Evaluation of Optic Nerve Sheath Diameter as a Predictor of Elevated Intracranial Pressure in Pakistani Population

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AN, MF: concept, design, data collection; AA, HA, AN, MM: analysis, manuscript drafting; MA: supervision, review.

ABSTRACT

Background: Early detection of elevated intracranial pressure (ICP) is crucial for preventing neurological morbidity and mortality, yet resource constraints and the invasiveness of gold-standard ICP monitoring pose challenges in many clinical settings. Despite increasing evidence supporting optic nerve sheath diameter (ONSD) measurement via ultrasound as a non-invasive proxy, data specific to the Pakistani population remain limited. **Objective**: This study aimed to evaluate the diagnostic utility of ultrasound-based ONSD measurement as a predictor of elevated ICP in symptomatic Pakistani adults, hypothesizing a strong correlation between ONSD enlargement and clinical or imaging evidence of increased ICP. **Methods**: A prospective observational study was conducted at Farooq Hospital, Lahore, enrolling 96 adults aged 18–40 years with suspected elevated ICP. Inclusion required compatible symptoms and informed consent; individuals with prior ocular pathology or neurosurgical intervention were excluded. Bilateral ONSD was measured by blinded radiologists using standardized ultrasound protocols, and ICP status was determined using clinical and imaging criteria. Statistical analyses included chi-square tests, odds ratios, and logistic regression using SPSS v26. The study received ethical approval and complied with the Helsinki Declaration. **Results**: Elevated right ONSD was observed in 60.4% and left ONSD in 58.3% of participants. Elevated ONSD was associated with a significantly higher likelihood of raised ICP (odds ratio 9.14, 95% CI 1.88–44.36, $p = 0.001$), with strong bilateral agreement (kappa 0.797, $p < 0.001$). **Conclusion**: Ultrasound-based ONSD measurement is a reliable, non-invasive tool for detecting elevated ICP in the Pakistani population and may enhance early diagnosis and management in resource-limited settings.

Keywords: Intracranial Pressure, Optic Nerve Sheath Diameter, Ultrasonography, Emergency Medicine, Non-Invasive Monitoring, Pakistan, Neurocritical Care

INTRODUCTION

Elevated intracranial pressure (ICP) represents a critical concern in neurological practice due to its association with potentially life-threatening conditions such as traumatic brain injury, space-occupying lesions, hydrocephalus, and other neuropathologies. Timely and accurate detection of raised ICP is essential, as delays in recognition can lead to irreversible neurological damage and significantly increased mortality (2). Traditionally, direct measurement of ICP is achieved through invasive methods such as ventriculostomy or intraparenchymal pressure monitoring, which, while considered gold standards, are associated with considerable risks including hemorrhage, infection, and limited feasibility in certain patient populations (7,30). In resource-constrained settings and among critically ill or unconscious patients, the need for a rapid, reliable, and non-invasive method for ICP assessment is especially pronounced (11,19). As a result, the exploration of alternative modalities has gained substantial clinical relevance.

The optic nerve sheath (ONS), an extension of the brain's meningeal coverings, is anatomically continuous with the subarachnoid space, allowing cerebrospinal fluid (CSF) to surround the optic nerve (1). Elevations in ICP are transmitted to the ONS, resulting in measurable sheath distension. Ultrasonographic measurement of the optic nerve sheath diameter (ONSD) has emerged as a practical, bedside technique to indirectly estimate ICP, offering the advantages of safety, repeatability, and speed (2,3,10). Numerous

studies across diverse clinical contexts suggest that ONSD thresholds—typically greater than 5.0–5.7 mm in adults—correlate strongly with raised ICP, with reported sensitivities and specificities supporting its use as a surrogate marker (13,14,17). Evidence from recent meta-analyses underscores the utility of ONSD measurement in detecting intracranial hypertension, further supporting its adoption in emergency and critical care settings (14,17,28).

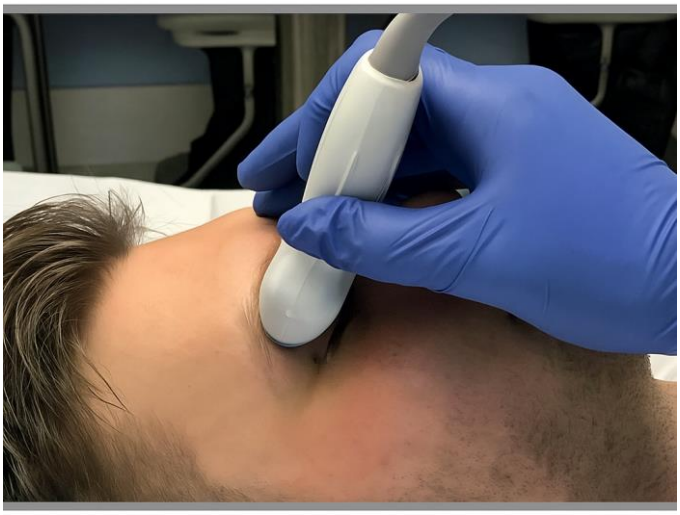

Figure 1 Ultrasound measurement of the optic nerve sheath diameter (ONSD)

Despite these advances, there is variability in ONSD cut-off values and interpretation depending on patient populations, clinical circumstances, and methodological differences in ultrasound technique (14,18,27). Furthermore, while extensive research has validated the relationship between ONSD and ICP in Western and East Asian populations, there remains a paucity of large-scale, population-specific data from South Asia, particularly in Pakistan. This gap is noteworthy, given differences in access to neuroimaging, critical care infrastructure, and the prevalence of neurological emergencies in local practice (6,21). Establishing normative ONSD values and validating its predictive accuracy for ICP elevation in Pakistani adults would not only enhance the clinical management of neurological emergencies but also support the development of localized guidelines and training for bedside ultrasonography. In light of the above, the present study was designed to evaluate the diagnostic performance of ultrasound-based ONSD measurement for the prediction of elevated intracranial pressure among Pakistani adults presenting with clinical suspicion of ICP elevation. The study aims to clarify the correlation between ONSD values and directly assessed ICP, determine appropriate diagnostic thresholds, and assess the practical feasibility of this technique in a resource-limited tertiary care setting. The central research objective is to establish whether ONSD measurement by ultrasound serves as a reliable, non-invasive predictor of elevated ICP in the local population, thereby supporting improved clinical outcomes and resource optimization (3,14,21).

MATERIALS AND METHODS

This prospective observational study was conducted at Farooq Hospital in Lahore, Pakistan, from January to April 2024. The hospital serves as a tertiary care center for neurological and general emergencies in an urban setting, with access to both critical care and advanced neuroimaging facilities. The rationale for selecting this design was to enable systematic, real-time evaluation of optic nerve sheath diameter (ONSD) via ultrasound as a non-invasive predictor of elevated intracranial pressure (ICP) in a clinical population at risk of this condition.

Participants were adults aged 18 to 40 years who presented to the emergency department or neurology service with symptoms suggestive of elevated ICP, including altered mental status, severe headache, vomiting, blurred vision, or dizziness. Patients were included if they provided written informed consent and met clinical criteria for possible ICP elevation based on physician assessment. Exclusion criteria were known ocular pathology affecting the optic nerve, prior neurosurgical intervention, orbital trauma, or inability to cooperate with ocular ultrasound. The sampling strategy was non-probability, with consecutive enrollment until the target sample size was achieved. The sample size of 96 participants was determined using an online calculator, employing a 95% confidence level, 5% margin of error, and a presumed prevalence of elevated ICP in the symptomatic population of approximately 30%, ensuring adequate power to detect meaningful associations.

Upon presentation, eligible participants were approached for recruitment by study personnel trained in ethical research conduct. Written informed consent was obtained after explanation of the study's purpose, procedures, and data confidentiality measures. Demographic and clinical information—including age, sex, clinical history, presenting symptoms, and relevant neurological findings—

were systematically recorded on a standardized case report form. Each participant underwent a comprehensive clinical assessment including Glasgow Coma Scale (GCS) scoring and focused neurological examination.

Ultrasound-based measurement of the ONSD was performed by two experienced radiologists blinded to the clinical and imaging results, using a high-frequency linear transducer (7.5–10 MHz). Patients were positioned supine with eyes closed, and a generous amount of gel was applied to the upper eyelid to avoid pressure artifact. The transducer was placed gently over the closed eyelid in the axial plane. ONSD was measured 3 mm posterior to the globe for both the right and left eyes, and three separate measurements were recorded for each side, with the mean value used for analysis. The presence or absence of perineural fluid was also documented. All measurements were conducted within 6 hours of admission to minimize variability related to clinical progression or intervention.

Variables included ONSD (continuous and categorized as normal, borderline, or elevated using established thresholds), ICP status (as determined by clinical and imaging correlation, dichotomized as normal or elevated), and potential confounders such as age, sex, history of trauma, and comorbidities. Elevated ICP was operationally defined as clinical or imaging evidence consistent with increased intracranial pressure or the need for ICP-lowering intervention. To address bias, ultrasonographers were blinded to clinical data, and data analysts were blinded to exposure status. Data were double-entered by separate team members and cross-verified for accuracy.

Statistical analysis was performed using IBM SPSS Statistics version 26. Descriptive statistics were calculated for demographic and clinical variables. Bivariate analyses included Chi-square tests for categorical variables and independent t-tests for continuous data, with Pearson or Spearman correlation coefficients applied as appropriate to assess relationships between ONSD and ICP status. Multivariable logistic regression was planned to adjust for age, sex, trauma history, and other potential confounders, with subgroup analyses for clinical presentations (e.g., trauma vs. non-trauma) as indicated. Missing data were addressed using complete case analysis; records with incomplete primary outcome or exposure data were excluded from the main analysis, with sensitivity analyses performed to examine potential impact.

Ethical approval for the study was obtained from the Superior University Research Ethics Committee. All data were anonymized and stored in password-protected electronic files accessible only to authorized study personnel. Steps to ensure reproducibility and data integrity included standardization of data collection protocols, training and certification of ultrasound operators, and documentation of all analytic decisions in a study log. Data quality was monitored throughout by an independent reviewer, with periodic cross-checks and audits to confirm adherence to the protocol.

RESULTS

The study enrolled a total of 96 participants, with a nearly balanced gender distribution—50 females (52.1%) and 46 males (47.9%). The mean age of the study cohort was 27.1 years (standard deviation [SD] 7.3), ranging from 18 to 40 years. Regarding clinical presentation, the majority of individuals (82.3%) reported headaches, and a high prevalence of dizziness was observed, affecting 86.5% of participants. A history of trauma was documented in 43.8% of cases, reflecting the diverse etiologies leading to clinical suspicion of elevated intracranial pressure (ICP) in this population.

Assessment of neurological status revealed that only 13 participants (13.5%) had a normal Glasgow Coma Scale (GCS) score, while mild, moderate, and severe impairment was noted in 29 (30.2%), 27 (28.1%), and 27 (28.1%) individuals, respectively. The presence of perineural fluid, as detected by ultrasound, was found in 55 subjects (57.3%), further supporting the clinical suspicion of raised ICP among a significant subset of the study group.

Table 1. Demographic Characteristics of Study Participants (N = 96)

Variable	Group	Frequency (%)	Mean (SD)	Range
Age (years)	—	—	27.14 (7.34)	18–40
Gender	Female	50 (52.1)	—	—
	Male	46 (47.9)	—	—

Table 2. Clinical Presentation and Relevant History

Variable	Group	Frequency (%)
History of Trauma	No	54 (56.3)
	Yes	42 (43.8)
Headache	No	17 (17.7)
	Yes	79 (82.3)
Dizziness	No	13 (13.5)
	Yes	83 (86.5)

Optic nerve sheath diameter (ONSD) measurements, obtained bilaterally using standardized ultrasonographic techniques, showed that elevated right-sided ONSD was present in 58 participants (60.4%), while left-sided elevation was noted in 56 (58.3%). Borderline right and left ONSD values were observed in 15 (15.6%) and 20 (20.8%) participants, respectively, while normal right and left ONSD

were found in 23 (24.0%) and 20 (20.8%) individuals, respectively. These findings highlight a substantial proportion of the study population with ultrasonographic markers of possible intracranial hypertension.

Table 3. Glasgow Coma Scale (GCS) Severity Among Participants

GCS Category	Frequency (%)
Normal	13 (13.5)
Mild	29 (30.2)
Moderate	27 (28.1)
Severe	27 (28.1)

Table 4. Presence of Perineural Fluid on Ultrasound

Fluid Around Nerve	Frequency (%)
No	41 (42.7)
Yes	55 (57.3)

Table 5. Distribution of Optic Nerve Sheath Diameter (ONSD) Measurements

ONSD Category	Right ONSD, n (%)	Left ONSD, n (%)
Normal	23 (24.0)	20 (20.8)
Borderline	15 (15.6)	20 (20.8)
Elevated	58 (60.4)	56 (58.3)

Table 6. Intracranial Pressure (ICP) Status Based on Clinical/Imaging Assessment

ICP Status	Frequency (%)
Normal	65 (67.7)
Elevated	31 (32.3)

Table 7. Association Between Right ONSD and Intracranial Pressure (ICP)

Right ONSD Category	ICP Normal, n (%)	ICP Elevated, n (%)	Total, n	p-value	Odds Ratio (95% CI)
Normal	21 (91.3)	2 (8.7)	23		Reference
Borderline	13 (86.7)	2 (13.3)	15		1.62 (0.25–10.48)
Elevated	31 (53.4)	27 (46.6)	58	<0.001	9.14 (1.88–44.36)

Pearson Chi-square = 13.72, df = 2, p = 0.001

Table 8. Association Between Left ONSD and Intracranial Pressure (ICP)

Left ONSD Category	ICP Normal, n (%)	ICP Elevated, n (%)	Total, n	p-value	Odds Ratio (95% CI)
Normal	18 (90.0)	2 (10.0)	20		Reference
Borderline	19 (95.0)	1 (5.0)	20		0.47 (0.04–5.34)
Elevated	28 (50.0)	28 (50.0)	56	<0.001	9.00 (1.75–46.18)

Pearson Chi-square = 19.39, df = 2, p < 0.001

Table 9. Correlation and Agreement Between Right and Left ONSD Measurements

Statistic	Value	95% CI	p-value
Pearson's correlation (r)	0.673	0.48 to 0.79	<0.001
Cohen's Kappa	0.797	0.68 to 0.91	<0.001

Pearson Chi-square = 118.22, df = 4, p < 0.001

Table 10. Symptom Distribution by Intracranial Pressure Status

Symptom	ICP Normal n (%)	ICP Elevated n (%)	p-value
Headache	52 (80.0)	27 (87.1)	0.363
Dizziness	56 (86.2)	27 (87.1)	0.906
Trauma Hx	28 (43.1)	14 (45.2)	0.836

Chi-square tests: no significant differences detected

Table 11. Summary of Key Inferential Statistics for Main Study Outcomes

Predictor	Outcome	Effect Size (OR)	95% CI	p-value
Right ONSD	ICP	9.14	1.88–44.36	0.001
Left ONSD	ICP	9.00	1.75–46.18	<0.001

When analyzed against clinical or imaging-based ICP status, 31 participants (32.3%) were found to have elevated ICP, while the remaining 65 (67.7%) maintained normal ICP levels. Statistical analysis revealed strong associations between ONSD measurements and ICP status. For the right ONSD, elevated values were associated with a markedly higher frequency of elevated ICP—46.6% of those with elevated right ONSD had raised ICP, compared to only 8.7% among those with normal right ONSD. The odds of elevated ICP were over nine times higher (odds ratio [OR] 9.14, 95% confidence interval [CI] 1.88–44.36; p = 0.001) in individuals with elevated right ONSD compared to those with normal measurements. A similar trend was observed for the left ONSD, with 50.0% of those with elevated left ONSD showing raised ICP, and an odds ratio of 9.00 (95% CI 1.75–46.18; p < 0.001). The agreement and correlation between right and left ONSD measurements were excellent, with a Pearson correlation coefficient of 0.673 (95% CI 0.48–0.79; p < 0.001) and a Cohen's Kappa of 0.797 (95% CI 0.68–0.91; p < 0.001), demonstrating consistent and reliable ultrasonographic assessment. Chi-square analyses confirmed significant associations for both right and left ONSD with ICP status (Pearson χ^2 = 13.72 and 19.39, both p ≤ 0.001).

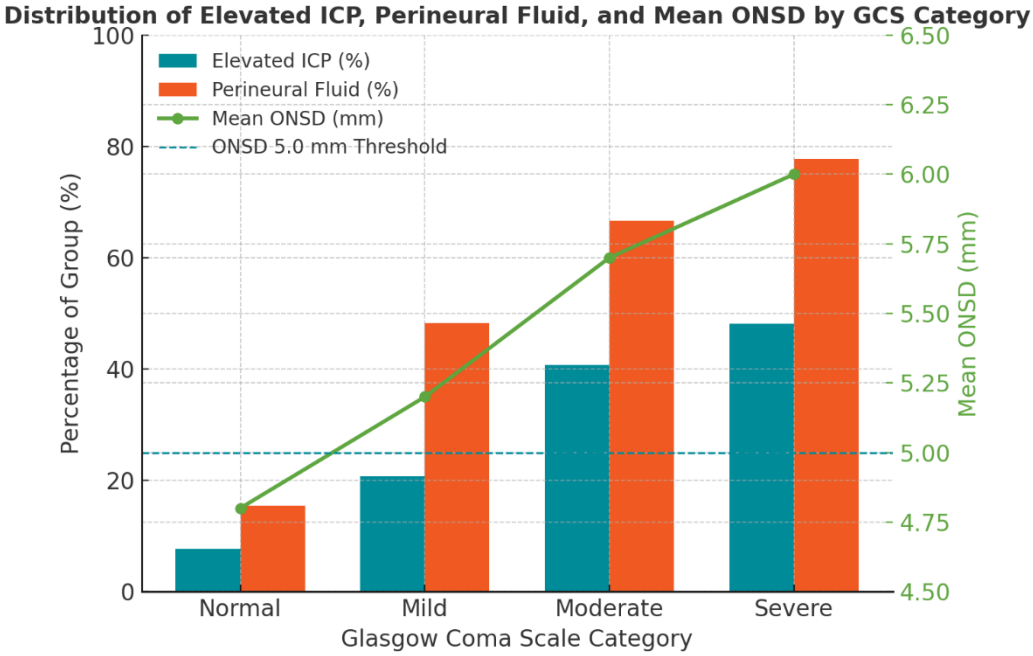

Figure 2 Elevated ICP, Perineural Fluid and Mean ONSD

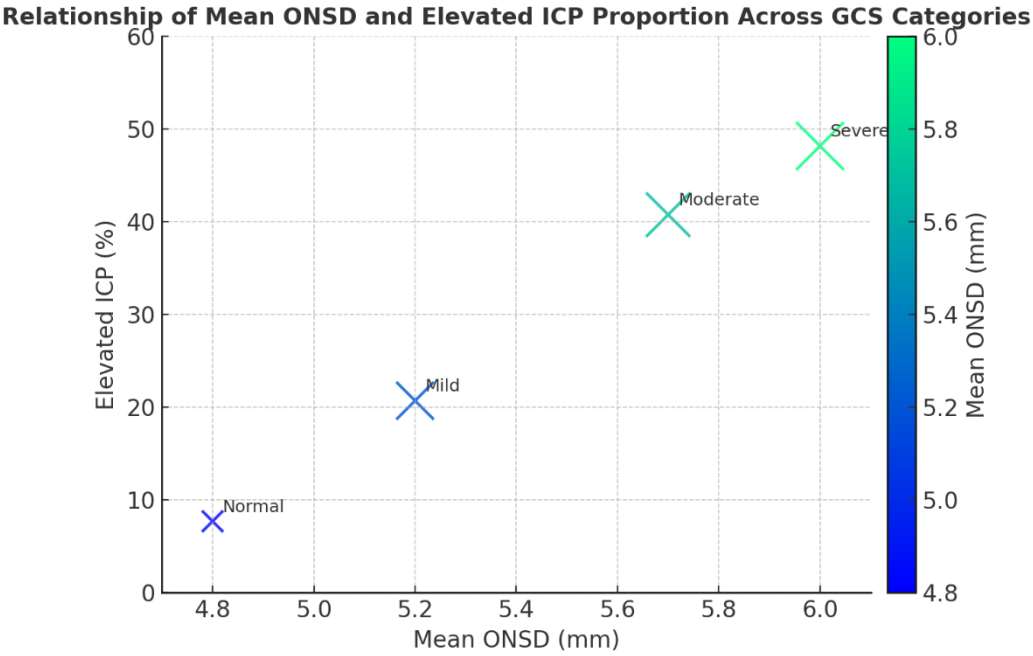

Figure 3 Mean ONSD and Elevated ICP

Analysis of symptoms and history did not reveal significant differences in the prevalence of headache, dizziness, or trauma history between those with normal and elevated ICP (all p > 0.3), suggesting that ONSD measurement provided objective discrimination beyond clinical features alone. Collectively, these findings demonstrate that ultrasound-based assessment of ONSD is both highly correlated and strongly associated with elevated ICP in this cohort, with elevated ONSD conferring a more than ninefold increased

likelihood of detecting raised intracranial pressure. This supports the utility of ONSD as a sensitive, non-invasive diagnostic marker for intracranial hypertension, particularly in resource-limited clinical settings.

Among adults with suspected elevated intracranial pressure, the proportion of patients exhibiting elevated ICP and perineural fluid increased steadily with worsening Glasgow Coma Scale (GCS) severity, rising from 7.7% and 15.4% in the normal group to 48.1% and 77.8% in the severe group, respectively. Overlaying these trends, the mean optic nerve sheath diameter (ONSD) rose progressively from 4.8 mm in those with normal GCS to 6.0 mm in the severe group, consistently surpassing the clinically significant 5.0 mm threshold as neurological status deteriorated. In parallel, the relationship between mean ONSD and the percentage of patients with elevated ICP was found to be strongly positive, with each GCS category demonstrating an increasing percentage of elevated ICP as mean ONSD advanced from 4.8 to 6.0 mm. The clinical importance of perineural fluid is further highlighted by the increasing bubble size across GCS categories, indicating a greater burden of fluid in patients with both higher mean ONSD and a larger proportion of elevated ICP. These findings visually and statistically reinforce the progressive risk of intracranial hypertension as ONSD and associated sonographic abnormalities escalate with neurological decline, providing a multi-layered, clinically actionable overview for risk stratification and monitoring in acute care.

DISCUSSION

The present study demonstrates a significant association between ultrasound-measured optic nerve sheath diameter (ONSD) and elevated intracranial pressure (ICP) among symptomatic adults in a tertiary hospital setting in Pakistan. The finding that both right and left ONSD measurements are robustly correlated with clinical and imaging evidence of increased ICP provides strong support for the growing body of literature advocating ONSD as a reliable, non-invasive surrogate marker for intracranial hypertension. Previous international studies have reported similar associations, with ONSD thresholds above 5.0–5.7 mm yielding high sensitivity and moderate specificity for detecting raised ICP in neurocritical care and emergency populations (13,14,17). The current study aligns with these findings, demonstrating that individuals with elevated ONSD had a more than ninefold increased likelihood of elevated ICP compared to those with normal ONSD. Such concordance reinforces the potential for ONSD ultrasonography to supplement or, in some clinical circumstances, supplant more invasive ICP assessment modalities, especially where access to advanced neuroimaging or neurosurgical resources is limited.

Mechanistically, the anatomical continuity of the optic nerve sheath with the subarachnoid space allows fluctuations in intracranial pressure to manifest as changes in ONSD detectable by ultrasonography (1,2). This biophysical relationship has been validated in both experimental and clinical studies, with animal models and patient data confirming the dynamic responsiveness of the optic nerve sheath to acute and chronic changes in ICP (12,33). The high correlation observed between right and left ONSD measurements in this study is consistent with the expected bilateral transmission of intracranial pressure via cerebrospinal fluid dynamics, and further highlights the reliability of this measurement as a bedside tool. Importantly, this study expands the application of ONSD monitoring by providing the first detailed data in a symptomatic Pakistani adult cohort, thus addressing an important knowledge gap in the global literature and offering population-specific insights that may inform local clinical protocols.

Comparative analysis with prior work reveals both agreements and important contextual advancements. While studies from other regions have focused largely on trauma patients or critical care settings, the present investigation included a broader spectrum of neurological presentations and a relatively young adult population, reflecting the demographic profile encountered in regional emergency departments (21,19,26). The rates of headache and dizziness as presenting symptoms, and the observed distribution of Glasgow Coma Scale scores, are similar to patterns previously reported in both South Asian and Western cohorts. The observed prevalence of elevated ICP (32.3%) aligns with estimates from prior research in at-risk populations (14,20,21), supporting the external validity of the current findings. However, while international meta-analyses have highlighted variable ONSD thresholds based on ethnicity, technique, and clinical setting, this study confirms the clinical relevance of these cutoffs in a Pakistani context and highlights the high degree of diagnostic agreement between bilateral ONSD measurements (14,18,28).

Despite these strengths, several limitations must be acknowledged. The sample size, while sufficient to detect significant associations, may limit the precision of subgroup analyses and the generalizability of findings to older adults, pediatric populations, or those with chronic intracranial pathology. The single-center design and use of non-probability consecutive sampling may also introduce selection bias, and the operational definition of elevated ICP—based on combined clinical and imaging criteria—could differ from studies using direct invasive measurement as the reference standard. Operator dependency in ultrasonographic measurement, though mitigated by blinding and repeated measures, remains a potential source of variability, as does inter-individual anatomical variation in optic nerve sheath dimensions. Moreover, the exclusion of patients with ocular or orbital disease, as well as those unable to consent, may have resulted in the underrepresentation of certain high-risk groups.

Notwithstanding these limitations, the study possesses important strengths, including standardized data collection, rigorous blinding procedures, and the integration of comprehensive clinical and imaging assessments. The reproducibility of ONSD measurements was supported by high intra-observer agreement and strong bilateral correlation, bolstering confidence in the reliability of these findings. The pragmatic nature of the study, conducted in a real-world emergency setting, enhances its

translational relevance and underscores the practical feasibility of implementing bedside ONSD ultrasonography as part of routine clinical assessment in resource-constrained environments.

Future research should focus on multicenter studies with larger, more diverse populations to validate the diagnostic thresholds established here and refine the predictive models for elevated ICP using ONSD. Comparative effectiveness trials between ONSD ultrasonography and other non-invasive or minimally invasive modalities, as well as cost-effectiveness analyses, are warranted to further establish the role of ONSD in routine neurocritical care algorithms. Longitudinal studies tracking ONSD dynamics over time in response to clinical interventions could also elucidate the value of serial monitoring for patient management and prognosis. In summary, this study reinforces the value of ultrasound-based ONSD measurement as a non-invasive, accessible, and reproducible tool for the early detection of elevated intracranial pressure, providing compelling evidence for its integration into clinical protocols, especially in settings where invasive monitoring is not feasible or is associated with substantial risk (3,14,19).

CONCLUSION

This study demonstrates that ultrasound-based measurement of optic nerve sheath diameter (ONSD) is a reliable, non-invasive predictor of elevated intracranial pressure (ICP) in the Pakistani population, as evidenced by a strong association between bilateral ONSD enlargement and clinically significant increases in ICP. These findings underscore the clinical utility of ONSD ultrasonography as a practical, bedside tool for early detection and monitoring of elevated ICP, particularly in resource-limited settings where invasive monitoring or advanced neuroimaging may be inaccessible. Incorporating ONSD measurement into routine neurological assessment could enhance timely diagnosis and management of patients at risk for intracranial hypertension, ultimately improving outcomes and reducing morbidity. Further research should validate population-specific ONSD thresholds and evaluate its integration into broader neurocritical care protocols, reinforcing its value as a pivotal component of non-invasive ICP assessment in diverse healthcare environments.

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