

# The relationship between computed tomography measurement of the optic nerve sheath diameter and elevated intracranial pressure in non-trauma patients



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**Background:** The early detection and treatment of raised intracranial pressure (ICP) is critical in the prevention of mortality and morbidity as a result of secondary ischemic brain injury. Measuring the optic nerve sheath diameter (ONSD) on computed tomography (CT) to predict raised ICP may be useful in cases where routine CT investigations of the brain are indicated and invasive ICP monitoring is not available, or a lumbar puncture (LP) is contraindicated.

**Objective:** The purpose of this study was to determine if the ONSD can be measured on digital images obtained by routine CT investigations of the brain, to identify patients with non-traumatic causes of elevated ICP, and to provide the observer with a non-invasive, objective measurement to predict elevated ICP.

**Method:** We conducted a cross-sectional, retrospective analysis of anonymised patient data, comparing the ONSD on CT imaging with the opening pressure manometry during LP on patients who presented with focal neurology or with a Glasgow coma scale score of less than 15. The study sample consisted of 67 patients,  $\geq 18$  years of age, treated at the emergency department of the Kimberly Hospital Complex from 01 March 2013 to 31 December 2014.

**Results:** An ONSD measurement of  $\geq 4.8$  mm identified patients with an elevated ICP with a sensitivity of 92.9% and a specificity of 97.6%, using a 95% confidence interval. Raising the ONSD cut-off value to  $\geq 5.0$  mm decreased the sensitivity to 85.7% but increased the specificity to 100%, eliminating all patients with a normal ICP.

**Conclusion:** The ONSD can be measured on digital images obtained by routine CT investigations of the brain to predict elevated ICP in non-trauma patients,  $\geq 18$  years of age, with acceptable sensitivity and specificity.

## Introduction

Raised intracranial pressure (ICP) is frequently associated with conditions such as meningitis, stroke and post resuscitation syndrome. The early detection and treatment of raised ICP is critical in the prevention of increased mortality and morbidity as a result of secondary ischemic brain injury.

Although invasive ICP monitoring is not routinely undertaken or available at peripheral referral hospitals, computed tomography (CT) imaging is often performed in these settings. Demonstrating a relationship between non-invasive CT measurement of the optic nerve sheath diameter (ONSD) and elevated ICP may be particularly useful in cases where routine CT investigations of the brain are indicated and invasive ICP monitoring is not available, or a lumbar puncture (LP) is contraindicated.

Other non-invasive methods, such as magnetic resonance imaging (MRI) and ultrasound (US) measurement of the ONSD, have already shown acceptable results as screening tools to estimate the probability of elevated ICP.<sup>1</sup> However, the routine use of MRI to measure the ONSD is limited by availability and time constraints in critically ill patients. Other limitations include expertise in obtaining images, especially after hours, as well as the use of non-routine sequences to make accurate measurements, precluding its widespread clinical utility.<sup>1</sup> On the contrary, although US is readily available, the ONSD measurement is operator dependent and only useful in predicting elevated ICP in the hands of experienced operators.<sup>2</sup>

The mechanism responsible for the distention of the optic nerve sheath complex can be explained by the communication between the subarachnoid space surrounding the optic nerve and the

intracranial subarachnoid space. The distended dural sheath can be measured on imaging as an increase in size of the optic nerve sheath complex when the ICP is elevated.<sup>3,4</sup> Noticeable differences in the ONSD occur within seconds after a change in ICP, making it possible to detect immediate changes in ICP by measuring the ONSD.<sup>5</sup> The use of clinical fundoscopy to exclude elevated ICP may provide false negative results, as papilledema may only develop several days after the ICP has increased.<sup>6</sup>

Bäuerle and Nedelmann<sup>7</sup> reported no correlation between the ONSD, gender and body mass index in patients  $\geq 18$  years of age, which enabled us to use a single age cut-off value to indicate elevated ICP in our study population. Additionally, the radiology department of the Kimberly Hospital Complex routinely performs CT investigations of the brain to assess for the safety of an LP prior to the procedure, in patients who present with either focal neurological signs or a decreased level of consciousness.<sup>8</sup>

We, therefore, hypothesised that patients  $\geq 18$  years of age with non-traumatic causes of elevated ICP could be identified by measuring the ONSD on digital images obtained by routine CT investigations of the brain, which would provide the observer with a non-invasive, objective measurement to predict elevated ICP.

## Method

### Study sample and design

We conducted a cross-sectional, retrospective analysis of anonymised patient data after ethics committee approval had been obtained, comparing ONSD on CT, with ICP measured by opening pressure manometry during LP.

The study sample incorporated patients,  $\geq 18$  years of age, who presented with either focal neurological signs or a decreased level of consciousness to the emergency department at the Kimberley Hospital Complex, during the period from 01 March 2013 to 31 December 2014. All patients who received both a CT scan of the brain and an LP where opening pressure manometry was determined were included in the study. Patients with a failed LP procedure, or for whom the time and technique of the LP were not recorded, were excluded from the study.

### Optic nerve sheath diameter measurement

The digital CT images were obtained from the picture archiving and communications system. All of the images were acquired with a Siemens Somatom Sensation 16-slice CT scanner, using the non-enhanced CT brain protocol with 1.0-mm slice thickness, kernel H60 sharp, field of view 200 mm and adjusted window width (50) and level (250),<sup>9</sup> on a matrix size of  $512 \times 512$ .

The ONSD measurements were performed by radiology registrars experienced in digital CT image reconstruction and measurement. All of the measurements were confirmed

by a qualified Radiologist. In order to avoid any bias, the ONSD measurements were determined without any prior knowledge of the LP opening pressure measurements.

The transverse diameter of the optic nerve sheath complex was measured perpendicular to its course in the orbit on double oblique axial images, 10 mm behind the globe, as described by Vaiman et al.,<sup>10</sup> and the average of the measured values for left and right ONCDs was used to represent the ONSD of the patients, consistent with the method used by Caffery et al.<sup>11</sup>

Figure 1 demonstrates a double oblique axial CT image of the optic nerve sheath complex, where measurements were taken, 10 mm behind the globe.<sup>10</sup>

### Lumbar puncture opening pressure measurement

The LP opening pressure values were obtained from patient data collected during the study period. The LP procedures were performed by medical officers working in the emergency department, according to the standardised protocol used at the Kimberley Hospital Complex. All LP opening pressure values were recorded with a manometer in centimetres of water ( $\text{cmH}_2\text{O}$ ), with the patient lying in the left lateral decubitus position, legs straight, and the patient relaxed at the time of measurement to avoid any false elevation of opening pressure because of the Valsalva effect.<sup>8</sup> The zero level of the manometer was adjusted to approximate the level of the left atrium, which corresponds to the position of the spinal canal in the left decubitus position.<sup>8</sup> All measurements were documented with the time and technique of the procedure.



**FIGURE 1:** Optic nerve sheath diameter measurement on an axial computed tomography image.

The medical officers performing the LP and recording the opening pressure had no prior knowledge of the ONSD measurement. Elevated opening pressure at LP was defined as a pressure  $>20$  cmH<sub>2</sub>O.<sup>12</sup>

## Statistical analysis

Numerical data were summarised by means and standard deviations. Sensitivity, specificity and predictive values (with 95% confidence intervals) were calculated for all possible cut-off values of ONSD, ranging from 3.1 mm to 5.9 mm, to find the ONSD cut-off value with the highest sensitivity and specificity for high LP opening pressure values measuring  $>20$  cmH<sub>2</sub>O.

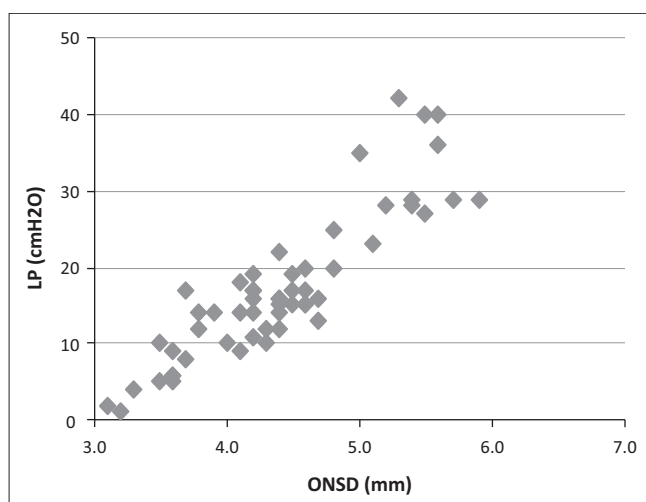
## Results

A total of 67 patients were referred for CT investigation of the brain to assess for safety of LP prior to the procedure. From this study population, two patients were excluded because of unsuccessful LP procedures and nine patients were excluded because the opening pressure or the time of the procedure was not recorded.

Of the 56 patients included in the study, 14 patients had elevated ICPs  $>20$  cmH<sub>2</sub>O and 42 patients presented with normal opening pressures  $\leq 20$  cmH<sub>2</sub>O.

An ONSD measurement of  $\geq 4.8$  mm yielded the highest combined accuracy for indicating elevated LP opening pressures  $>20$  cmH<sub>2</sub>O, with a statistically significant correlation of 0.88 ( $p < 0.01$ ) between ONSD and LP opening pressure as demonstrated in Figure 2.

The sensitivity for the ONSD cut-off value  $\geq 4.8$  mm was 92.9% (95% CI 68.5% – 98.7%) and the specificity was 97.6% (95% CI 87.7% – 99.6%); the positive predictive value was 92.9% (95% CI 68.5% – 98.7%) and the negative predictive value was 97.6% (95% CI 87.7% – 99.6%) for identifying elevated LP opening pressure.



ONSD, optic nerve sheath diameter; LP, lumbar puncture.

**FIGURE 2:** Correlation between lumbar puncture opening pressure (cmH<sub>2</sub>O) and optic nerve sheath diameter (mm).

CT measurements  $<4.8$  mm were recorded in 42 (75.0%) patients and  $\geq 4.8$  mm in 14 (25.0%) patients. The correlations with the LP opening pressures are summarised in Table 1.

Lowering the ONSD cut-off to  $\geq 4.4$  mm yielded 100% sensitivity but decreased specificity to 64.3%. Raising the ONSD cut-off to  $\geq 5.0$  mm decreased sensitivity to 85.7% but increased specificity to 100% for raised LP opening pressure.

## Discussion

Invasive ICP monitoring is not routinely performed or available at most peripheral referral hospitals in South Africa. However, the availability of CT imaging at these sites provides us with an opportunity to predict elevated ICP by measuring the ONSD. This method is particularly useful in cases where routine CT investigations of the brain are indicated and invasive ICP monitoring is not available, or an LP is contraindicated. It may also be used to identify patients who require referral for invasive ICP monitoring.

Kalantari et al.<sup>13</sup> demonstrated a strong correlation between non-invasive MRI and CT measurements of the ONSD with raised ICP. Similarly, Geeraerts et al. reported that an enlarged ONSD at MRI was a robust predictor of raised ICP with a sensitivity of 90% and a specificity of 92% in a retrospective study of 38 patients who required both invasive ICP monitoring and MRI, with a best single retro-orbital ONSD cut-off value of 5.82 mm. They increased their sensitivity for detecting raised ICP to 100% by lowering the cut-off to 5.3 mm.<sup>1</sup> Although MRI measurement of the ONSD yielded excellent results, it is not usually indicated in these settings. Geeraerts et al.<sup>1</sup> also made use of a special non-routine proton density or T2-weighted turbo spin echo fat-suppressed sequence to measure the ONSD. The generalised use of MRI measurement of the ONSD is limited by availability, time constraints in critically ill patients, metal implants and operator expertise, especially after hours.

Using retro-orbital ultrasound to measure the ONSD, as performed by Rajajee et al.<sup>2</sup> demonstrated similar results with a best single ONSD cut-off measuring  $\geq 4.8$  mm, a sensitivity of 96% and a specificity of 94% for indicating elevated ICP. The use of US to measure the ONSD is operator dependent, and these results were obtained by neuro-intensivists experienced in US measurement of the ONSD.<sup>2</sup> Du Toit et al.<sup>8</sup> correlated US measurement of the ONSD with LP opening pressure with acceptable negative predictive values, but failed to demonstrate acceptable results to predict elevated ICP, highlighting the need for technical expertise

**TABLE 1:** Computed tomography optic nerve sheath diameter measurements compared to lumbar puncture opening pressure.

CT ONSD	Normal $\leq 20$ cmH <sub>2</sub> O†		Raised $>20$ cmH <sub>2</sub> O‡	
	LP opening pressure	%	LP opening pressure	%
$<4.8$ mm	True negative 41	73.2	False negative 1	1.8
$\geq 4.8$ mm	False positive 1	1.8	True positive 13	23.2

CT ONSD, computed tomography optic nerve sheath diameter; LP, lumbar puncture.

†,  $n = 42$ ; ‡,  $n = 14$ .

when using this method to measure the ONSD and likely limiting its generalised clinical utility to predict elevated ICP.

Our results demonstrated a strong correlation between ONSD and LP opening pressure using a best single ONSD cut-off measuring  $\geq 4.8$  mm, with an acceptable sensitivity of 92.9% and specificity of 97.6% for predicting elevated ICP. Lowering the ONSD cut-off to  $\geq 4.4$  mm yielded 100% sensitivity but decreased specificity to 64.3%, and raising the ONSD cut-off to  $\geq 5.0$  mm decreased sensitivity to 85.7% but increased specificity to 100%, effectively eliminating all cases with normal ICP.

Sekhon et al.<sup>14</sup> reported a strong correlation between ICP and ONSD measured on CT using a retro-orbital cut-off value of 6.0 mm; they also found that ONSD measurement was a much better predictor of ICP than traditional CT findings such as sulcal and basal cisternal effacement, ventricular compression and cerebral herniation. Possible reasons for the difference in the published ONSD cut-off values for predicting elevated ICP include the different imaging modalities used for ONSD measurement, inter-observer variability and the distance behind the globe where the measurements were taken. However, various authors<sup>1,2</sup> consistently found a positive correlation between the ONSD measurement and elevated ICP.

We used the same technique as Vaiman et al.,<sup>10</sup> who obtained the most reliable results for ICP monitoring, measuring the transverse ONSD 10 mm behind the globe. To ensure accuracy and reproducibility, we used a constant window width (50) and level (250) for CT measurement of the ONSD, in keeping with published results from Fidor-Mikita and Krupski.<sup>9</sup>

Although invasive ICP monitoring remains the gold standard for diagnosing elevated ICP, it is not routinely performed in these settings and it is not readily available.<sup>1</sup> The advantages of measuring the ONSD on CT include the use of images obtained from routine CT brain investigations, as well as the availability of the necessary equipment and expertise to obtain the images and perform the ONSD measurements at most referral centres.

Our study is limited by its retrospective nature and relatively small sample size, but compares well with that of Geeraerts et al.<sup>1</sup> who performed a retrospective study on 38 patients. The novelty of measuring the ONSD on CT images requires further investigation with larger prospective studies investigating the relationship between CT and MRI measurement of the ONSD, the specific CT window width and level settings required for accurate measurement of the ONSD and correlation with invasive ICP. This should address some additional limitations we encountered during this study.

## Conclusion

The ONSD can be measured on digital images obtained by routine CT investigations of the brain to predict elevated ICP in non-trauma patients  $\geq 18$  years of age, providing the

observer with a non-invasive objective measurement to predict elevated ICP. Measuring the ONSD can help identify patients who need early referral and treatment to prevent secondary brain injury. The ONSD cut-off with the highest combined sensitivity and specificity for elevated ICP measured  $\geq 4.8$  mm. Raising the ONSD cut-off to  $\geq 5.0$  mm decreased sensitivity, but excluded all patients with a normal ICP in our study population.

## Acknowledgements

### Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

### Authors' contributions

D.L. planned the study, wrote the protocol, performed the data collection and data interpretation and wrote the draft manuscript. D.H. was the supervisor in this study, assisted with the planning, interpretation of results and write up. G.J. assisted with the planning, performed the data analysis, assisted with the data interpretation and write up. All authors approved the final paper.

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