

Optic Nerve Sheath Diameter Measurements by CT Scan in Ventriculoperitoneal Shunt Obstruction

Syed Javed H. Zaidi MD and Loren G. Yamamoto MD, MPH, MBA

Abstract

The objective of the study was to determine differences in optic nerve sheath diameter (ONSD) measurements taken from computed tomography (CT) scans of patients with ventriculoperitoneal shunt (VPS) obstruction versus controls. Inpatients 0-15 years with confirmed VPS obstruction requiring neurosurgical intervention were identified using ICD9 codes. ONSDs, orbit, cranium, and foramen magnum sizes were measured on their pre-surgical CT. Controls included cases at times when their VPS was not obstructed and age and gender matched patients with a CT scan done in the emergency room for head trauma (normal CT findings). Paired T-tests were used for both case-control comparisons. In order to compare the optic nerve sheath size more accurately, the ONSD width was divided by the width of the orbit and by the foramen magnum (antero-posterior) length. Twenty patients were identified with 25 events of VPS obstruction. The right ONSD (RON) was chosen to study. RON/orbit width and RON/foramen magnum diameter for the VPS obstruction versus self-controls, were 0.22 and 0.22, compared to 0.19 and 0.18, respectively, for the non-obstructed self-controls ($P = .044$ and $P = .008$, respectively). The same measurements for the VPS obstruction versus age and gender matched controls were 0.22 and 0.21 for the VPS obstruction cases, respectively, compared to 0.17 and 0.16, respectively for the age and gender matched controls ($P < .001$ and $P < .001$, respectively). This data confirms that the optic nerve diameter increases during a VPS obstruction. ONSD measurements by ultrasound could add to the evaluation for VPS obstruction.

Keywords

optic nerve sheath diameter, ventriculoperitoneal shunt obstruction, increased intracranial pressure

Introduction

Cranial computed tomography (CT) is currently the most common method used to assess ventriculoperitoneal shunt (VPS) function in children. Cranial radiation in the range that is sustained during a CT scan has been found to cause cognitive harm during infancy resulting in lower cognitive testing performance in adulthood.¹ Since cellular brain development is still active in children even after infancy, it should be assumed that high cranial radiation exposure poses cognitive harm to children as well. Most patients with VP shunts receive multiple cranial CT scans since the symptoms suggestive of VP shunt malfunction are very non-specific (sleepiness, fussiness, vomiting, and headache). Funduscopic evaluations are of limited utility in the emergency department (ED) setting since papilledema is a late sign of increased intracranial pressure (ICP). It would be desirable to find a screening method for determining VPS malfunction that does not require cranial radiation exposure. Ophthalmic ultrasonography performed through the closed upper eyelid to measure the optic nerve size (ONS) is easily available, portable, non-invasive, and comfortable enough that it usually does not require sedation, even for young children. An increase in ICP directs cerebrospinal fluid into the space between the

dura and optic nerve called the optic nerve sheath. This is visible on imaging as an increase in size of the nerve (including the nerve sheath). Previous studies have demonstrated a correlation between the ONS and intracranial pressure in adults.²⁻⁶ There have been a few studies in children.⁷⁻¹¹ However, these studies were limited to small groups of children, often in controlled environments with no comparison data and a lack of patient size correction for ONS diameters.

Since cranial CT scans also contain optic nerve size data, the purpose of this study was to utilize existing retrospective CT scan data to further validate the relationship between ONS and VPS malfunction causing raised ICP, to determine if ultrasound assessment of ONS can be used as a screening measure for VPS malfunction.

Materials and Methods

This was a retrospective review of CT scans of patients with known VPS malfunction compared to CT scans of controls seen at Kapi'olani Medical Center for Women and Children in Honolulu, Hawai'i. VPS malfunction cases were identified among inpatients age 0 to 15 years by medical records using ICD9 codes (996.2, 348.1, 799.82) for the period November 2008 to June 2012. Western IRB approval was obtained prior to our review of patient data (WIRB PRO NUM: 20112196). The electronic medical records for these patients were reviewed to verify the presence of VPS malfunction by confirming that an invasive measure to relieve obstruction was performed within 48 hours of the CT scan that included VP shunt surgical revision/replacement, serial lumbar punctures (LP) (at least 3), or serial VPS taps (at least 3). This defined the VPS malfunction CT group.

Two different CT scan control groups were identified; gender and age matched controls and VPS self-controls. Age and gender matched control CT scans were obtained by reviewing CT scan log books. The log book was reviewed to find an age and gender matched patient who received an ED CT scan for head trauma. Age matching was done by matching patients with controls who had a date of birth within six months of each other. Then, the electronic medical records were reviewed to determine that the CT scan was normal and the patient was discharged home from the ED without intervention.

VPS self-controls were CT scans from patients in the VPS malfunction group, during periods when their CT scans did not show any evidence of obstruction or elevated ICP and they needed no intervention to decrease ICP (including shunt taps or VPS revisions).

The CT scan images identified in the three groups were re-

viewed by a single study investigator (SJZ) who was assisted by a CT technician. The following measurements were recorded: right/left horizontal optic nerve sheath diameter (ONSD), right/left vertical ONSD, right/left horizontal/vertical ONSD in the retrobulbar area, right/left vertical orbit diameter, anterior-posterior (AP) length of the foramen magnum, AP length of skull (mid forehead to occiput), and skull circumference. General demographic information for all patients was also collected.

VPS malfunction and VPS self-control CT measurements were compared using a paired T-test. VPS malfunction and age and gender matched control CT measurements were also compared using a paired T-test. To create a more universal comparison method that was not patient size/age dependent, the VPS malfunction group and age and gender matched control group were additionally compared by correcting the optic nerve size measurements. After comparing image quality and slice thickness on available CT scans, the right optic nerve's horizontal width (RON) was chosen for this study, because it was measured more accurately. Twenty patients with 25 confirmed episodes of VPS malfunction were initially identified. All data points could not be measured on some cases, leaving us with 19 episodes of VPS malfunction amongst 14 patients. One patient had three episodes and three patients had two episodes. The remaining patients had a single episode.

It has been found that the orbital width increases with age.¹³ It is therefore prudent to use a correction factor for age and size that most closely correlates with changes in skull size rather than the absolute measurements of ONSD, which is more likely to be highly variable amongst our wide age range of subjects. To date, a widely accepted, empirically-validated methodology for adjusting ONSD measurements has not been established. Hence, two measures, right horizontal orbital width (ROW) and foramen magnum sizes, were used as correction factors

for patients' size resulting in the values RON1 (RON divided by the ROW) and RON2 (RON divided by the AP length of the foramen magnum) respectively for cases, and CRON1 and CRON2 for controls. These were chosen since it is known that the skull dimensions grow with the child, potentially yielding a useful correction factor. The foramen magnum size is obtainable on CT, but not on ultrasound. The orbit width is obtainable on both.

Results

Table 1 summarizes the VPS malfunction cases compared to self-controls. A self-control could not be found for 6 episodes, because a CT scan was not performed during a period when the patient's VPS was working, with no evidence of raised ICP, or the patient was hospitalized (for intercurrent illness with no signs of raised ICP) but no CT scan was obtained. Therefore, 13 paired comparisons amongst 9 patients remained. Table 2 summarizes the VPS malfunction cases compared to age matched general controls. In both tables 1 and 2, bold italic numbers identified cases in which the control value (no VPS malfunction) was the same or larger than the VPS malfunction value. In these cases, if such a control was employed, it would result in incorrectly concluding that the VPS was working (an error). These cases were included in the analysis so as not to introduce a selection bias based in the results.

Table 1 shows an error rate for RON of 2/13 (15%), for RON1 of 3/13 (23%), and for RON2 1/13 (8%). Table 2 shows an error rate for RON of 6/19 (32%), RON1 5/19 (25%), and RON2 0/19 (0%). Table 3 summarizes the statistical comparison between the ONS of the VPS malfunction patients compared to the two different control groups. These demonstrate that, overall, the ONS measurements of the VPS malfunction patients are larger than that of the controls.

Table 1. Optic nerve sizes (mm) in VPS malfunction patients compared to self-controls. *Italic bold font numbers indicate control values that are the same or larger than VPS malfunction values.*

RON – right optic nerve horizontal diameter of VPS malfunction patient CRON – same as above in the same patient but during a period when VPS was working. RON1 – RON / right orbit width. CRON1 – CRON / right orbit width. RON2 – RON / foramen magnum AP length. CRON2 – CRON / foramen magnum AP length.								
Case	Age(yrs)	Sex	RON	RON1	RON2	CRON	CRON1	CRON2
1	10.7	M	7.81	0.25	0.23	5.86	0.18	0.14
1	10.7	M	8.19	0.25	0.25	5.86	0.18	0.14
2	5.9	M	5.78	0.23	0.17	5.82	0.22	0.16
2	6.0	M	4.18	0.15	0.12	6.03	0.23	0.17
2	8.1	M	6.01	0.22	0.18	5.69	0.22	0.17
3	10.8	M	7.92	0.22	0.24	6.95	0.19	0.22
3	11.1	M	9.69	0.31	0.26	6.95	0.19	0.22
4	14.9	M	5.99	0.19	0.26	5.73	0.20	0.24
5	4.4	F	5.78	0.21	0.19	5.56	0.19	0.17
10	14.3	F	5.88	0.19	0.22	4.28	0.13	0.16
11	10.2	F	7.80	0.26	0.28	6.35	0.21	0.21
13	3.8	F	6.04	0.23	0.20	5.47	0.20	0.18
14	0.8	F	5.39	0.20	0.25	4.33	0.16	0.18

Table 2. Optic nerve sizes (mm) in VS malfunction patients compared to general controls. *Italic bold font numbers indicate control values that are the same or larger than VPS malfunction values.*

RON – right optic nerve horizontal diameter of VPS malfunction patient CRON – same as above in the same patient but during a period when VPS was working. RON1 – RON / right orbit width. CRON1 – CRON / right orbit width. RON2 – RON / foramen magnum AP length. CRON2 – CRON / foramen magnum AP length.								
Case	Age(yrs)	Sex	RON	RON1	RON2	CRON	CRON1	CRON2
1	10.7	M	7.81	0.25	0.23	5.82	0.18	0.16
1	10.7	M	8.19	0.25	0.25	5.71	0.17	0.17
2	5.9	M	5.78	0.23	0.17	4.73	0.14	0.12
2	6.0	M	4.18	0.15	0.12	4.18	0.11	0.11
2	8.1	M	6.01	0.22	0.18	4.84	0.14	0.14
3	10.8	M	7.92	0.22	0.24	6.02	0.18	0.16
3	11.1	M	9.69	0.31	0.26	6.02	0.18	0.16
4	14.9	M	5.99	0.19	0.26	6.44	0.20	0.19
5	4.4	F	5.78	0.21	0.19	5.36	0.16	0.16
6	0.2	M	5.83	0.23	0.22	5.83	0.23	0.20
7	0.3	M	5.39	0.22	0.20	5.39	0.22	0.18
8	3.5	M	3.94	0.14	0.14	5.08	0.15	0.13
9	1.0	M	5.35	0.18	0.21	5.10	0.17	0.18
10	14.3	F	5.88	0.19	0.22	4.71	0.15	0.15
11	10.2	F	7.80	0.26	0.28	5.70	0.17	0.16
12	9.8	M	5.82	0.20	0.20	5.19	0.17	0.14
12	9.9	M	5.89	0.20	0.21	5.18	0.18	0.15
13	3.8	F	6.04	0.23	0.20	4.94	0.17	0.14
14	0.8	F	5.39	0.20	0.25	5.39	0.20	0.22

Table 3. Statistical comparisons (paired T-tests). *P*-values are singled-sided probabilities.

RON – right optic nerve horizontal diameter of VPS malfunction patient CRON – same as above in the same patient but during a period when VPS was working. RON1 – RON / right orbit width. CRON1 – CRON / right orbit width. RON2 – RON / foramen magnum AP length. CRON2 – CRON / foramen magnum AP length.						
	RON	CRON	RON1	CRON1	RON2	CRON2
VPS malfunction versus self-controls						
Mean	6.65	5.76	0.22	0.19	0.22	0.18
Standard deviation	1.50	0.80	0.04	0.03	0.04	0.03
Mean difference		0.89		0.03		0.04
<i>P</i> -value		.010		.022		.004
VSP malfunction versus general controls						
Mean	6.24	5.34	0.21	0.17	0.21	0.16
Standard deviation	1.42	0.56	0.04	0.03	0.04	0.03
Mean difference		0.90		0.04		0.05
<i>P</i> -value		.002		< .001		< .001

Discussion

Age and gender matched controls are not necessarily a reliable comparison to a VPS patient because they might not be the same size as the patient. Also, it is possible that the patient's previous history of hydrocephalus could have affected their orbit size measurements. Therefore, it may be useful to consider other strategies for adjusting measurements for underlying differences in patient size and history. To date, a widely accepted, empirically-validated methodology for adjusting ONSD measurements has not been established.

Both Tables 1 and 2 demonstrate that the lowest error rates occur when using the foramen magnum as a correction factor. Using the foramen magnum correction might result in a more accurate estimation of true positivity or provide for a stronger positive predictive value. However, in attempting to apply this method to ultrasonography, the foramen magnum size cannot be measured using ophthalmic ultrasound. Orbital width, though not providing as accurate a conclusion as the foramen magnum as a correction factor, can still be measured by ophthalmic ultrasound, and would potentially be the best correction factor in this regard. If the optic nerve disc or sheath diameter is to be used as a useful screening measure, a normal range that is not age or size dependent must be established. Alternatively, a table of normal values based on age or size must be established. Methods to measure optic nerve sheaths without X-ray include ultrasound and MRI scanning. While MRI could simply visualize the brain, MRI availability is more limited, and the entire MRI scan is slow, requiring sedation. A more limited MRI scan that views the optic nerve sheath size and a single cut through the lateral ventricles could be done much faster and would likely not require sedation. Such brief/limited MRIs are currently being done at some centers to assess patients for VP shunt malfunction.¹²

Since ophthalmic ultrasound is capable of measuring the ONS and orbital width, the results of our study support the use of ultrasonography as a potential screening tool to detect acute increases in ICP from VPS malfunction. Other studies have shown a positive correlation of the measurement of optic nerve sheath diameters by ultrasonography with increased ICP in adults,²⁻⁶ but there are only a few studies performed in children.⁷⁻¹¹

Some studies have measured the ONS by MRI and found a positive correlation with increased ICP. One study suggested that the upper limit of normal for optic nerve sheath diameter is 4.5 mm (measured 3 mm behind the globe) in patients over 1 year of age,⁷ and 4.0 mm in children less than 1 year of age and that ONSDs in excess of these values are strongly suggestive of raised intracranial pressure. Another study suggested the ONS is regarded as definitely enlarged when exceeding 5 mm in children above age 4 and concluded that ultrasound studies of the optic nerve may contribute information about the acutely increased ICP in critically ill patients.⁸

Measurements of the subarachnoid pressure of the optic nerve showed inter-individual variation and a linear relationship with ICP during cadaver testing. Hansen et al. concluded that the

human ONS has sufficient elasticity to allow a detectable dilation in response to intracranial hypertension.³ They, however, recommended serial ultrasonography studies to demonstrate pathologically enlarged sheaths or ongoing enlargement. A more recent study in 2008 directly correlated ventriculostomy measurements of ICP with ultrasonographic ONS measurements and provides further support for the use of ONS measurements as a noninvasive test for elevated ICP.⁶ Others support transorbital ultrasonography and measurement of ONS as a reliable means to identify pediatric patients with raised ICP.^{7-9, 11}

This was, however, not supported in a prospective study involving measurements done by emergency physicians.¹⁰ The level of operator experience is a possible confounder in assessing the intrinsic value of using ultrasound as a means to measure ONSD. The small dimensions to be measured and the frequent occurrence of artifact in the sonographic area of interest may yield inconsistent results when performed by inexperienced operators. This limitation may be minimized if inexperienced providers are required to perform a minimum number of supervised measurements of both distended and nondistended optic nerve diameters prior to independently performing ONSD measurements that would affect management. Small differences in measurement of the ONSD related to the experience level of the operator could also be due to the model of the ultrasound device used or the position of the probe. As the optic nerve courses through the orbit, it can be visualized from a variety of angles in relation to the globe. Different ONSD measurements can result from differences in probe position. More studies and a larger population size may be necessary to establish ER physician proficiency in measuring ONSD after an adequate amount of training.¹⁴

All ONS measurement methods are likely not identical. Measuring the ONS 3 mm behind the globe by MRI is likely different than measuring the ONS by ophthalmic ultrasound. The obtained values of ONS in Tables 1 and 2 are larger than those in the ultrasound studies, even for our controls. Thus, while the relationship between larger ONS and VPS malfunction is confirmed, the method of measurement appears to affect the critical values; thus a table of normal values would need to take this into account and further define the exact means of acquiring the measurement.

Since ultrasound is non-invasive and relatively easy to perform (Figure 1), a potentially effective strategy could be to perform ONS measurements on VPS patients at regular visits (for example at some immunization and annual physicals), while their VPS is working. If the patient presents subsequently with symptoms and signs of VPS malfunction, a clinician could utilize these baseline measurements to determine if the patient's current ONS measurements are enlarged. Standardization of how these measurements are obtained is crucial to minimize inter-observer variation. Storage of the baseline ultrasound images and measurement values in the electronic medical record would contribute to the consistency of the measurement.

The obtained CT results and their significance can be extrapolated to the use of transorbital ultrasonography to obtain



Figure 1. Ultrasound probe over the closed upper eyelid used to visualize the underlying globe and optic nerve diameter.

the same measurements as determinants of raised ICP. It does have to be taken into account that CT measurements of the optic nerve sheath may differ from ultrasonographic measurements of the same. Also, absolute ONSD measurements are age/size dependent requiring a correction factor such as the orbit width, which can be measured on ultrasound as well.

Conclusion

Ventriculoperitoneal shunt malfunction results in an increase in the size of the optic nerve. This is consistent with other studies. Since these measurements can be obtained non-invasively without radiation via ultrasound, this could be a useful screening test if measurement standards and normal value data (or baseline pre-VPS malfunction measurements) are available.

Conflict of Interest

None of the authors identify a conflict of interest.

Authors' Affiliations:

- Department of Pediatrics, University of Hawai'i John A. Burns School of Medicine, Honolulu, HI; and Emergency Department, Kapi'olani Medical Center for Women & Children, Honolulu, HI

Correspondence to:

Syed Javed Hasan Zaidi MD; Pediatric Cardiology Fellow, The Heart Institute for Children, Advocate Medical Center, Hope Children's Hospital, 4440 West 95th Street, Oaklawn, IL 60453; Ph: (708) 684-5580; Email: syedjaved.zaidi@advocatehealth.com

References

- Hall P, Adami HO, Trichopoulos D, et al. Effect of low doses of ionising radiation in infancy on cognitive function in adulthood: Swedish population based cohort study. *BMJ*. 2004 Jan 3;328(7430):19.
- Liu D, Kahn M. Measurement and relationship of subarachnoid pressure of the optic nerve to intracranial pressures in fresh cadavers. *Am J Ophthalmol*. 1993 Nov 15;116(5):548-56.
- Hansen HC, Helmke K. Validation of the optic nerve sheath response to changing cerebrospinal fluid pressure: ultrasound findings during intrathecal infusion tests. *J Neurosurg*. 1997 Jul; 87(1):34-40.
- Tayal VS, Neulander M, Norton HJ, Foster T, Saunders T, Blaivas M. Emergency department sonographic measurement of optic nerve sheath diameter to detect findings of increased intracranial pressure in adult head injury patients. *Ann Emerg Med*. 2007 Apr;49(4):508-14. Epub 2006 Sep 25.
- Blaivas M, Theodoro D, Sierzenski PR. Elevated intracranial pressure detected by bedside emergency ultrasonography of the optic nerve sheath. *Acad Emerg Med*. 2003 Apr;10(4):376-81.
- Kimberly HH, Shah S, Marill K, Noble V. Correlation of optic nerve sheath diameter with direct measurement of intracranial pressure. *Acad Emerg Med*. 2008 Feb; 15(2):201-4.
- Newman WD, Hollman AS, Dutton GN, Carachi R. Measurement of optic nerve sheath diameter by ultrasound: a means of detecting acute raised intracranial pressure in hydrocephalus. *Br J Ophthalmol*. 2002 Oct;86(10):1109-13.
- Helmke K, Hansen HC. Fundamentals of transorbital sonographic evaluation of optic nerve sheath expansion under intracranial hypertension II. Patient study. *Pediatr Radiol*. 1996 Oct; 26(10):706-10.
- Malayeri AA, Bavarian S, Mehdizadeh M. Sonographic evaluation of optic nerve diameter in children with raised intracranial pressure. *J Ultrasound Med*. 2005 Feb; 24(2):143-7.
- Le A, Hoehn ME, Smith ME, Spentzas T, Schlappy D, Pershad J. Bedside Sonographic Measurement of Optic Nerve Sheath Diameter as a Predictor of Increased Intracranial Pressure in Children. *Ann Emerg Med*. 2009 Jun;53(6):785-91.
- McAuley D, Paterson A, Sweeney L. Optic nerve sheath ultrasound in the assessment of pediatric hydrocephalus. *Childs Nerv Syst*. 2009 Jan;25(1):87-90. doi: 10.1007/s00381-008-0713-6. Epub 2008 Sep 23.
- Patel PB, Krug SE. Chapter 24. *Imaging Decision-Making Strategies and Considerations*. In: Fuchs S, Yamamoto L (eds). APLS, The Pediatric Emergency Medicine Resource, 5th edition. Jones and Bartlett (Sudbury, MA), 2012. Online chapter at www.aplsonline.com (5/1/2013).
- Sforza C, Grandi G, Catti F, Tomassi DG, Ugolini A, Ferrario VF. Age- and sex-related changes in the soft tissues of the orbital region. *Forensic Science International*. 185(2009 115.e1-115.e8.
- Hightower S, Chin EJ, Heiner JD. *Determination of increased intracranial pressure by ultrasound*; http://depts.washington.edu/doemuw/files/pdf/Intracranial_Pressure.pdf.