How do we measure the optic nerve sheath diameter?
¿Cómo medimos el diámetro de la vaina del nervio óptico?
¿Como medimos o diâmetro da bainha do nervo óptico?

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Abstract

Intracranial hypertension (ICH) is an emergency situation in neurocritical care patients, as, if not controlled and treated aggressively, can lead to brain herniation, death and unfavorable outcome. Therefore, it is fundamental to manage ICH in order to minimize secondary brain injury. In many conditions, the patients can present ICH for a long time before inserting an invasive catheter to detect it, or in some conditions, the invasive catheter may not be available or might be contraindicated. Non-invasive methods may be interesting surrogates to raise the suspect or exclude ICH. Among these, the ultrasound measurement of the optic nerve sheath diameter (ONSD) may be one of the most accurate and affordable methods. The advantages of ONSD measurement are its availability, relatively quick training, the possibility to be performed at patients' bedside and repeatability. In order to reduce the interobserver variability, it is important to respect some methodological points, ideally using a protocol to guarantee high quality and consistent data. The cutoff for the diameter measurement to define ICH is not uniform across the studies. However, some strategies can be used to reduce the variability among measurements. In this viewpoint, we discuss a methodological plan for the ultrasonographic measurement of the optic nerve sheath diameter, the clinical applications of this method, the advantages and limitations of using this non-invasive method to detect ICH as soon as possible.

Keywords: Optic nerve sheath diameter, ultrasound, intracranial hypertension.

Resumen

La hipertensión intracraneal (HIC) es una situación de emergencia en pacientes de neurocríticos, ya que, si no se controla y trata de manera agresiva, puede conducir a una herniación cerebral, muerte y a un resultado desfavorable. Por lo tanto, es fundamental gestionar la HIC para minimizar el daño cerebral secundario. En muchas condiciones, los pacientes pueden presentar HIC durante un largo período de tiempo antes de insertar un catéter invasivo para detectarla, o en algunas condiciones, el catéter invasivo puede no estar disponible o estar contraindicado. Los métodos no invasivos pueden ser sustitutos interesantes para generar sospecha o excluir la HIC. Entre estos, la medición por ultrasonido del diámetro de la vaina del nervio óptico (DVNO) puede ser uno de los métodos más precisos y accesibles. Las ventajas de la medición de DVNO son su disponibilidad, el entrenamiento relativamente rápido, la posibilidad de realizarla junto a la cama del paciente y la repetibilidad. Para reducir la variabilidad entre observadores, es importante respetar ciertos puntos metodológicos, idealmente utilizando un protocolo que garantice datos de alta calidad y consistentes. El umbral para la medición del diámetro para definir la HIC no es uniforme en todos los estudios. Sin embargo, algunas estrategias pueden usarse para reducir la variabilidad entre mediciones. En este punto de vista, discutimos un plan metodológico para la medición ultrasonográfica del diámetro de la vaina del nervio óptico, las aplicaciones clínicas de este método, las ventajas y limitaciones de usar este método no invasivo para detectar la HIC lo antes posible.

Resumo

A hipertensão intracraniana (HIC) é uma situação de emergência em pacientes de neurocríticos, pois, se não for controlada e tratada de maneira agressiva, pode levar à hérnia cerebral, morte e a um desfecho desfavorável. Portanto, é fundamental gerenciar a HIC para minimizar os danos cerebrais secundários. Em muitas condições, os pacientes podem apresentar HIC por um longo período antes de inserir um cateter invasivo para detectá-la, ou em algumas condições, o cateter invasivo pode não estar disponível ou pode ser contraindicado. Métodos não invasivos podem ser substitutos interessantes para levantar suspeitas ou excluir a HIC. Entre esses, a medição por

ultrassom do diâmetro da bainha do nervo óptico (DBNO) pode ser um dos métodos mais precisos e acessíveis. As vantagens da medição de DBNO são sua disponibilidade, o treinamento relativamente rápido, a possibilidade de ser realizada ao lado da cama do paciente e a repetibilidade. Para reduzir a variabilidade entre observadores, é importante respeitar alguns pontos metodológicos, idealmente utilizando um protocolo para garantir dados de alta qualidade e consistentes. O ponto de corte para a medição do diâmetro para definir a HIC não é uniforme entre os estudos. No entanto, algumas estratégias podem ser usadas para reduzir a variabilidade entre as medições. Neste ponto de vista, discutimos um plano metodológico para a medição ultrassonográfica do diâmetro da bainha do nervo óptico, as aplicações clínicas desse método, as vantagens e limitações de usar esse método não invasivo para detectar a HIC o mais rápido possível.

1. Introduction

Intracranial hypertension (ICH) is a life threatening condition and an emergency in the management of neurocritical patients, which has to be immediately treated in order to avoid secondary brain damage and poor outcomes [Balestreri et al. (2006)]. The classic physical examination signals (pupillary dilatation, motor posturing and decreased level of consciousness) and computed tomography (CT) findings (compression of basal cisterns and midline shift) related to ICH may not be sufficiently sensitive for the detection of elevated intracranial pressure (ICP)[Robba et al. (2019)]. In addition, the fact that the neurological worsening that happens in ICH is not easily recognized, especially when clinical examination is not reliable (a severe underlying neurological illness, sedation, delirium).

The gold standard approach to detect intracranial hypertension is the monitoring of ICP by an invasive intracranial device [Balestreri et al. (2006)]. However, this is a neurosurgical procedure with its inherent risks of local bleeding, infection and in some cases it is not immediately available, or not available at all [Chesnut et al. (2012, 2020)]. In addition, huge variability exists regarding indications for invasive ICP insertion across different countries [Robba et al. (2021a)]. Considering this, a non-invasive tool able to promptly assess at bedside ICH would be desirable [Pansell et al. (2023); Robba et al. (2017a); Caldas et al. (2022); Bittencourt Rynkowski and Caldas (2022)]. The ultrasound measurement of optic nerve sheath diameter (ONSD) is an elegant and good option as a non-invasive surrogate of ICP [Robba et al. (2021b); Sekhon et al. (2014a); Hansen and Helmke (1997a)], and many authors have demonstrated a linear association with invasive intracranial pressure [Robba et al. (2018, 2017b)]. Since there is a broad availability of ultrasound machines with linear transducers, and the learning curve for ONSD measurement is feasible [Betcher et al. (2018)], ultrasound ONSD measurement is a promising method to be used to raise the suspect or exclude ICH [Robba et al. (2019); Chesnut et al. (2012); Altayar et al. (2021); Chelly et al. (2016a)].

Here we review the technique, discuss the applications and consider the limitations of applying the ultrasound ONSD measurement to detect or discharge ICH.

2. What does ONSD represent?

The optic nerve (ON) is an extension of the brain easily accessed through the orbita. It is surrounded by the subarachnoid space, with cerebral spinal fluid and vessels, all enveloped by the sheath (the continuity of dura mater).

The optic nerve sheath has a strong anatomical relationship with the subarachnoid space. During the rise of ICP, this results in an increase of the pressure in the cerebrospinal fluid, which results in an enlargement of subarachnoid space and consequently of the ONSD sheath in particular in the most distensible segment, about 3 mm behind the globe [Robba et al. (2018); Hansen and Helmke (2019); Stevens et al. (2021)]. The ONSD enlargement after ICP increase has been demonstrated using different image methods such as magnetic resonance image (MRI), CT and ultrasound showing a good correlation, especially in MRI studies [Schroeder et al. (2020); Romagnosi et al. (2020); Sekhon et al. (2014b)]. Importantly, the increase in the ONSD can occur almost at the same time of ICP increment, or in less than 2 minutes [Hansen and Helmke (1997b)].

3. Technique to perform ONSD measurement

3.1. Position and initial assessment

Before starting the exam, it is important to check whether the neck and the head of the patient are positioned in a neutral position, in order to provide correct venous drainage. It is also very important to consider all the extracranial conditions that could lead to ICH and interfere in our result interpretation [Hansen and Helmke (2019)].

Also, to compare the baseline measurement with the following ones, it is fundamental to maintain the same head position and grade of head elevation. A slightly larger diameter is expected in supine position, whereas a minimum size reduction can be observed as the head goes up [Wu et al. (2022)]. Some authors have demonstrated that, if the same measurement technique is maintained, there is a low intra and inter variability between operators [Betcher et al. (2018)]. The comparative advantage of using ultrasound compared to other methods is its practicality, as it can be performed at bedside, without need of moving the patient, without exposure to radiation, and allowing measurements to be repeated as many times as necessary.

3.2. First of all, look for the correct structures

The 7.5 MHz linear probe should be placed perpendicular to the globe, on the temporal area of the eyelid. The probe should be then angled in order to display the optic disc and the entry of the optic nerve into the globe. The nerve appears in B-mode as a linear central dark band perpendicular to the globe [Robba et al. (2017b); Stevens et al. (2021); Wu et al. (2022); Geeraerts et al. (2009)]. In order to better detect the nerve course and minimize errors induced by acoustic shadow cones and false images in B-mode imaging, the CLOSED protocol recommend

to add the color doppler mode to identify central retinal artery (CRA) and central retinal vein (CRV) **(Figure 1)**[Hansen and Helmke (2019); Aspide et al. (2022)].

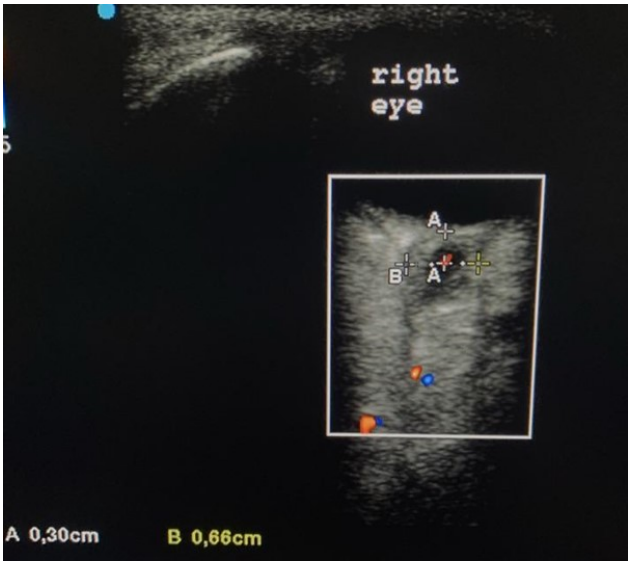

Figure 1: The measurement of the optic nerve sheath diameter through the transorbital window.
First it was identified the central retinal artery (in red, in the middle of the optic nerve) in the small box on the left side. On the right side, after identification of central retinal artery, it was measured the vertical line in the middle of the nerve (A-A': 0.3 cm) and the perpendicular horizontal line (B-B': 0.66 cm- enlarged diameter). The diameter of the optic nerve sheath was measured at the internal border of the sheath (ONSDint), as the subarachnoid space was identified.

3.3. Second, identify the meninges

To measure the ONSD it is fundamental to identify the sheath boundaries and therefore the meninges. After detecting the nerve, going from the center to the outside, the subarachnoid space can be observed,as a hyperechoic stripped band surrounding the optic nerve **(Figure 2)**, one at each side of the central nerve [Stevens et al. (2021); Pansell et al. (2022)]. After the subarachnoid space, a hypoechoic band (one each side) that corresponds to the sheath, an extension of dura mater can be visualized [Chae et al. (2016a); El-Hajj et al. (2024); Aspide et al. (2022)]. Finally, outside the sheath, there is a great hyperechoic space that continues with its side, corresponding to retrobulbar fat **(Figure 2)**.

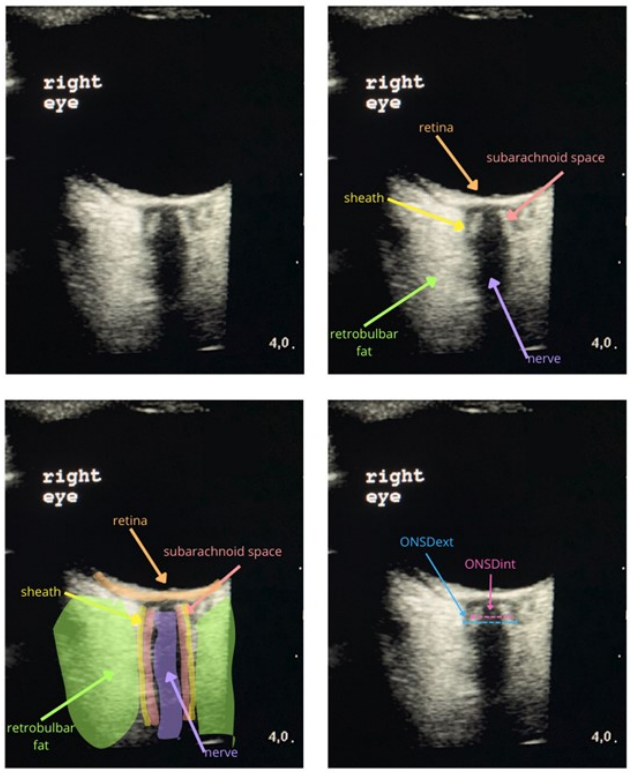

Figure 2: The identification of the structures related to the optic nerve sheath. Structures are painted to facilitate its identification. Retina is orange, the nerve is purple, the subarachnoid space is light pink, the sheath is yellow, the retrobulbar fat is green. The external optic nerve sheath diameter (ONSDext) is blue and the internal optic nerve sheath diameter (ONSDint) is pink.

The best point of reference to measure the ONSD is exactly the limit between the subarachnoid space (hyperechoic stripped band) and the internal limit of the sheath (hypoechoic band); this point corresponds to the internal diameter of ONS (ONSDint)[Pansell et al. (2022)] **(Figure 2)**.

3.4. Third, measure accurately the diameter

When ICP increases, the ONSD will enlarge mainly around 3mm behind the retina (or the papilla) [Hansen and Helmke (2019)]. The measurement starts setting this first reference distance, with an electronic caliper, from the retina (exactly behind the eyeball) going vertically down 3mm, following the center of the optic nerve [Stevens et al. (2021)]. This point should be marked.

The second measure, the diameter of ONS, will be an horizontal line, from one to the other side of the sheath. This second line, the horizontal one, passes through the marked point of 3mm behind the eyeball, being perpendicular to that first vertical one **(Figure 2)** [Stevens et al. (2021); Geeraerts et al. (2009); Chandrapatham et al. (2021)].

To set the ONS boundaries, the limit of the horizontal diameter of ONS, it is important ideally to accurately identify the sheath, and in particular ONSDint, the internal diameter of ONS. Nonetheless, when it is not possible to identify the subarachnoid space, the surrogate will be the ONSDext [Pansell

et al. (2023)] **(Figure 2 & 3)**.

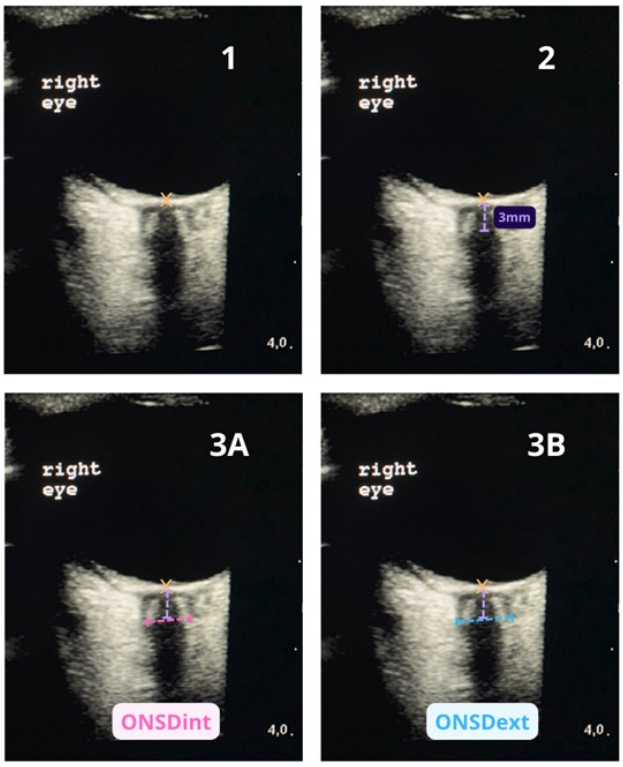

Figure 3: The steps for measurement of the optic nerve sheath diameter.
Step by step to measure the optic nerve sheath diameter (ONSD). 1 - First localize the retina / papilla ("X" in orange); 2 - Draw a vertical line, in the middle of the optic nerve, 3 mm down from the retina ("X" in orange); 3 - Draw an horizontal line passing through the marked point of 3 mm behind the eyeball. If it is possible to identify the subarachnoid space, the diameter will be measured from one to the other external side of the subarachnoid space, that will be the ONSDint (#A). When it is not possible tto find the subarachnoid border, it is recommended to be measured exactly at the external border of the sheath, the ONSDext.

3.5. Caution is needed

Some caveats have to be taken in account when measuring ONSD. When using the ONSDext as the reference of ONSD, this measurement presents a higher sensitivity to exclude ICH **(Figure 3)**; in fact, ONSD values lower than 6mm as a cutoff at the external border of the sheath presents a very low risk of ICH [Caldas et al. (2022); Robba et al. (2018)]. However, the specificity is reduced using this technique, compared to ONSD int. However, the small difference between measurement of internal or external border of dura mater seems not to be significant and the diameter measurement is comparable between the 2 techniques [Pansell et al. (2022)].

Furthermore, the ONSD measurement lacks accuracy, as it is operator dependent and a number of artifacts can affect its precision **(Figure 3)**. In order to reduce the bias and interobserver variance, it is possible to correct the measurement of the sheath proportionally to anthropomorphic measurements, adjusting for the eyeball diameter (ED) and also for the optic nerve diameter (OND)[Pansell et al. (2022)]. This may compensate for baseline variations, despite this approach is not yet an established recommendation.

Another important point is about the elastic properties of the sheath that can be altered in situations of sustained extremely high peaks of ICH. The ONSD gets enlarged in ICH situation, but when the fibers of sheath are disruptured, it may not be possible to return to a normal diameter (even getting normal ICP), as it has been described in subarachnoid hemorrhage (SAH) patients [Romagnosi et al. (2020); Kim et al. (2014)]. However, when the elastic properties of the sheath are maintained, the ONSD usually decreases and normalizes when previous ICH (with enlarged ONSD) is controlled. ONSD decrease can occur in minutes or hours [Pansell et al. (2022)].

3.6. Threshold for high ICP

Ultrasound-derived ONSD [Caldas et al. (2022)] cutoffs have been shown to be sensitive [Robba et al. (2019)] in detecting acute intracranial hypertension in high-risk patients, but accuracy is limited due to the technique heterogeneity, different types of measurements described in literature, ultrasound resolution, the optic nerve anatomy and different size of personal structure [Pansell et al. (2022)]. Considering all these factors, it is difficult to define a precise cutoff measurement of ONSD that fits all patients [Schroeder et al. (2020)]. The result of ONSD measurement must be contextualized according to the case, the sex (women can present a larger ONSD), even the age (elderly can present a larger ONSD), especially for isolated measurements. In general, it is more important to interpret the values of ONSD as changes over time [Schroeder et al. (2020)] and from baseline. In adults, even in elderly, values lower than 5.2 mm are commonly interpreted as normal [Altayar et al. (2021); Hansen and Helmke (2019)], while higher values can be pathological indicating a tendency to increase the diameter and represent ICH. An ONSD >5.8 mm indicates increased ICP with a sensitivity of 90% and a specificity of 84% [Bäuerle and Nedelmann (2011)]. The precise cut-off value is divergent in literature and recent publications suggest a threshold $\geq$ 6.0 mm to optimize accuracy [Chae et al. (2016a)].

3.7. Clinical applications of ONSD measurement

Ultrasound measurement of ONSD has been shown to correlate well with invasive measurements of ICP [Robba et al. (2018)]. The majority of studies that measured ONSD to detect raised ICP were performed in patients with traumatic brain injury to compare it with an invasive method [Chesnut et al. (2012); Altayar et al. (2021); Schroeder et al. (2020); non-invasive ICP monitoring international consensus group et al. (2023)]. However, because of the above mentioned limitations, ONSD cannot substitute invasive ICP methods. Nevertheless, this tool may be useful in patients with different pathologies where ICP is not routinely indicated or even contraindicated, but there is some risk of developing cerebral edema and and ICH [Caldas et al. (2022); Zoerle et al. (2020); Cardoso et al. (2021)].

Stroke patients with malignant cerebral infarction and regional edema may present subtle clinical manifestations of ICH

development [Yun and Ding (2020)]. The ultrasound ONSD measurement can be used in this context as an initial reference and its comparative subsequent enlargement can be an alert of evolution to ICH [Lee et al. (2020)]. The early detection of ICH can help in the decision for decompressive craniectomy (DC) avoiding delays together with clinical signals of herniation avoiding secondary neurological damage [Lee et al. (2020); Jeon et al. (2014); Pallesen et al. (2019)]. Lee et al., in a study of stroke patients, found that CT ONSD measurement could predict late malignant progression of cerebral infarct compared to baseline values [Lee et al. (2020)]. Batur et al. showed that sequential use and follow up with ultrasound ONSD measurement can help to detect the patients in the emergency department at risk for ICH, and that would benefit from intensive care unit admission, as well as to detect those who will need DC [Batur et al. (2023)].

Acute liver failure (ALF) is another condition that generally evolves with cerebral edema and ICH, associated with increased mortality and disability. However, the insertion of an invasive intracranial catheter to detect ICH in this situation can be risky and not frequently performed. Although there is not an established use recommendation of routine ONSD measurement in ALF, some studies have shown an increasing clinical use for the detection of ICH [Cardoso et al. (2021); Zorzi et al. (2024)].

Meningitis and encephalitis are serious infections whose pathophysiology is complex. Its inflammation, cerebral edema, venous thrombophlebitis, hydrocephalus and impaired cerebral autoregulation can culminate with ICH[Hayman et al. (2018); Sinha and Parnia (2017); Chelly et al. (2016b); Chae et al. (2016b); Tariq et al. (2017)]. It is estimated that 90% of acute bacterial meningitis develop ICH [El-Hajj et al. (2024)]. Unfortunately, ICP monitoring is not a current practice in the management of meningitis. A non-invasive method, like measurement of ONSD, could be a good triage tool to identify ICH [El-Hajj et al. (2024); Tariq et al. (2017); Wang et al. (2016)]. According to this rationale as a method of triage, the practical use of ONSD measurement can be explored whenever we expect ICH can be present.

4. Conclusion

US measurements are dependent on the operator's experience and skills. ONSD is a basic plus skill and training to perform the right measurement applying the correct technique is a necessity attending neurocritical patients. It is a practical method, being performed almost immediately bedside, not moving the patient, without exposure to radiation, allowing a prompt comparison as soon as the management is applied. Moreover, the ultrasound method is reliable, easy to find in the hospitals.

Importantly, we recognize the value of this non-invasive bedside screening method, particularly when the invasive measurement of intracranial pressure is not readily accessible.

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