Revista Iberoamericana de las Ciencias de la Salud | RICS ISSN: 2395 - 8057

Medición del diámetro de la vaina del nervio óptico con ultrasonido ocular y su correlación con hallazgos tomográficos de edema cerebral en pacientes con traumatismo craneoencefálico

Measurement of the diameter of the optic nerve sheath with ocular ultrasound and its correlation with tomographic findings of cerebral edema in patients with traumatic brain injury

Mensuração do diâmetro da bainha do nervo óptico com ultrassonografia ocular e sua correlação com achados tomográficos de edema cerebral em pacientes com traumatismo cranioencefálico

Gisela Ponce y Ponce de León
Universidad Autónoma de Baja California, México
giselaponce@uabc.edu.mx
https://orcid.org/0000-0001-9708-3102

José de Jesús Mayagoitia Witrón
Hospital General de Mexicali, México
josemaya01@prodigy.net.mx
https://orcid.org/0000-0002-7388-157X

Alejandro Mayagoitia Ponce
Facultad de Medicina, Universidad Autónoma de Guadalajara, México
alejandromayagoitia026@gmail.com
https://orcid.org/0000-0001-9515-1618

Resumen

Introducción. El traumatismo craneoencefálico (TCE) es la tercera causa de deceso en México por causas violentas o accidentes, de ahí que se le considere un grave problema de salud pública (Cabrera Rayo *et al*., 2009; Valdez, 2011). La medición del diámetro de la vaina del nervio óptico (DVNO) por ultrasonido evalúa de manera indirecta la presión intracraneana. Diferentes estudios han demostrado que existe una correlación adecuada entre el diámetro de la vaina del nervio óptico y el edema cerebral reportado por tomografía, en especial en situaciones agudas como el traumatismo craneoencefálico (Hansen, Helmeke y Kunze, 2009; Uscanga, Castillo y Arroyo, 2005). **Objetivo.** Evaluar la correlación entre la medición del diámetro la vaina del nervio óptico por ultrasonido ocular y los hallazgos tomográficos de edema cerebral en pacientes con traumatismo craneoencefálico en la Unidad de Cuidados Intensivos del Hospital General de Mexicali. **Métodos.** Estudio descriptivo, longitudinal y de correlación realizado con 16 pacientes que ingresaron a la UCI del 1 de agosto de 2016 al 3 agosto de 2017. Se realizó medición diaria del diámetro de la vaina del nervio óptico con ultrasonido, y cada tercer día tomografía axial computarizada para el cálculo de edema cerebral. **Resultados.** Edad promedio de 34.8 años, con una desviación estándar de 14.4 años; 43.7 % sexo femenino y 56.2 % sexo masculino .140 (.025)*. Las causas de TCE más frecuentes fueron por accidente automovilístico (56.3 %) y atropellamiento (18.8 %). Asimismo, se halló correlación significativa entre la medición del DVNO por ultrasonido y el cálculo de edema cerebral por TAC; primera medición r de Spearman .577 (.019)* ojo derecho; segunda medición, ojo derecho r de Spearman .683 (.004)*, ojo izquierdo r de Spearman .600 (.014)*; tercera medición r de Spearman 1.000 (.01)* ojo derecho y r de Spearman .667 (.035)* ojo izquierdo; cuarta medición de r de Spearman 1.000 (.01)* ojo derecho y r de Spearman .745 (.035)* ojo izquierdo; quinta medición r de Spearman 1.000 (.01) * ojo derecho. **Discusión.** Se encontró concordancia con estudios que demuestran la correlación del DNO con la PIC en enfermos con TCE.[3-5] **Conclusiones.** Se halló una adecuada correlación en la medición del diámetro de la vaina del nervio óptico con ultrasonido ocular y los resultados tomográficos de edema cerebral. Por tanto, se considera que la medición del DVNO es una alternativa válida para el monitoreo neurológico del TCE.

Palabras clave: edema cerebral, nervio óptico, tomografía, traumatismo craneoencefálico, ultrasonido.

Abstract

Introduction. Traumatic brain injury (TBI) is the third cause of death in Mexico due to violent deaths and accidents, it is considered a serious public health problem, Valdez (2011), Cabrera Rayo et al. (2009). The measurement of the diameter of the optic nerve sheath by ultrasound indirectly evaluates the intracranial pressure. Different studies have shown that there is an adequate correlation between the diameter of the optic nerve and intracranial pressure (ICP), especially in acute situations such as traumatic brain injury, Uscanga, Castillo y Arroyo (2005), Hansen, Helmeke y Kunze (2009). **Objective.** To evaluate if there is a correlation between the measurement of the diameter of the optic nerve sheath (DONS) by ocular ultrasound and the tomographic findings of cerebral edema in patients with traumatic brain injury in the Intensive Care Unit of the General Hospital of Mexicali. **Methods.** Descriptive, longitudinal and correlation study in 16 patients admitted to the ICU from August 1, 2016 to August 3, 2017. Daily measurement of the diameter of the optic nerve sheath was performed with ultrasound, and every third day computerized axial tomography for the calculation of cerebral edema. **Results.** Average age of 34.8 years, with a standard deviation of 14.4 years; 43.7% female and 56.2% male .140 (.025)*. Most frequent cause due to automobile accident (56.3%); in second place, run over (18.8%). Significant correlation between the measurement of the DONS by ultrasound and the calculation of cerebral edema by CT; First measurement r of Spearman .577 (.019) * right eye; Second measurement, right eye r of Spearman.683 (.004) *, left eye r of Spearman .600 (.014) *; Third Spearman r measurement 1,000 (.01) * right eye and Spearman r .667 (.035) * left eye; Fourth measurement of Spearman's r 1,000 (.01) * right eye and Spearman's r .745 (.035) * left eye; Fifth measurement of Spearman 1,000 (.01) * right eye. **Discussion.** It is consistent with studies that show a correlation between and IC diameter of the DONS in patients with TBI. [3-5] **Conclusions**. An adequate correlation was found in the measurement of the diameter of the optic nerve sheath with ocular ultrasound and tomographic findings of cerebral edema. The DONS measurement is an alternative in the neurological monitoring in the TCE.

Key words: cerebral edema, optic nerve, tomography, traumatic brain injury, ultrasound.

Resumo

Introdução O traumatismo cranioencefálico (TCE) é a terceira causa de morte no México devido a causas violentas ou acidentes, por isso é considerado um grave problema de saúde pública (Cabrera Rayo et al., 2009, Valdez, 2011). A medida do diâmetro da bainha do nervo óptico (DVNO) pelo ultrassom avalia indiretamente a pressão intracraniana. Os estudos mostraram uma boa correlação entre o diâmetro da bainha do edema do nervo óptico e cérebro relatado tomografia, especialmente em situações agudas, tais como traumatismo craniano (Hansen, Helmeke e Kunze, 2009; Uscanga, Castillo e Arroyo, 2005). Objetivo Avaliar a correlação entre a medida do diâmetro da ultra-sonografia ocular bainha do nervo óptico e achados tomográficos de edema cerebral em pacientes com traumatismo craniano na Unidade de Cuidados Intensivos Mexicali Hospital Geral. Métodos Estudo de correlação longitudinal e descritivo com 16 pacientes internados na UTI 1 de agosto de 2016 a 3 de Agosto de 2017. medição diária do diâmetro do ultra-som bainha do nervo óptico foi realizada, e a cada terceiro dia tomografia computadorizada para o cálculo do edema cerebral. Resultados Idade média de 34,8 anos, com desvio padrão de 14,4 anos; 43,7% feminino e 56,2% masculino 0,140 (0,025) *. As causas mais frequentes de TCE foram acidentes de carro (56,3%) e acidentes de viação (18,8%). Da mesma forma, foi encontrada correlação significativa entre a medida do DVNO pela ultrassonografia e o cálculo do edema cerebral pela TC; primeiro r medição de Spearman .577 (0,019) * olho direito; segunda medida, olho direito r de Spearman .683 (0,004) *, olho esquerdo r de Spearman, 600 (0,014) *; terceira medição de Spearman r 1.000 (0,01) * olho direito e Spearman r, 667 (0,035) * olho esquerdo; quarta medição do olho direito de Spearman r 1.000 (.01) * e olho esquerdo de Spearman .745 (.035) *; quinto Spearman r medição 1.000 (0,01) * olho direito. Discussão Encontramos concordância com estudos que demonstram a correlação do NOD com a PIC em pacientes com TCE.3-5 Conclusões. Encontramos uma correlação adequada na medida do diâmetro da bainha do nervo óptico com a ultrassonografia ocular e os resultados tomográficos do edema cerebral. Portanto, considera-se que a medição de DVNO é válido para monitorização alternativa TCE neurológica.

Palavras-chave: edema cerebral, nervo óptico, tomografia, traumatismo craniano, ultra-som.

Fecha Recepción: Julio 2018 **Fecha Aceptación:** Diciembre 2018

Introduction

As a result of a clear knowledge of the physiopathology of traumatic brain injury (TBI), a management based on the primary lesion and on the prevention and early treatment of secondary injury has been carried out. While it is true that a variable proportion of the primary lesions occur at the very moment of the injury as a direct result of trauma to the cortex or by acceleration-deceleration movements of the brain within the skull, many of the secondary lesions appear after minutes, hours and even days of the initial injury, which damages the brain tissue even more, so the period for the appropriate and timely therapeutic intervention may vary (Valdez, 2011).

Now, there are currently several options to monitor the management of the patient with TBI. According to the American Clinical Guide (Brain Trauma Foundation), the monitoring of intracranial pressure (ICP) is recommended in all patients who have a Glasgow of 9 points, who has been operated for evacuation of occupant lesion in the intracranial space, in TCE moderate with compression of mesencephalic cisterns or deviation of the midline, in patients requiring sedation for mechanical ventilation and who have presented hemodynamic instability (Cabrera Rayo et al., 2009). In this regard, several studies have shown that the persistent elevation of ICP is associated with a poor prognosis. Mortality associated with a CIP less than 20 mmHg is 18.4% and increases to 55.6% with figures above 40 mmHg, cerebral ischemia and various herniation syndromes (Barcena-Orbe et al., 2006; Treggiari, Schutz, Yanez and Romand, 2007).

Due to the fact that elevated ICP is a common factor in severe TBI, monitoring it facilitates a more rational and accurate management of the patient, since it avoids unnecessary therapeutic actions. On the other hand, the monitoring of the ICP systematically, as it would be with the measurement of the sheath of the optic nerve by ultrasound, allows a better

assessment of neurological deterioration, as well as the certainty that the therapeutic measures used are those indicated (Cabrera Rayo et al., 2009).

Currently, new PIC neuromonitoring techniques are available (invasive and non-invasive). The ideal technique would be one that is not invasive, easy to use, with high sensitivity and specificity, and without risk of complications, that can be performed by health care personnel in charge of the patient, with a low learning curve (10 measurements with 3 abnormal scans for a doctor with experience in ultrasound, and 25 scans suitable for an inexperienced physician) (Dougborg, Javouhey, Geeraerts, Messere and Kassai, 2011, Newmn, Hollman, Duttongn and Carachi, 2002, Strumwasser et al., 2011). Likewise, it should be easily accessible to the health institution and at low cost, with an adequate correlation with the gold standard that is the measurement of ICP through an intraventricular catheter. Explained that, it can be said that monitoring with ocular ultrasound to measure the diameter of the optic nerve sheath could become the ideal method for this purpose (Uscanga, Castillo y Arroyo, 2005).

For this reason, the objective of this study was to determine whether the measurement of the diameter of the optic nerve sheath by ocular ultrasound was correlated to the tomographic findings of cerebral edema in patients with traumatic brain injury in the Intensive Care Unit of the General Hospital of Mexicali.

Methodology

The present study was descriptive, longitudinal and correlation, since it sought to determine if the measurement of the diameter of the optic nerve sheath (DVNO) by ocular ultrasound was correlated with the tomographic findings of cerebral edema in patients with traumatic brain injury in the Care Unit Intensives of the General Hospital of Mexicali. We included patients with head trauma who entered the mentioned unit, both sexes, over 18 years of age, with Glasgow <8 and with informed consent by the closest relative. We excluded those patients who did not meet these criteria (ie, burned, with bilateral eye trauma, with life expectancy of less than 24 hours and patients included in other research studies). Likewise,

patients who were transferred to another hospital or whose file was incomplete were not taken into account.

With the prior authorization of the Ethics and Research Committee of the General Hospital of Mexicali, the study was initiated once the patients who met the aforementioned inclusion criteria were selected. The procedure followed was as follows:

Eye ultrasound

1. We used Siemens portable ultrasound equipment with a 5-13 MHz transducer.
2. The ultrasound was calibrated to visualize structures up to 5-6 cm deep.
3. To the patient in the supine position, with elevation of the head at 20º, the transducer was placed on the upper eyelid with the eyes closed until a hypoechoic line was seen with clearly defined margins posterior to the eyeball.
4. The probe was always placed gently with the eyelid closed, and not on the cornea or sclera to avoid abrasions at this level.
5. Above the eyelid, the methylcellulose gel was applied in an abundant amount to avoid the interposition of air bubbles between the transducer and the surface of the skin.
6. The images were obtained in a transverse / axial plane.
7. Ocular and orbital exploration was done systematically, starting with a parasagittal plane, passing through the center of the eye and starting from this initial plane, angulating the transducer to right and left, the "sweep" from the innermost part to the external one of the organ studied. Finally, it was explored in the axial plane, also passing through the center of the cornea and the vitreous chamber, and angulating the transducer from the upper part to the lower part until observing the entire balloon (table 1) (Uscanga, Castillo y Arroyo, 2005).

Tabla 1. Escala de calificación del edema cerebral por tomografía computada

Característica	Valor
• Visibilidad de los surcos del vértex (D/I) (en tres cortes tomográficos a nivel del vértex)	3/3 (6)
• Visibilidad de la línea interhemisférica	(1)
• Visibilidad de la cisterna de Silvio (D/I)	1/1 (2)
• Visibilidad de las cisternas ambiens (D/I)	1/1 (2)
• Visibilidad de la cisterna prepontina	(1)
• Visibilidad de la cisterna interpeduncular	(2)
• Identificación de la diferenciación entre las sustancias	(1)
• Densidad de la sustancia blanca en la cápsula interna (D/I)	1/1 (2)
• Densidad de la sustancia blanca en centros semiovales (D/I)	1/1 (2)
• Dimensiones de las astas frontales de ventrículos laterales (D/I) (en el corte axial donde se observa la cabeza del núcleo caudado)	1/1 (2)
• Dimensión del tercer ventrículo (en el corte axial donde se identifican los ganglios basales)	(1)
Calificación total:	22

Nota: Se considera edema cerebral leve entre 17 y 22 puntos; edema cerebral moderado entre 13 y 16, y edema cerebral severo menor a 12.

Fuente: Elaboración propia

8. The nerve was visualized as a black streak, which appeared in the posterior part of the image to the posterior portion of the eyeball; this image should have been centered on the monitor. If the lens or iris were not visible in the image, the plane was off-axis and could result in underestimation of the DVNO (figure 2) (Shelvin, 2015).

Figura 1. Ultrasonido ocular

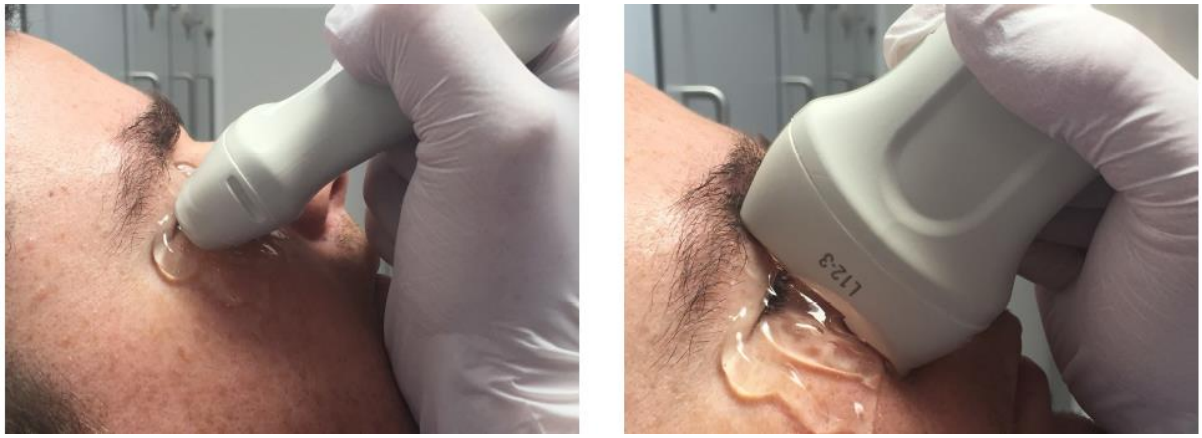
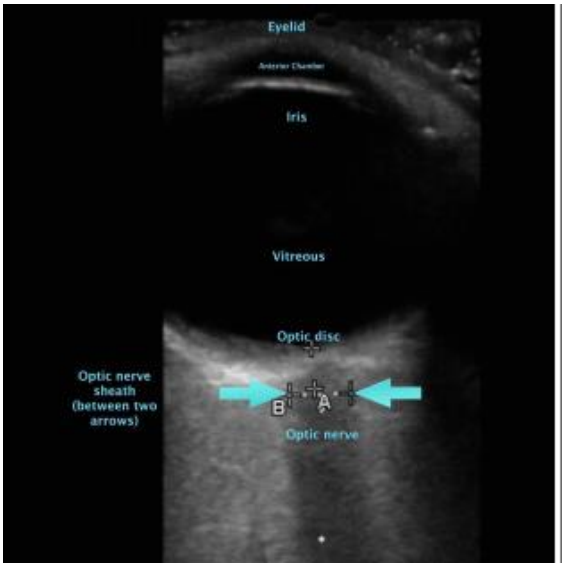


Imagen transversal Imagen parasagital

Fuente: Shevlin (2015)

9. Both eyes should be evaluated in case of unilateral papilledema.
10. Active viewing time should be minimized. Once optimal vision of the optic nerve had been achieved, the image had to be saved and the transducer removed from the eyelid in order not to unnecessarily expose the ultrasonic energy.
11. The sheath of the optic nerve was measured 3 mm behind the retina, point from which a transverse line was drawn from edge to edge of the optic nerve sheath, which has been considered the point at which the maximum DVNO occurs by effect of the increase in the CIP. It should be noted that to avoid errors in the DVNO measurement, the 3 mm trace below the posterior border of the retina must be respected, since otherwise there is a risk of bias in the subsequent determinations (Figures 1 and 2). (Shelvin, 2015).

Figura 2. Imagen ultrasonográfica transversa de la anatomía ocular



Fuente: Shevlin (2015)

12. It is considered a normal DVNO when its length is between 3 mm and 4.9 mm, with a diameter of 5 mm (Shelvin, 2015).

Computed tomography

1. It was performed by a radiologist every third day to calculate cerebral edema (mild edema = 17 to 22 points, moderate edema = 13 to 16 points, severe edema = or <12 points), using the Uscanga scale as a reference (see table 1) (Uscanga, Castillo y Arroyo, 2005).

Statistical design

For the analysis of the data, the SPSS package for Windows version 22.0 was used. The analysis of the type of distribution of the quantitative variables was expressed by means of their mean and standard deviation. The qualitative variables were expressed in percentages, with confidence intervals of 95%. For the analysis of these variables, chi-square was used. A level of $p < 0.05$.

Results

In the year that the present study was carried out (from August 1, 2016 to August 3, 2017), 21 patients with traumatic brain injury were admitted to the Intensive Care Unit of the General Hospital of Mexicali, of which five were excluded: one with traumatism on the face, two for transfer to another hospital and two deaths. Of the 16 patients who participated in the study, the average age was 34.8 years, with a minimum of 18 years and a maximum of 56 years, and with a standard deviation of 14.4 years. Of all the patients, 43.7% corresponded to the female sex and 56.2% to the male sex, Spearman r .140 (.025) *.

On the other hand, 93.8% had severe TBI and 6.3% moderate TBI. Of these patients, 48.8% had subdural hematoma and 18.8% epidural hematoma. Only 31.3% entered with a skull fracture, Spearman's r 16.0 (.38). The most frequent mechanism of injury was by automobile accident (56.3%), followed by running over (18.8%), motorcycle accident (12.5%) and fall and physical aggression (6.3%, respectively).

On average, the days of hospital stay were 6.9, with 6 days of ventilatory support, Spearman's r .950 (.05) *. Likewise, the diameter of the optic nerve sheath was measured daily

with ultrasound, and every third day with CT. On admission there was an average of 5.5 mm in the right eye and 5.8 mm in the left eye in the measurement of the DVNO by ultrasound, while on entering the mean in the DVNO measurement of the right eye was 5.0 mm and 4.9 in the left eye.

In relation to the assessment of cerebral edema by CT, upon admission to the Intensive Care Unit, 37.5% of severe edema and 62.5% of moderate edema were reported, while upon discharge 18.8% of severe edema, 25% of moderate edema were recorded. and 56.2% mild edema. Two deaths were reported. Table 2 and 3 show how a statistically significant relationship is found in most measurements (* $p < 0.001$).

Tabla 2. Relación de escala de cuantificación del edema cerebral por tomografía computarizada y medición del diámetro del nervio óptico por ultrasonido.
(N = 16)

	TAC 1	Medición 1	TAC 2	Medición 2	TAC 3	Medición 3	TAC 4	Medición 4	TAC 5	Medición5
Pac 1	3	7.3*	3	7.3*	3	7.7*	3	7.4*	3	6.8
Pac 2	2	5.3*	2	5.3	3	6.4*	2	5.3*	-	-
Pac 3	2	5.2*	2	5.2*	3	6.2*	3	6.7*	3	7.9*
Pac 4	3	6.4*	3	6.4*	3	5.7	3	6.6*	3	6.9*
Pac 5	3	6.6*	3	6.6*	2	5.4	-	-	-	-
Pac 6	2	5.6*	2	5.6*	3	6.9*	3	6.1*	2	5.5
Pac 7	2	4.3*	2	4.3*	2	4.6*	2	4.4*	-	-
Pac 8	2	4.0*	2	4.0*	2	5.1*	2	5.3*	3	6.4*
Pac 9	2	4.3*	2	4.3*	2	4.5*	2	4.7*	2	4.8*
Pac 10	3	6.2*	3	6.2*	3	5.8*	-	-	-	-
Pac 11	2	5.4	2	5.4	2	5.3	2	5.1*	2	3.8*
Pac 12	3	5.8	2	5.8	2	5.4	-	-	-	-
Pac 13	3	6.2*	3	6.2*	3	7.2*	3	6.7*	3	6.6*
Pac 14	2	5.1	2	5.1*	2	5.1*	-	-	-	-
Pac 15	2	5.7	3	5.7*	2	5.7	-	-	-	-
Pac 16	2	4.9*	2	4.9*	2	5.5	2	5.0*	2	5.0*

*p < 0.001

Fuente: Elaboración propia a partir de los datos obtenidos del expediente clínico

Tabla 3. Correlación de la medición del diámetro del nervio óptico con ultrasonido y cálculo del edema cerebral por tomografía computarizada

N = 16

Mediciones	Ojo derecho r Spearman/p	Ojo izquierdo r Spearman/p
Primera medición	.577 (.019) *	149 (.58)
Segunda medición	.683 (.004) *	.600 (.014) *
Tercera medición	1.000 (.01) *	.667 (.035) *
Cuarta medición	1.000 (.01) *	.745 (.035) *
Quinta medición	1.000 (.01) *	.471 (.286)

P = < 0.05

Fuente: Elaboración propia

Discussion

In previous studies (Alted, Bermejo and Chico, 2009, Carrillo et al., 2014, Deotti et al., 2011) it has been reported that TBI occurs more frequently in men than in women, in a 3: 1 ratio, and affects mainly the population whose age ranges between 15 and 45 years, results that agree with those obtained in this study, because the average age recorded was 34.8 years, with a minimum of 18 years and a maximum of 56 years , with a standard deviation of 14.4 years. Also, 43.7% were female and 56.2% were male.

On the other hand, other studies have indicated that the most frequent causes of TBI have been traffic accidents (42%), falls (23%) and assaults (14%) (Luviano García, 2010), figures similar to those found in the present study, where it has been reported that the main causes of the TBI have been the traffic accident (56.3%) and the run over (18.8%).

Similarly, several studies have shown a good correlation of DVNO with ICP, especially in patients with TBI (Lacerda, Abreu, Ortega, Diaz and Miranda, 2017, Maas, Hukkelhoven, Marshall and Steyerberg, 2005, Maas et al., 2007). Shirodkar et al., 2014). In the study conducted by Soldatos et al. (2008), where patients with TBI were included, an adequate correlation was found between the DVNO and the ICP, as it was demonstrated that an DVNO above 5.4 mm correlated with an ICP elevation of more than 20 mmHg, with a sensitivity of 74.1% and a specificity of 100%.

Dubourg et al. (2011) and Lavinio and Menon (2011) performed a meta-analysis that included six studies with statistically similar characteristics, which consisted of a total of 231

patients, which served to show that there is a correlation between DVNO and intracranial hypertension (HI).), using the ICP measurement with an intraventricular catheter as a comparator and gold standard. In this study it was demonstrated that with a DVNO cut-off point above 5.4 mm, a good correlation with a PIC above 20 mmHg, a sensitivity of 90% and a specificity of 85% is presented.

On the other hand, it has been shown that the diameter of the optic nerve sheath in its intraorbital segment is directly related to changes in intracranial pressure (ICP), since the optic nerve has an intraorbital, an intracanalicular and a subarachnoid portion, and it is in the intraorbital segment of the optic nerve (NO) where the DVNO measurement is made. In this way, the DVNO measurement by ultrasound indirectly evaluates intracranial pressure (Carrillo *et al.*, 2014).

Similarly, a correlation between a diameter greater than 0.5 cm with alterations in the tomography has been sought, which has made it possible to find a correlation between the measurement of DVNO and alterations in the image as displacement of the midline, alteration in space ventricular, herniation, etc .; the latter with sensitivity and speci fi city from 75% to 100%, and from 65% to 95%, respectively (Estrada Rojo et al., 2012; Girsing et al., 2007; Hightower, Chin and Heiner, 2012; Neuman et al. ., 2002; Ronald, Grant, Bath and Broshek, 2009; Strumwasser et al., 2011). The results of the present study, therefore, agree with those of previous investigations, since a significant relationship was reported between the measurement of the optic nerve with ocular ultrasound and the calculation of cerebral edema with CT ($p < 0.05$) (Lacerda et al., 2007; Maas et al., 2005; Shirodkar et al., 2014).

Finally, in the study conducted by Lobato et al. (2012) in patients with TBI, who underwent sequential CT and ICP monitoring, it was observed that 27 patients (48.9%) developed PIC deterioration, of which 21 (37.5%) presented concurrent changes in the CT, and 6 (10.7%) did not show it.

Conclusion

From the results obtained in this study it can be concluded that a significant correlation was observed between the measurement of the diameter of the optic nerve sheath by ocular ultrasound and the tomographic findings of cerebral edema in patients with traumatic brain injury, for which reason it is proposed as part of the neurological monitoring in patients with TBI, since it is an easy procedure to perform, non-invasive and does not represent a cost for the patient.

References

Alted, E., Bermejo, S. y Chico, M. (2009). Actualización en el manejo del traumatismo craneoencefálico grave. *Medicina Intensiva, 33*(1), 16-30.

Bárcena-Orbe, A., Rodríguez-Arias, C. A., Rivero-Martín. B., Cañizal-García, J. M., Mestre-Moreiro, C., y Calvo-Pérez, J. C. (2006). Revisión del traumatismo craneoencefálico. *Neurocirugía*, *17*, 495-518.

Cabrera Rayo, A., Martínez Olazo, O., Ibarra Guillén, A., Morales Salas, R., Laguna Hernández, G. y Sánchez Pompa, M. (2009). Traumatismo craneoencefálico severo. *Asociación Mexicana de Medicina Crítica y Terapia Intensiva*, *23*(2), 94-101.

Carrillo, R., Flores Rivera, O., Peña Pérez, C., Carrillo Córdova, L., Carrillo Córdova, J., Carrillo Córdova, C. y Carrillo Córdova, D. (2014). Evaluación ultrasonográfica del diámetro de la vaina del nervio óptico (DVNO) para la medición de la presión intracraneana (PIC): a propósito de un caso. *Gaceta Médica de México*, *150*(2), 165-70.

Deotti, S., Mollá Domenech, F., Nácher Fernández, B., Atienza Vicente, C., Mañas, B., García Belenguer, A., y Solves Camallonga, C. (2011). Nuevo dispositivo para la medida no invasiva de la presión intracraneal absoluta. *Revista de Biomecánica, 57*,63-65. Recuperado de https://www.ibv.org/publicaciones/revista-de-biomecanica/revista-de-biomecanica-57-diciembre-2011.

Dubourg, J., Javouhey, E., Geeraerts, T., Messerer, M. y Kassai, B. (2011). Ultrasonography of optic nerve sheath diameter for detection of raised intracranial pressure: a systematic review and meta-analysis. *Intensive Care Med*, *37*(7), 1059-68.

Estrada Rojo, F., Montes Gómez, J., Tabla Ramón, E., Solís Luna, B., Navarro Arguelles, H., Martínez Vargas, M., y Pérez Arredondo, A., (2012). Neuroprotección y traumatismo craneoencefálico. *Revista de la Facultad de Medicina de la UNAM*, *55*(4), 16-29.

Girisgin, A., Kalkan, E., Kocak, S., Cander, B., Gul, M. y Seniz, M. (2007). The role of optic nerve ultrasonography in the diagnosis of elevated intracranial pressure. *Emergency Medicine Journal*, *24*(4), 251-4. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2658229/.

Hansen, H. C., Helmeke, K. y Kunze, K. (2009). Optic nerve sheath Enlargement in Acute Intracranial Hypertension. *Neuro-Ophthalmology*, *14*(6), 345-354.

Hightower, S., Chin, E. y Heiner, J. (2012). Detection of Increased Intracranial Pressure by Ultrasound. *Journal of Special Operations Medicine*, *12*(3), 19-22.

Lacerda, A., Abreu, D., Ortega, A., Díaz, J. y Miranda, G. (2007). Protocolo para el tratamiento quirúrgico precoz en el control de la hipertensión intracraneal en el traumatismo craneoencefálico grave. *Revista Chilena de Neurocirugía*, *29*,45-51. Recuperado de https://issuu.com/ipx_chile/docs/revista29.

Lavinio, A. y Menon, D. (2011). Intracranial pressure: why we monitor it, how to monitor it, what to do with the number and what's the future? *Curr Opin Anesthesiol*, *24*(2), 117-123.

Lobato, R. D., Alen, J. F., Pérez-Núñez, A., Alday, R., Gómez, P. A., Pascual, B., y Lagares, A. (2012). Utilidad de la TAC secuencial y la monitorización de la presión intracraneal para detectar nuevo efecto masa intracraneal en pacientes con traumatismo craneal grave y lesión inicial tipo I-II. *Neurocirugía*, *16*(3), 217-271.

Luviano García, J. A. (2010). Importancia del tiempo puerta PIC y puerta TAC en el paciente con trauma craneoencefálico severo. *Revista de la Asociación Mexicana de Medicina Crítica y Terapia Intensiva*, *24*(1), 25-29.

Maas, A., Hukkelhoven, C., Marshall, L. y Steyerberg, E. (2005). Prediction of outcome in traumatic brain injury with computed tomographic characteristics: a comparison between the computed tomographic classification and combinations of computed tomographic predictors. *Neurosurgery*, *57*(6), 1173-82.

Maas, A., Steyerberg, E., Butcher, I., Dammers, R., Lu, J., Marmarou, A., Mushkudiani, N., y McHigh, G. (2007). Prognostic value of computerized tomography scan characteristics in traumatic brain injury: results from the IMPACT study. *Neurotrauma*, *24*(2), 303-14. Doi: 10.1089/neu.2006.0033.

Newman, W., Hollman, A., Duttongn, G. y Carachi, R. (2002). Measurement of optic nerve sheath diameter by ultrasound: a means of detecting acute raised intracranial pressure in hydrocephalus. *Br J Ophthalmol*, *86*(10), 1109-13.

Ronald, M., Grant, L., Barth, J., Bush, S. y Broshek, D. (2009). Recommendations for Diagnosing a Mild Traumatic Brain Injury: A National Academy of Neuropsychology Education Paper. *Archives of Clinical Neuropsychology*, *24*(1), 3-10.

Shevlin, C. (2015). Optic nerve sheath ultrasound for the bedside diagnosis of a intracranial hypertension: pitfalls and potential. *Critical Horizons*, *1*, 22-30.

Shirodkar, Ch., Manimala Rao, S., Mutkule, D., Harde, Y., y Venkategowda, P. and Uma Mahesh, M. (2014). Optic nerve sheath diameter as a marker for evaluation and prognostication of intracranial pressure in Indian patients: An observational study. *Indian Journal of Critical Care Medicine*, *18*(11), 728-734. Doi: 10.4103/0972-5229.144015.

Soldatos, T., Karakitsos, D., Chatzimichail, K., Papathanasiou, M., Gouliamos, A. y Karabinis, A. (2008). Optic nerve sonography in the diagnostic evaluation of adult brain. *Critical Care*, *12*(3), 67-71. Recuperado de https://www.ncbi.nlm.nih.gov/pubmed/18477382.

Strumwasser, A., Kwan, R., Yeung, L., Miraflor, E., Ereso, A., Castro Moure, F., y Patel, A. (2011). Sonographicoptic nerve sheath diameter as an estimate of intracranial pressure in adult trauma. *J Surg Res*, *170*(2), 265-71.

Treggiari, M. M., Schutz, N., Yanez, N. D. y Romand, J. A. (2007). Role of intracranialpressure values and patterns in predicting outcome of traumatic brain injury: a systematic review. *Neurocrit Care*, *6*, 04-12.

Uscanga, M., Castillo, J. y Arroyo, G. (2005). Hallazgos por tomografía computada en pacientes con trauma craneoencefálico: su relación con la evolución clínica y cálculo del edema cerebral. *Revista Neurología, Neurocirugía y Psiquiatría*, *38*(1), 11-19.

Valadez, R. (2011). Traumatismo craneoencefálico. *Educación Médica Continua*. Recuperado de http://cbpharma.blogspot.mx/2011/03/traumatismo-craneoencefalico-tce.html.

Rol de Contribución	Autor (es)
Conceptualización	Gisela Ponce y Ponce de León y José de Jesús Mayagoitia Witrón (igual)
Metodología	Gisela Ponce y Ponce de León y José de Jesús Mayagoitia Witrón (igual)
Software	Gisela Ponce y Ponce de León y Alejandro Mayagoitia Ponce (igual)
Validación	Gisela Ponce y Ponce de León, José de Jesús Mayagoitia Witrón (igual) y Alejandro Mayagoitia Ponce (apoya)
Análisis Formal	Gisela Ponce y Ponce de León, José de Jesús Mayagoitia Witrón y Alejandro Mayagoitia Ponce (igual)
Investigación	Gisela Ponce y Ponce de León, José de Jesús Mayagoitia Witrón y Alejandro Mayagoitia Ponce (igual)
Recursos	José de Jesús Mayagoitia Witrón (principal) y Alejandro Mayagoitia Ponce (apoya)
Curación de datos	Gisela Ponce y Ponce de León (principal) y Alejandro Mayagoitia Ponce (apoya)
Escritura - Preparación del borrador original	Gisela Ponce y Ponce de León y José de Jesús Mayagoitia Witrón (igual)
Escritura - Revisión y edición	Gisela Ponce y Ponce de León, José de Jesús Mayagoitia Witrón (igual) y Alejandro Mayagoitia Ponce (apoya)
Visualización	Gisela Ponce y Ponce de León, José de Jesús Mayagoitia Witrón (igual) y Alejandro Mayagoitia Ponce (apoya)
Supervisión	Gisela Ponce y Ponce de León (principal)
Administración de Proyectos	Gisela Ponce y Ponce de León y José de Jesús Mayagoitia Witrón (igual)
Adquisición de fondos	Gisela Ponce y Ponce de León y José de Jesús Mayagoitia Witrón (igual)