The role of optic nerve sheath diameter and jugular bulb vein saturation in monitoring consciousness in patients with increased intracranial pressure in brain trauma

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Abstract

***Objective*: An increased intracranial pressure (ICP) caused by brain trauma is a leading factor of morbidity and mortality. This elevated pressure diminishes cerebral perfusion pressure (CPP) and cerebral blood flow (CBF). Currently, several ICP monitoring modalities exist, such as optic nerve sheath diameter (ONSD) and jugular venous oxygen saturation (SvjO2). This study aimed to determine the role of measuring ONSD and SjvO2 in monitoring changes in consciousness in post-surgical patients with the potential for increased intracranial pressure in moderately severe brain trauma.**

***Design*: An observational study with a prospective approach.**

***Setting*: Conducted at Dr. Wahidin Sudirohusodo Central General Hospital Makassar and educational network hospitals.**

***Patient and participants*: The participants were patients aged over 17 years old with head trauma with increased intracranial pressure who were scheduled to undergo cranial surgery and were being treated in the Intensive Care Unit (ICU) and Resuscitation Room.**

***Interventions*: ONSD, SjvO2, and consciousness measurements in subjects with potential increased ICP improved 24 hours and 48 hours after surgery.**

***Measurement and results*: The post-op ONSD and SjvO2 values significantly decreased compared to pre-op. There was a significant negative correlation between post-op ONSD and post-op Glasgow Coma Scale (GCS), where a decrease in ONSD indicated an increase in GCS in patients with moderate brain trauma. The ONSD and SjvO2 values in the post-op severe head trauma group did not correlate with post-op GCS improvement in patients with severe brain trauma.**

***Conclusions*: The mean values of ONSD and SjvO2 in individuals with traumatic brain injuries and elevated intracranial pressure exhibited a decline post-surgery. This decrease aligned with improved consciousness levels and elevated intracranial pressure following surgical intervention. Consequently, the investigation established an association between ONSD, SjvO2, and GCS, indicating their potential utility as dynamic monitoring indicators for individuals with head trauma and increased intracranial pressure.**

Key words: Intracranial pressure, optic nerve sheath diameter, jugular venous oxygen saturation,

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Introduction

Increased intracranial pressure (ICP) is one of the main causes of secondary brain damage with high morbidity and mortality. (1,2) Increased ICP can be caused by head injury, intracerebral hemorrhage, subarachnoid hemorrhage, hydrocephalus, meningitis, stroke, etc. so that the pressure reaches ≥20 mmHg. (3-5) The Centers for Disease Control estimates that in 2010, 2.5 million people suffered a traumatic brain injury. Increased ICP causes tissue damage by disrupting cerebral perfusion. Therefore, early identification along with ICP monitoring is very important to prevent further brain damage and improve patient outcomes. (6) Factors associated with increased ICP are hypercarbia, hypoxemia, ETT suction, positioning, isometric muscle contractions, Valsalva maneuver, seizures, and hyperthermia. (7-11) An increase in one of these three components: the total volume of brain parenchyma, CSF, and relatively constant cerebral blood volume, results in intracranial compliance. (12-16) Increased ICP reduces cerebral perfusion pressure (CPP) and blood delivery to the brain which compromises brain function. (2,17,18)

Cerebral perfusion pressure (CPP) and cerebral blood flow (CBF) are monitored as part of ICP monitoring that can be detected through CT and MRI modalities, but are not always available in all medical services. (19-21) Optic nerve sheath diameter (ONSD) ultrasonography (USG) examination has proven to be a monitoring procedure for increased ICP that can be easily performed bedside so it is easy to apply in the Intensive Care Unit (ICU). (6,7) Increased ICP and CSF are related to the optic nerve and nerve sheath optics resulting in ONSD enlargement with cut points varying from 4.8 to 5.9 mm. (8-10,22,23)

Another method is monitoring jugular vein oxygen saturation (SjvO2) which is a technique for estimating the global balance between the brain's oxygen supply and its metabolic needs. (23-25) Measurement of SjvO2 via a catheter in the jugular bay, provides information about cerebral metabolism that one jugular bulb represents blood oxygen saturation in the contralateral hemisphere or even variations in the ipsilateral hemisphere measures the relationship between CBF and the rate of cerebral oxygen metabolism. (26-29)

The ONSD and SjvO2 are methods that can both monitor patients with ICP and can be useful as a determine ventilator removal and extubation. (4,5) Therefore, researchers are interested in examining the role of ONSD and SjvO2 as monitoring changes in consciousness in post-surgical patients with the potential for increased ICP in moderate to severe brain trauma. (30)

Materials and methods

The design used in this research was observational with a prospective approach. This research was carried out at Dr. Wahidin Sudirohusodo Central General Hospital Makassar and educational network hospitals from July 2023 to November 2023. The population included in this study were head trauma patients with increased intracranial pressure who were going to undergo cranial surgery and treated in the ICU and resuscitation room. The research sample of 32 was obtained from a population that met the inclusion criteria and agreed to take part in the research. Inclusion criteria included 1) head trauma patients with increased intracranial pressure, 2) age >17 years, and 3) patients undergoing surgery.

The exclusion criteria in this study were 1) cervical spinal cord injury, 2) severe coagulopathy, 3) platelets <100,000/mm^3, and 3) patients taking immunosuppressants. Meanwhile, the dropout criteria in this study were 1) surgical complications that occurred, 2) complications of ICP monitoring, and 3) the patient withdrew from the study. This research has met the ethical requirements of the Human Biomedical Research Ethics Commission, Faculty of Medicine, Hasanuddin University, and the Network Hospital Education and Research Section.

The first step in conducting this research were to 1) history taking, clinical examination, and physical and supporting examination to determine an increase in ICP; 2) collect samples according to the inclusion criteria; 3) provide an explanation of the aims and benefits of the research; 4) signing informed consent; 5) measurement of ONSD, SjvO2, and GCS; 6) surgery on patients; 7) measurement of ONSD, SjvO2, and GCS 24 hours and 48 hours after surgery; 8) data collection; and 9) data analysis and reporting.

The data obtained was processed, and the ONSD and SjvO2 trend results were displayed in the form of narratives, tables, or graphs in the form of averages and standard deviations, as well as frequencies and percentages, using SPSS 25 for Windows. Analysis of factors influencing changes in ONSD and SjvO2 between before and after surgery was analyzed using the independent sample t-test or ANOVA test if the data were normal and the Wilcoxon signed rank test if the data was not normal. The normality test was carried out using the Shapiro-Wilk normality test. Interpretation of the results used a degree of significance α (p alpha) of 5%.

The study has been approved by the appropriate ethics committee and has, therefore, been performed in

accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All persons gave their informed consent prior to their inclusion in the study.

Results

Descriptive analytics

Data was taken from 32 samples involving three main variables, namely optic nerve sheath diameter (ONSD), jugular venous oxygen saturation (SjvO2), and Glasgow coma scale (GCS). For the ONSD variable, the diameter of the optic nerve sheath was measured in both eyes of the patient using ultrasound techniques. ONSD measurement results range from minimum to maximum values (**Table 1**). The SjvO2 variable measured jugular bulb venous saturation in patients. The results of these measurements were recorded for each patient in the sample. SjvO2 data has similar characteristics to ONSD, namely having minimum, maximum, mean, median, and standard deviation values (**Table 2**). In addition, GCS was used to measure the patient's level of consciousness. GCS scores ranged from 3 (lowest level of awareness) to 15 (highest level of awareness) (**Table 3**). From the results of the data distribution test, there were 23 patients with moderate head trauma who were extubated after surgery, and there were 4 patients who had delayed extubation. Meanwhile, 5 patients with severe head trauma all underwent delayed extubation after surgery (**Table 4**).

Bivariate analytics

1. Assumptions test.
   The normality test findings using Shapiro-Wilk demonstrated that only the ONSD measurement data was normally distributed, whereas the other data was not (**Table 5**). As a result, ONSD was examined using parametric statistics, while SjvO2 and GCS were assessed using non-parametric statistics.
2. Hypothesis test
   a. ONSD in patients with increased ICP improved after surgery.
      The Wilcoxon signed-rank test was used to test the differences and to see the effect of surgery based on ONSD measurements (**Table 6**). The post-op ONSD value significantly decreased by 3.7% compared to pre-op ($p<0.01$); the 24-hour ONSD value significantly decreased by 7.6% compared to pre-op ($p<0.001$); the 48-hour ONSD value significantly decreased by 11.3% compared to pre-op ($p<0.001$). These results indicated that there were significant differences in ONSD over time at different measurement times, thus supporting the hypothesis that ONSD experiences significant improvement during the postoperative period, and these differences may contribute to the understanding of changes in consciousness in postoperative patients with potential increased intracranial pressure.
   b. SjvO2 in patients with increased ICP improved after surgery.
      The Wilcoxon signed-rank test was used to test differences and to see the effect of surgery based on SjvO2 measurements (**Table 7**). The post-op SjvO2 value significantly decreased by 0.7% compared to pre-op ($p<0.01$); the 24-hour SjvO2 value significantly decreased by 7.4% compared to pre-op ($p<0.001$); the 48-hour SjvO2 value significantly decreased by 10.2% compared to pre-op ($p<0.001$). These findings indicated that there were significant differences in SjvO2 over time at different measurement times, thus supporting the hypothesis that SjvO2 experiences significant changes during the postoperative period. These changes may be an important factor in understanding changes in consciousness in post-surgical patients with the potential for increased intracranial pressure.
   c. Patient awareness with increased ICP improved after surgery.
      The Wilcoxon signed-rank test was used to test differences and to see the effect of surgery on patient consciousness (**Table 8**). The post-op GCS value decreased by 11.0% compared to pre-op, but this was not statistically significant ($p>0.05$); the 24-hour GCS value significantly increased by 15.8% compared to pre-op ($p<0.01$); the 48-hour GCS value significantly increased by 19.5% compared to pre-op ($p<0.001$). These results indicated that there were significant differences in GCS scores over time at different measurement times, thus supporting the researcher's hypothesis that GCS scores experience significant changes during the postoperative period.
   d. Correlation of ONSD and SjvO2 measurements with GCS in moderate brain trauma.
      Samples were taken from 27 patients with moderate brain trauma. Correlation results using the Spearman test are shown in **Table 9**. There was a significant negative correlation between post-op ONSD and post-op

GCS, where a decrease in ONSD indicated an increase in GCS. This correlated with improved GCS in patients with moderate brain trauma. In this study, most patients with moderate brain trauma did not undergo delayed extubation after the evaluation during surgery, and the ONSD and SjvO2 values, which showed improvement, could be used as a reference in making clinical decisions.

Table 10 shows the significant negative correlation of the 24-hour ONSD and SjvO2 with the 24-hour GCS in patients with moderate brain trauma. The decrease in ONSD indicated an increase in GCS. This correlated with improved GCS in patients with moderate brain trauma. In this study, most of the samples showed an increased GCS compared to before surgery. This could be related to changes after surgical intervention, thus indicating an improvement in intracranial pressure and cerebral metabolism.

Table 11 shows the significant negative correlation of the 48-hour ONSD and SjvO2 with the 48-hour GCS in moderate brain trauma patients. The decrease in ONSD indicated an increase in GCS. This was associated with the development of clinical improvement seen 48 hours after surgery. Most of the patients in the brain trauma group were extubated immediately after surgery. The effects of surgical intervention and maintenance during treatment contributed to the improvement of cerebral flow and prevention of secondary brain injury. This can be monitored by improving the results of the ONSD and SjvO2 measurements.

e. Correlation of ONSD and SjvO2 with GCS in severe head trauma.

Samples were taken from 5 patients with moderate brain trauma. The results of the Spearman correlation carried out are shown in **Table 12**. The results show that the ONSD and SjvO2 values in the post-op severe head trauma group did not correlate with post-op GCS improvement. In this study, all patients with severe head trauma had delayed extubation after surgery and the patients were still under sedation so GCS evaluation could not be carried out.

Table 13 shows that there was no significant correlation between the 24-hour SjvO2 and the 24-hour GCS ($p>0.05$). This was related to the patients who were still under sedation because the extubation was delayed. Therefore, GCS evaluation could not be carried out.

Table 14 shows that there was no significant correlation between the 48-hour SjvO2 and the 48-hour GCS ($p>0.05$). This was related to the patients with severe head injuries after taking a sedation holiday to evaluate GCS, showing that the majority did not experience improvement in GCS.

Discussion

ONSD in patients with increased ICP changed after surgery

ONSD decreased over time after surgery. This could be important for understanding ICP development in post-surgery patients. Changes in ONSD in these patients may be due to medical factors related to surgery and ICP dynamics. In surgeries for moderate to severe head injuries, procedures can impact the flow of cerebrospinal fluid around the brain, and pressure might cause the ONSD to expand as a natural response. (31)

The results of this study showed significant changes in ONSD at various postoperative time points, namely immediately after surgery, 24 hours after surgery, and 48 hours after surgery (**Figure 1**). This was consistent with the finding that increased ICP can lead to increased ONSD. (32,33) Several studies revealed that there is a linear relationship between CSF pressure around the optic nerve and ICP, and ONSD changes almost in line with changes in ICP. (32) The decrease in ONSD may reflect a decrease in ICP that occurs postoperatively, which can be attributed to the management of cerebral edema, improvement in cerebrospinal fluid circulation, or resolution of edema. (33-35) These findings highlight the potential of ONSD as a useful non-invasive indicator in the postoperative monitoring of patients with the potential for increased ICP. (33,36,37)

SjvO2 in patients with increased ICP changed after surgery

The results showed a significant decrease in SjvO2 values at various postoperative times, indicating altered jugular bulb venous oxygen levels, especially in patients with potential ICP increase. A decreased SjvO2 suggests a relative increase in cerebral metabolic rate of oxygen (CMRO2) or a relative decrease in cerebral blood flow, aiding in diagnosing cerebral desaturation (**Figure 2**). (38) Various factors, such as head injury or hyperventilation, may affect the CMRO2-oxygen supply relationship. (39)

Monitoring SjvO2 has become crucial in assessing

global oxygenation and cerebral blood flow. To measure SjvO2, a catheter is retrogradely inserted into the internal jugular vein, considering the side affected or predominant in venous drainage. The normal SjvO2 range is 55-75%, with values exceeding 75% indicating hyperemia, microvascular changes, or reduced cerebral metabolic needs, potentially leading to neurological disorders. (11)

Contrary to the expected desaturation, this study observed high SjvO2 values or hyperemia before surgery, gradually decreasing to normal levels 48 hours post-surgery. The hyperemic phase involves decreased cerebrovascular resistance, vasodilatory metabolites, and hyperglycolysis disrupting post-traumatic brain vascularization. (40-42)

The consciousness of patients with increased ICP changes after surgery

In this study, changes in GCS were observed at various time points: before surgery (Pre-op), after surgery (Post-op), 24 hours post-surgery, and 48 hours post-surgery. The results of the Friedman test showed that there was a significant difference in GCS scores between these time points ($\chi^2=53.147$, df=3, $p<0.001$). This difference indicated that the postoperative process in patients with increased ICP influenced their level of consciousness.

The level of intensity of ICP management was found to correlate with GCS results at six months post-injury. (35) This suggests that controlling ICP with higher intensity can contribute to improved neurological function. Patients with a mean ICP >15.8 mmHg, a total ICP >15 mmHg over 25.5, or a total ICP >20 mmHg over 6 at 72 hours post-injury have an unfavorable neurologic prognosis. (35) These findings confirm the association between ICP values and patient prognosis, in line with the researchers' hypothesis that changes in ICP can influence changes in patient GCS.

The higher the GCS score, the lower the patient's risk of experiencing an increase in ICP which can result in a poor prognosis. However, the relationship between GCS, ICP, and patient prognosis remains complex. Thus, GCS remains a very useful tool for clinicians in assessing the severity of traumatic brain injury and in monitoring patient progress during treatment. (37,38)

Conclusion

The average ONSD and SjvO2 in brain trauma patients with increased ICP decreased after surgery. This can be correlated with the level of consciousness in brain trauma patients with increased ICP, which improved after surgery. Thus, this study found a relationship between ONSD, SjvO2, and GCS, which can be used as a dynamic monitoring modality in head trauma patients with increased ICP.

Table 1. Descriptive analysis for ONSD measurement variables

Time	Mean±SD	Median	Range
Pre-op	6.71±0.52	6.67	2.55
Post-op	6.46±0.46	6.47	2.00
24 hours post-op	6.20±0.48	6.20	1.70
48 hours post-op	5.97±0.45	5.97	1.55

Legend: ONSD=optic nerve sheath diameter; SD=standard deviation.

Table 2. Descriptive analysis for SjvO2 measurement variables

Time	Mean±SD	Median	Range
Pre-op	90.87±8.60	89.40	28
Post-op	87.62±9.57	87.50	31.20
24 hours post-op	81.48±8.40	78.85	31.30
48 hours post-op	79.92±8.55	77.35	8.55

Legend: SjvO2=jugular vein oxygen saturation; SD=standard deviation.

Table 3. Descriptive analysis for GCS measurement variables

Time	Mean±SD	Median	Range
Pre-op	11.06±1.74	11.50	7
Post-op	9.84±4.40	12.00	11
24 hours post-op	11.31±4.91	14.00	12
48 hours post-op	13.50±3.47	15.00	12

Legend: GCS=Glassgow coma scale; SD=standard deviation.

Table 4. Data on distributive consciousness in post-operative brain trauma

Type of brain trauma	Post-op GCS		Total
	Delayed extubation	Extubation	
Moderate brain trauma	4	23	27
Severe brain trauma	5	0	5
Total	9	23	32

Legend: GCS=Glassgow coma scale.

Table 5. Normality test results

Variable	Results
ONSD	0.063*
SjvO2	p<0.001**
GCS	p<0.001**

Legend: ONSD=optic nerve sheath diameter; SjvO2=jugular vein oxygen saturation; GCS=Glassgow coma scale.
*data was normally distributed via the Shapiro-Wilk normality test; **data was not normally distributed.

Table 6. Wilcoxon signed-rank test of ONSD 24 hours and 48 hours post-op values compared to pre-op

Variables	n	Mean	SD	Decrease (%)	p
ONSD pre-op	32	6.71	0.54	0.25 (3.7)	0.003
ONSD post-op	32	6.46	0.44		
ONSD pre-op	32	6.71	0.54	0.51 (7.6)	<0.001
ONSD 24 hours	32	6.20	0.51		
ONSD pre-op	32	6.71	0.54	0.76 (11.3)	<0.001
ONSD 48 hours	32	5.95	0.47		

Legend: ONSD=optic nerve sheath diameter; SD=standard deviation.

Table 7. Wilcoxon signed-rank test of SjvO2 24 hours and 48 hours post-op values compared to pre-op

Variables	n	Mean	SD	Decrease (%)	p
Sjv02 pre-op	32	90.88	8.61	0.63 (0.7)	0.009
Sjv02 post-op	32	87.62	9.57		
Sjv02 pre-op	32	90.88	8.61	6.77 (7.4)	<0.001
Sjv02 24 hours	32	81.48	8.41		
Sjv02 pre-op	32	90.88	8.61	9.24 (10.2)	<0.001
Sjv02 48 hours	32	79.01	8.56		

Legend: SjvO2=jugular vein oxygen saturation; SD=standard deviation.

Table 8. Wilcoxon signed-rank test of GCS 24 hours and 48 hours post-op values compared to pre-op

Variables	n	Mean	SD	Decrease (%)	p
GCS pre-op	32	11.06	1.74	1.22 (11.0)*	0.237
GCS post-op	32	9.84	4.40		
GCS pre-op	32	11.06	1.74	-1.75 (15.8)**	0.001
GCS 24 hours	32	12.81	3.41		
GCS pre-op	32	11.06	1.74	-2.16 (19.5)**	<0.001
GCS 48 hours	32	13.22	3.52		

Legend: GCS=Glassgow coma scale; SD=standard deviation.
*decrease; **increase.

Table 9. Correlation of post-op ONSD and SjvO2 with post-op GCS in moderate brain trauma patients

ONSD and SjvO2 compared to GCS	r	p
ONSD post-op	-0.471	0.013*
SjvO2 post-op	-0.529	0.005*

Legend: ONSD=optic nerve sheath diameter; SjvO2=jugular vein oxygen saturation; GCS=Glassgow coma scale; r=correlation coefficient.
Data tested by Spearman test. *significant.

Table 10. Correlation of 24 hours ONSD and SjvO2 with 24 hours GCS in moderate head trauma patients

ONSD and SjvO2 compared to GCS	r	p
ONSD 24 hours	-0.435	0.023*
SjvO2 24 hours	-0.240	0.028*

Legend: ONSD=optic nerve sheath diameter; SjvO2=jugular vein oxygen saturation; GCS=Glassgow coma scale; r=correlation coefficient.
Data tested by Spearman test. *significant.

Table 11. Correlation of 48 hours ONSD and SjvO2 with 48 hours GCS in moderate brain trauma patients

ONSD and SjvO2 compared to GCS	r	p
ONSD 48 hours	-0.491	0.009*
SjvO2 48 hours	-0.477	0.037*

Legend: ONSD=optic nerve sheath diameter; SjvO2=jugular vein oxygen saturation; GCS=Glassgow coma scale; r=correlation coefficient.
Data tested by Spearman test. *significant.

Table 12. Correlation of post-op ONSD and SjvO2 with post-op GCS in severe brain trauma patients

ONSD and SjvO2 compared to GCS	r	p
ONSD post-op	0.714	0.982^{ns}
SjvO2 post-op	0.592	0.917^{ns}

Legend: ONSD=optic nerve sheath diameter; SjvO2=jugular vein oxygen saturation; GCS=Glassgow coma scale; r=correlation coefficient.
Data tested by Spearman test. ^{ns}not significant.

Table 13. Correlation of 24 hours ONSD and SjvO2 with 24 hours GCS in severe brain trauma patients

ONSD and SjvO2 compared to GCS	r	p
ONSD 24 hours	0.229	0.710[ns]
SjvO2 24 hours	-0.335	0.581[ns]

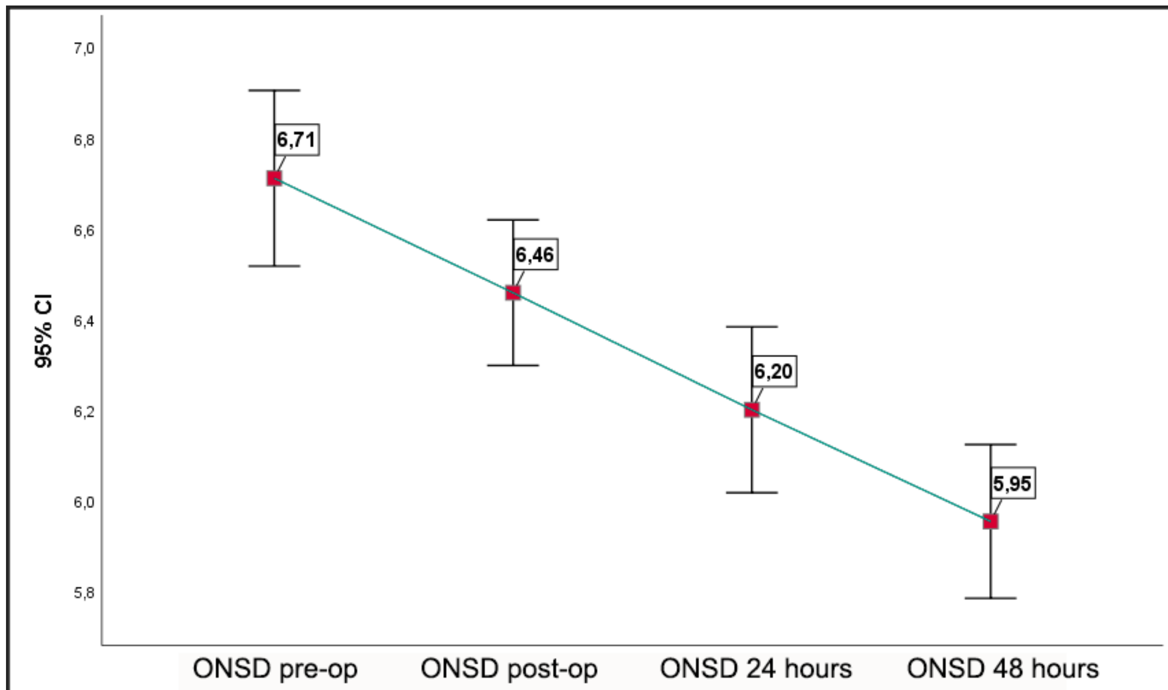
Legend: ONSD=optic nerve sheath diameter; SjvO2=jugular vein oxygen saturation; GCS=Glassgow coma scale; r=correlation coefficient.
Data tested by Spearman test. [ns]not significant.

Table 14. Correlation of 48 hours ONSD and SjvO2 with 48 hours GCS in severe brain trauma patients

ONSD and SjvO2 compared to GCS	r	p
ONSD 48 hours	-0.459	0.437[ns]
SjvO2 48 hours	-0.335	0.581[ns]

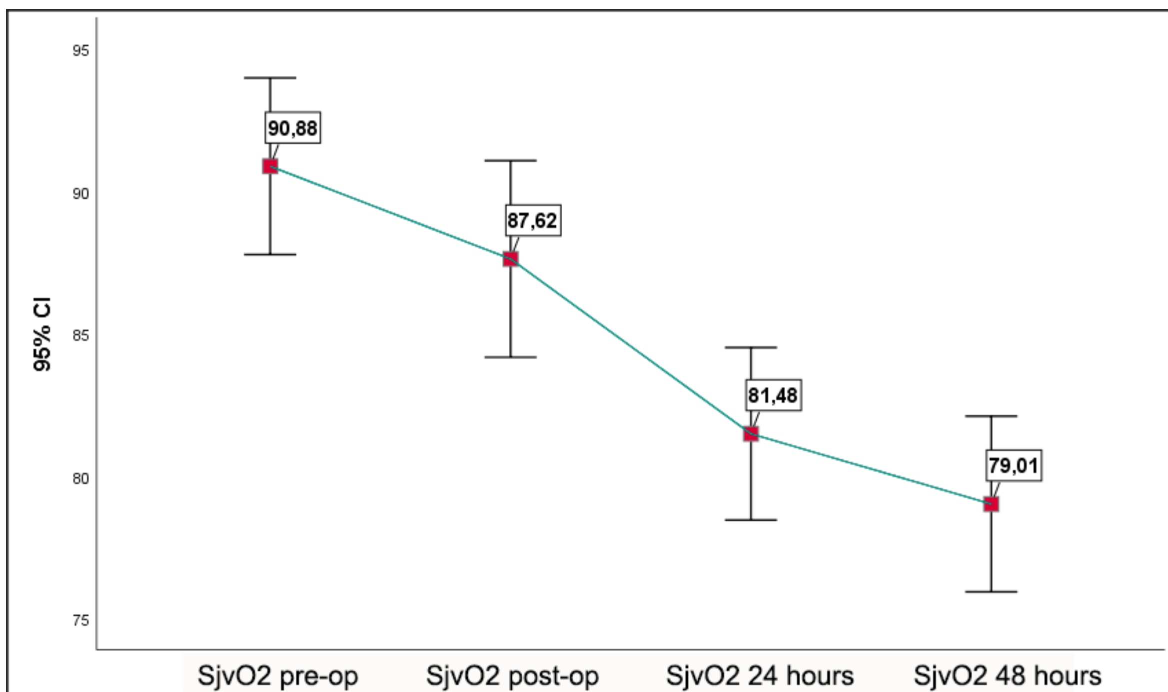
Legend: ONSD=optic nerve sheath diameter; SjvO2=jugular vein oxygen saturation; GCS=Glassgow coma scale; r=correlation coefficient.
Data tested by Spearman test. [ns]not significant.

Figure 1. ONSD value trend



Legend: ONSD=optic nerve sheath diameter.

Figure 2. SjvO2 value trend



Legend: SjvO2=jugular vein oxygen saturation.

References

1. Hioe AS. Pengukuran Diameter Selubung Nervus Optikus (Optic Nerve Sheath Diameter) Berbasis Ultrasonografi: Metode Pemantauan Tekanan Intrakranial Non-invasif Selanjutnya? Cermin Dunia Kedokteran 2022;49:108-11.
2. Schmidt EA, Despas F, Traon AP-L, Czosnyka Z, Pickard JD, Rahmouni K, et al. Intracranial pressure is a determinant of sympathetic activity. Front Physiol 2018;9:1-13.
3. Thamrin MH, Airlangga PS. Pengukuran Optical Nerve Sheath Diameter (ONSD) untuk Monitoring Tekanan Intrakranial (TIK) di Intensive Care Unit (ICU). Jurnal Anestesiologi Indonesia 2019;11:28-37.
4. Colak T, Celik K. The association between cervical collar and intracranial pressure measured by the optic nerve sheath diameter in trauma patients refered to the emergency department. Signa Vitae 2020;16:89-95.
5. Sommeng F, Arif SK. Pemantauan Oksigen Otak Dengan Pengukuran Saturasi Oksigen Vena Jugularis (SjvO2) Sebelum Ekstubasi Pada Pasien Cedera Otak Traumatik. Wal'afiat Hospital Journal 2022;3:8-12.
6. Montorfano L, Yu Q, Bordes SJ, Sivanushanthan S, Rosenthal RJ, Montorfano M. Mean value of B-mode optic nerve sheath diameter as an indicator of increased intracranial pressure: a systematic review and meta-analysis. Ultrasound J 2021;13:1-12.
7. Sulistyani S, Danuaji R. Perbedaan Optic Nerve Sheath Diameter (ONSD) Pada Responden Normal Dan Nyeri Kepala. Biomedika 2019;11:96-104.
8. Bender M, Lakicevic S, Pravdic N, Schreiber S, Malojcic B. Optic nerve sheath diameter sonography during the acute stage of intracerebral hemorrhage: a potential role in monitoring neurocritical patients. Ultrasound J 2020;12:1-8.
9. Lee SH, Yun SJ, Kim DH. Optic nerve sheath diameter measurement for predicting raised intracranial pressure in pediatric patients: A systematic review and meta-analysis. Hong Kong J Emerg Med 2022;29:177-86.
10. Canac N, Jalaleddini K, Thorpe SG, Thibeault CM, Hamilton RB. Review: Pathophysiology of intracranial hypertension and noninvasive intracranial pressure monitoring. Fluids Barriers CNS 2020;17:1-21.
11. Senapathi TGA, Wiryana M, Sinardja K, Nada KW, Sutawan IBKJ, Ryalino C, et al. Jugular bulb oxygen saturation correlates with full outline of responsiveness score in severe traumatic brain injury patients. Open Access Emerg Med 2017;9:69-72.
12. Kim Y, Kim CK, Jung S, Ko S-B. Brain Oxygen Monitoring via Jugular Venous Oxygen Saturation in a Patient with Fulminant Hepatic Failure. Korean J Crit Care Med 2016;31:251-5.
13. Ugras GA, Yuksel S. Factors Affecting Intracranial Pressure and Nursing Interventions. J J Nurs Care 2014;1:1-6.
14. Tripathy S, Ahmad SR. Raised intracranial pressure syndrome: A stepwise approach. Indian J Crit Care Med 2019;23:S129-35.
15. Ragland J, Lee K. Critical Care Management and Monitoring of Intracranial Pressure. J Neurocrit Care 2016;9:105-12.
16. Pinto VL, Tadi P, Adeyinka A. Increased Intracranial Pressure. Treasure Island (FL): StatPearls Publishing; 2022.
17. Tan TK, Cheng MH, Sim EY. Options for managing raised intracranial pressure. Proc Singapore Healthc 2015;24:156-64.
18. Cannata G, Pezzato S, Esposito S, Moscatelli A. Optic Nerve Sheath Diameter Ultrasound: A Non-Invasive Approach to Evaluate Increased Intracranial Pressure in Critically Ill Pediatric Patients. Diagnostics (Basel) 2022;12:767.
19. Suasti NWL. Regulation and Intervention of Intracranial Pressure. Biosci Med J Biomed Transl Res 2021;5:981-7.
20. Kayana IBA, Maliawan S, Kawiyana IKS. Intracranial pressure monitoring technique. Jurnal Medika Udayana [Internet]. 2013 [cited 2023 May];2:480-501. Available from: https://ojs.unud.ac.id/index.php/eum/article/view/4935
21. Dunn LT. Raised intracranial pressure. J Neurol Neurosurg Psychiatry 2002;73 Suppl 1:i23-7.
22. Shirodkar CG, Rao SM, Mutkule DP, Harde YR, Venkategowda PM, Mahesh MU. Optic nerve sheath diameter as a marker for evaluation and prognostication of intracranial pressure in Indian patients: An observational study. Indian J Crit Care Med 2014;18:728-34.
23. Sitanaya SN, Kamayanti F, Nugroho HA, Prabowo B. Comparing ultrasonographic optic nerve sheath diameter to head computed tomography scan to predict intracranial pressure elevation. SAGE Open Med 2022;10:20503121221077834.
24. Richter J, Sklienka P, Chatterjee N, Maca J, Zahorec R, Burda M. Elevated jugular venous

oxygen saturation after cardiac arrest. Resuscitation 2021;169:214-9.
25. Gómez-Sandoval E, Hernandez-Flores M, Soriano-Orozco R, Gómez-Gonzalez MN, Valdez-Medina MDR. Correlation between cerebral venous-arterial pCO2 difference with jugular venous oxygen saturation as global cerebral ischemia in severe traumatic brain injury. Intensive Care Med Exp 2015;3(Suppl 1):6-7.
26. Ballesteros-Flores CG, De Jesús-Montelongo F, López-Ramírez I, Alarcón-Sánchez LL, González-Arista J, González-Chávez MS. Saturación venosa yugular de oxígeno en pacientes con trauma craneoencefálico 2011;3:62-6.
27. Saboori P, Walker G. Brain Injury and Impact Characteristics. Ann Biomed Eng 2019;47: 1982-92.
28. Jain S, Iverson L. Glasgow Coma Scale. Treasure Island (FL):StatPearls Publishing; 2023.
29. Chauhan R, Bloria S, Luthra A. Management of postoperatif neurosurgical patient. Indian J Neurosurg 2019;8:179-84.
30. The Brain Trauma Foundation, The American Association of Neurological Surgeons, The Joint Section on Neurotrauma and Critical Care, Critical pathway for the treatment of established intracranial hypertension. J Neurotrauma 2000; 17:493-5.
31. Robba C, Bacigaluppi S, Cardim D, Donnelly J, Bertuccio A, Czosnyka M. Non-invasive assessment of intracranial pressure. Acta Neurol Scand 2016;134:4-21.
32. Robba C, Santori G, Czosnyka M, Corradi F, Bragazzi N, Padayachy L, et al. Optic nerve sheath diameter measured sonographically as non-invasive estimator of intracranial pressure: a systematic review and meta-analysis. Intensive Care Med 2018;44:1284-94.
33. Kimberly HH, Shah S, Marill K, Noble V. Correlation of optic nerve sheath diameter with direct measurement of intracranial pressure. Acad Emerg Med 2008;15:201-4.
34. Elwishi M, Dinsmore J. Monitoring the brain. BJA Educ 2019;19:54-9.
35. Chen M, Wu H, Li Z, Ge S, Zhao L, Zhang X, Qu Y. Intracranial-Pressure-Monitoring-Assisted Management Associated with Favorable Outcomes in Moderate Traumatic Brain Injury Patients with a GCS of 9–11. J Clin Med 2022; 11:6661.
36. Geeraerts T, Velly L, Abdennour L, Asehnoune K, Audibert G, Bouzat P, et al. Management of severe traumatic brain injury (first 24 hours). Anaesth Crit Care Pain Med 2018;37:171-86.
37. Haddad S, Aldawood AS, Alferayan A, Russell NA, Tamim HM, Arabi YM. Relationship between intracranial pressure monitoring and outcomes in severe traumatic brain injury patients. Anaesth Intensive Care 2011;39:1043-50.
38. Cormio M, Valadka AB, Robertson CS. Elevated jugular venous oxygen saturation after severe head injury. J Neurosurg 1999;90:9-15.
39. Schell RM, Cole DJ. Cerebral monitoring: jugular venous oximetry. Anesth Analg 2000; 90:559-66.
40. Bouma GJ, Muizelaar JP, Choi SC, Newlon PG, Young HF. Cerebral circulation and metabolism after severe traumatic brain injury: the elusive role of ischemia. J Neurosurg 1991;75:685-93.
41. McLeod AD, Igielman F, Elwell C, Cope M, Smith M. Measuring cerebral oxygenation during normobaric hyperoxia: a comparison of tissue microprobes, near-infrared spectroscopy, and jugular venous oximetry in head injury. Anesth Analg 2003;97:851-6.
42. Andersen BJ, Marmarou A. Post-traumatic selective stimulation of glycolysis. Brain Res 1992;585:184-9.

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