Utility of Transcranial Doppler in Estimating Cerebral Perfusion Pressure in Traumatic Brain Injury: A Prospective Observational Trial

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Abstract

Title Utility of transcranial Doppler (TCD) in estimating cerebral perfusion pressure (eCPP) in traumatic brain injury—a prospective observational trial.

Aim To validate the utility of a noninvasive technique of eCPP estimation using transcranial Doppler (TCD).

Materials and Methods Eighteen patients with severe traumatic brain injury (TBI) requiring intracranial pressure (ICP) monitoring as per the Brain Trauma Foundation guidelines were prospectively recruited for the study. ICP was measured in all patients using an intraventricular catheter. Mean arterial pressure (MAP) was recorded from an intra-arterial catheter. Cerebral perfusion pressure (CPP) was calculated as the difference between MAP and ICP. Middle cerebral blood flow velocities were recorded using TCD, and CPP was estimated from the middle cerebral artery (MCA) flow velocities (eCPP) using the formula eCPP = (MAP × end diastolic velocity [EDV]/mean velocity [MV]) + 14. Total 185 simultaneous readings of CPP and eCPP were available for analysis. Reliability statistics between CPP and eCPP were computed to calculate the intraclass correlation (ICC).

Results The average CPP measured using intraventricular catheter was 73.2 (+/−12.4), and the mean estimated eCPP was 76.7 (+/−10.9). We found a very good Pearson's correlation between CPP and eCPP (r = 0.743) with a Cronbach's α of 0.843. In 86.2% of examinations, the estimation error of measuring CPP was within 10 mm Hg, and in 93.1% examinations, it was within 15 mm Hg.

Conclusion eCPP estimated using TCD can serve as reliable noninvasive alternative in situations in which ICP monitoring is not available, even in moderate or mild head injury.

Keywords
- cerebral perfusion pressure
- intracranial pressure
- transcranial Doppler

Introduction

Cerebral perfusion pressure (CPP), the mathematical difference between the mean arterial pressure (MAP) and intracranial pressure (ICP), is one of the most important factors influencing outcome following head injury.[1] The Brain Trauma Foundation (BTF) guidelines emphasize the importance of maintaining a CPP of 60 to 70 mm Hg.[2] Currently estimation of CPP requires the use of invasive ICP monitoring that requires surgical expertise, and it also exposes the patient to the risks of hemorrhage and infection. These techniques are also used primarily in severe head injuries in which the patient is sedated and ventilated, thereby limiting its utility only to these patients. Patients with moderate head injury who have the potential to deteriorate due to inadequate CPP are therefore vulnerable to

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secondary insults. Empirically targeting a high MAP value is also counterproductive, leading to an increased risk of systemic complications and is associated with poorer outcomes.[2] Therefore, there is a need for a noninvasive technique of reliably estimating CPP that will prevent hypoperfusion of the brain and improve outcomes. Transcranial Doppler (TCD) is a noninvasive and easily portable technique that offers the clinician an opportunity to study the cerebral hemodynamics at the bedside and reliably estimate CPP. The unique advantage in this technique is its repeatability and cost-effectiveness. Czonyka et al were able to noninvasively estimate CPP from the formula derived from the flow velocities in the basal cerebral arteries using TCD.[3]

Materials and Methods

Eighteen patients with severe TBI requiring ICP monitoring as per the BTF guidelines were prospectively recruited for the study. All patients were sedated with morphine and midazolam according to the institutional protocol to maintain a Richmond Agitation Sedation Scale (RASS) of −4, and mechanical ventilation was instituted to maintain normocarbia ($PaCO_2$ of 33–35 mm Hg). ICP was continuously measured in all patients using an intraventricular catheter inserted into the right frontal horn and connected to an external transducer leveled to the tragus (the gold standard technique for monitoring ICP). MAP was recorded from an intra-arterial catheter with the transducer also at the level of the tragus. CPP was calculated as the difference between MAP and ICP.

Blood flow velocities were recorded three times a day using TCD (Sonosite, M-turbo), insonating the middle cerebral artery (MCA) of both sides with a 2-MHz probe through the transtemporal window until the ICP monitor was removed. Flow velocities were also recorded whenever the ICP increased or decreased by a value of 10 mm Hg from the baseline value. The measured CPP was simultaneously documented and compared with the estimated CPP (eCPP) from the MCA flow velocities. The eCPP was calculated using the following equation[3]:

$$eCPP = (MAP \times \text{end diastolic velocity [EDV]} / \text{mean velocity [MV]}) + 14$$

Pearson's correlation coefficient and Cronbach's α were used to verify the agreement between both the values. Reliability statistics between CPP and eCPP were computed to calculate the intraclass correlation (ICC).

Results

Total 185 recordings were obtained for the 18 patients enrolled in the study, and ►**Fig. 1** shows each simultaneous reading of eCPP and measured CPP. All patients were males with severe head injury. The mean CPP was 72.37 (+/−12.50), and the mean eCPP was 75.15 (+/−10.33). We found a very good Pearson's correlation between CPP and eCPP ($r = 0.743$) with a Cronbach's α of 0.843. There was also very good ICC between CPP and eCPP with an ICC of 0.843 (0.791–0.883). A scatter plot of the CPP against the eCPP revealed that most of the values lay very close to the reference line (►**Fig. 2**). The Bland Altman plot between the CPP and eCPP difference and the mean of the CPP and eCPP showed that most values were between the reference lines implying less variation and better correlation (►**Fig. 3**). In 86.2% of examinations, the estimation error of measuring CPP was within 10 mm Hg, and in 93.1% examinations, it was within 15 mm Hg. We found that TCD had a high positive predictive value (93.7%) for estimating normal CPP (60 mm Hg), whereas the predictive value to estimate low CPP (< 60 mm Hg) was 78.6%.

Discussion

Maintaining an appropriate CPP for a particular patient prevents secondary brain insults due to hypoperfusion if it is too low, and systemic complications or vasogenic edema if treatment is administered to keep it too high. Traditionally CPP has been estimated using invasive ICP monitors and intra-arterial lines. Insertion of an ICP monitor requires neurosurgical expertise, and the patient is exposed to the risk of intracranial hemorrhage and infection. In cases in which parenchymal monitors are used the cost is greatly increased, and due to all these factors, there are very few centers in India that routinely monitor ICP. Therefore, a method to noninvasively estimate CPP will be of great utility in patients with severe head injuries who are not undergoing ICP monitoring, as well as in the management of patients with mild and moderate head injuries in whom invasive techniques would not be a practical option. Estimation of the ICP from radiology is not very accurate, and it will not be possible to repeat computed tomographic (CT) scans very frequently.

In 1982 Aaslid et al developed the technique of TCD, utilizing the transtemporal window to record the flow velocities in

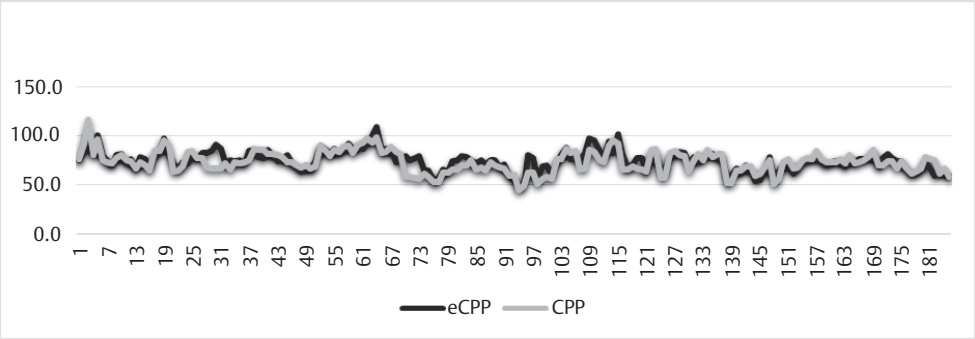

Fig. 1 All readings of estimated cerebral perfusion pressure (eCPP) and simultaneously measured cerebral perfusion pressure (CPP).

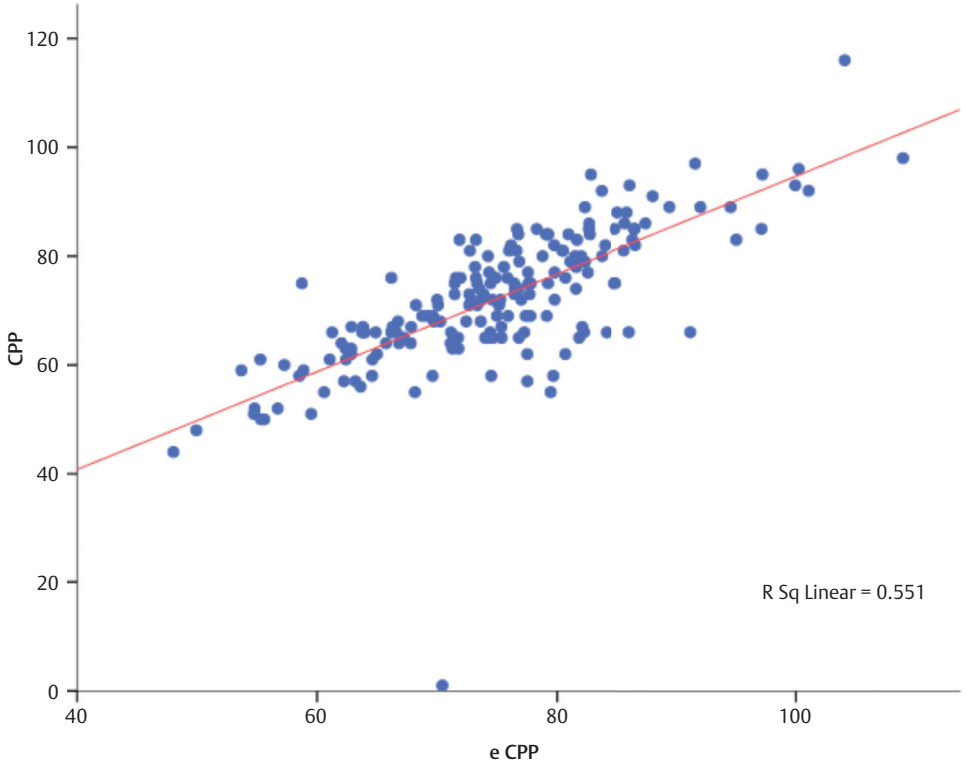

Fig. 2 Scatter plot of CPP against estimated cerebral perfusion pressure (eCPP) showing most values close to the reference line.

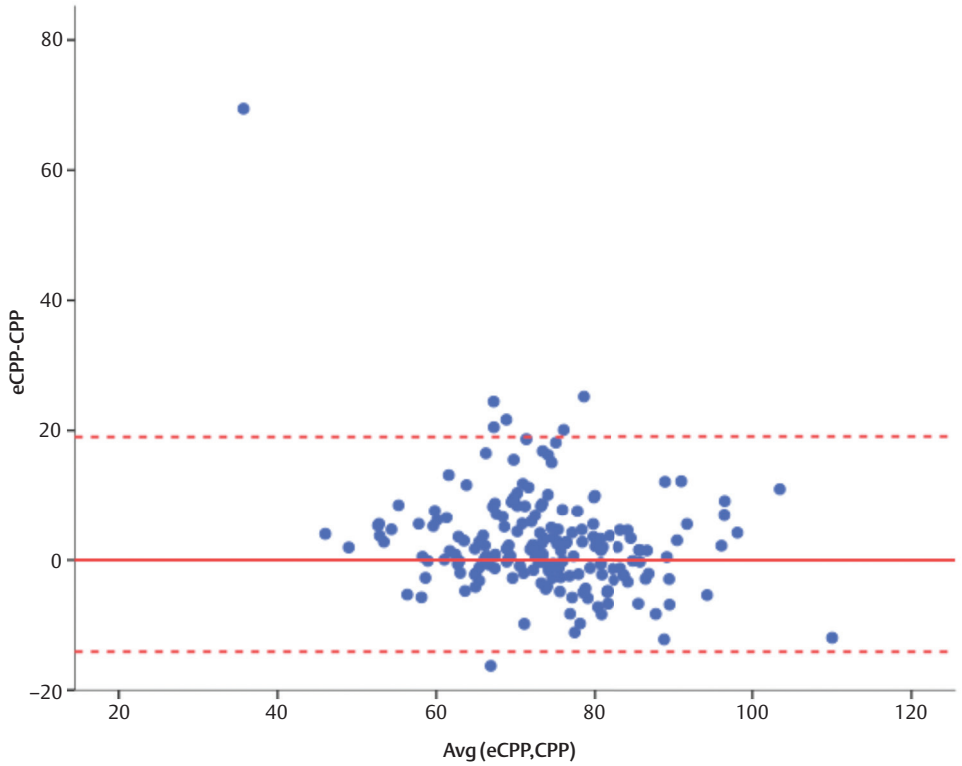

Fig. 3 Bland Altman plot between the difference and mean of cerebral perfusion pressure (CPP) and estimated cerebral perfusion pressure (eCPP) showed most of the values between the reference lines.

the basal cerebral arteries.[4] TCD gives an opportunity to the treating physician to have a close look at the flow velocities in the cerebral circulation and also offers the opportunity to closely monitor trends in the flow velocity. Aaslid et al also used the concept of a critical closing pressure to estimate CPP using TCD.[5]

Czosnyka et al used a formula derived from regression analysis with TCD to estimate CPP and had a good correlation between the invasive and noninvasive technique (r =0.73).[3] They concluded that noninvasive estimation of CPP using TCD ultrasonography may be of value in situations in which monitoring changes in CPP are required without invasive measurement of ICP. We have used the same formula to calculate CPP in our study. They were able to estimate CPP with a difference of 10 and 15 mm Hg in at least 71% and 84% their recordings, respectively. We found that in 86.2% of examinations, the estimation error of measuring CPP was within 10 mm Hg, and in 93.1% examinations, it was within 15 mm Hg. This difference could be because the original study had used intraparenchymal monitors, which have the tendency to overestimate ICP,[6] and we have used intraventricular catheters, which is the gold standard technique. Gura et al used this formula to estimate CPP with a correlation coefficient of 0.92 ($p < 0.0001$).[7]

An estimation difference of 10 mm Hg for CPP is an acceptable trade-off between the risk of an indwelling catheter and the benefit of a noninvasive method to estimate CPP.

Estimation of Intracranial Pressure

Using the same methods of estimating CPP, we also attempted to estimate ICP using the formula:

$$\text{Estimated ICP (eICP)} = \text{MAP} - \text{eCPP}$$

However, the results were not as good as those we obtained for CPP estimation, the reasons for which are not clear yet. This is an ongoing study, and we are looking into factors that contribute to this discrepancy in ICP estimation. We are also looking at confounding variables that play a role in the noninvasive estimation of CPP and ICP.

Utility of Pulsatility Index

Though Pulsatility Index (PI) has traditionally been given importance as a reflector of the distal cerebrovascular resistance, studies have proven that it may not be an accurate reflector of the ICP.[8] In our study also, we found that PI was not a good indicator of ICP.

Limitations of the Study

This is an ongoing study, and only a small number of patients are being reported, though the total number of 185 readings makes the study fit for statistical analysis. TCD measurement of flow velocities is operator dependent, and there is a long learning curve before the values are reliable.

Conclusion

Noninvasive estimation of CPP using TCD is a useful technique in situations in which invasive ICP monitoring is not possible. It prevents hypoperfusion of the brain if the CPP is too low and can also prevent unnecessary treatment to raise the blood pressure if it is adequate.

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