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Transcranial Doppler in Non-Invasive Assessment of Increased Intracranial Pressure in Traumatic Brain Injury

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ABSTRACT

Background: The basic aims of transcranial ultrasound-based intracranial pressure monitoring are to help doctors maintain optimal brain perfusion and oxygenation while also preventing surgical and medical issues. Transcranial Doppler ultrasonography (TCD) provides a non-invasive evaluation of cerebral blood flow (CBF) or velocity.

Objective: Measuring cerebral blood flow velocity in the main intracranial vessels non-invasively and with high diagnostic accuracy by using TCD.

Patients and Methods: 60 patients with traumatic brain injury (TBI) had been treated at Emergency Department (ED). In the first six hours following trauma, TCD ultrasonography was carried out as soon as breathing and hemodynamic stability were achieved. S probe was used for the examination, and the Phillips Affinity G 50 gadget was used. The trans temporal window, or temporal region just above the zygomatic arch, was covered by an ultrasound transducer.

Results: The range of age of our patients varied from 18 to 66 years with an average of 38 ± 13.76. TCD parameters were normal in 47(78.3%) while abnormal findings were recorded in 13(21.7%) patients. Hypoperfusion was detected in 9(15%) and 4(6.6%) patients showed vasospasm. Patients with normal TCD parameters had less days of mechanical ventilation and duration of hospital stay than the patients diagnosed with hypoperfusion or vasospasm by TCD, with P value <0.001. Pulsatility index (PI) showed sensitivity of 81.82%, specificity of 81.63%, PPV of 50.0% and NPV of 95.2%.

Conclusion: With great diagnostic accuracy, the TCD can non-invasively monitor the CBF velocity in the major intracranial vessels.

Keywords: TCD, Intracranial pressure, CBF, Ultrasound.

INTRODUCTION

The inherent ability of the blood arteries to quickly modify cerebrovascular resistance and make up for variations in cerebral perfusion pressure is known as cerebral autoregulation, and it keeps CBF comparatively constant [(1)]. Larger arteries may also play a role in changes in cerebrovascular resistance, but arterioles are typically where these changes occur. The CBF is kept constant between 50 and 170 mm Hg by cerebral autoregulation[(2)]. Cerebral edema and the disruption of the blood-brain barrier may arise at elevated blood pressure, while CBF is pressure passive beyond the autoregulatory range, placing the brain at risk of ischemic damage [(3)].

Cerebral pressure autoregulation refers to the brain's innate capacity to maintain constant blood flow despite fluctuations in cerebral perfusion pressure or arterial blood pressure. It is a vital line of defense against post-TBI and subarachnoid hemorrhage with secondary ischemic insults. The prognosis has been demonstrated to be impacted by cerebral autoregulation impairment [(4)].

The diagnosis of localized vascular stenosis, the detection of embolic signals inside the brain's basal arteries, and the evaluation of relative flow changes may all be accomplished with the use of transcranial Doppler (TCD). TCD can also be used to assess the physiologic health of a particular vascular territory by tracking blood flow responses to changes in blood pressure (cerebral autoregulation), changes in end-tidal CO_2 (cerebral vasoreactivity), or changes in motor and cognitive activation (neurovascular coupling or functional hyperemia) [(5)].

Cerebral circulatory arrest (CCA) occurs when the intracranial arteries are compressed and blood flow to the brain is suspended due to a drop in cerebral perfusion pressure, which is connected to an increase in intracranial pressure (ICP) and pulsatility index (PI) [(6)].

TCD can reveal the pattern of CBF that leads to CCA and brain death, which can be monitored continuously at the patient's bedside. Diastolic CBF approaches zero when the ICP rises to match the diastolic perfusion pressure. Diastolic blood flow returns with a persistent increase in ICP, but in the opposite direction (reversed flow), which the TCD interprets as retrograde flow [(7)]. Moreover, systolic waveforms start to surge. The distinguishing feature of CCA is the retrograde or oscillating diastolic flow combined with systolic spikes, which lead to no net forward CBF. When diagnosing cerebral circulatory arrest, TCD has an extremely high sensitivity of 96.5 percent and specificity of 100%; nevertheless, transient arrest should be ruled out by having a systolic blood pressure of more than 70 mmHg [(7)].

It has been demonstrated that increases in ICP cause decreases in cerebral perfusion pressure, which are reflected in the (TCD) pulsatility index [(8)].

With great precision, the TCD can non-invasively detect CBF velocity in the major cerebral

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arteries. When the ICP increases to meet the diastolic perfusion pressure, the diastolic CBF approaches zero. With a prolonged rise in ICP, diastolic blood flow returns, but it does so in the opposite direction—called reversed flow—which the TCD interprets as retrograde flow. Systolic waveforms also begin to spike. The combination of systolic spikes and retrograde or oscillating diastolic flow, which results in no net forward CBF, is what sets CCA apart [(9)]. TCD has a high sensitivity (96.5%) and specificity (100%). However, momentary arrest should be ruled out if the systolic blood pressure is more than 70 mm Hg at the time of the TCD assessment [(10)].

Objective: Measuring cerebral blood flow velocity in the main intracranial vessels non-invasively and with high diagnostic accuracy by using TCD.

PATIENTS AND METHODS

This observational prospective study was conducted on 60 patients with TBI presenting to Emergency Department of Tanta University Hospital over a period of 6 months.

Inclusion criteria

Patients with TBI who were scheduled to undergo brain computed tomography scan. GCS ≤ 12. (Severe TBI GCS is ≤8, while moderate TBI GCS is from 9 to 12). Recent trauma (less than 6 hours after trauma).

Exclusion criteria

Patients on medications affecting intracranial pressure were excluded before performing the first TCD like antipsychotics, vitamin A (at doses >25,000 IU daily) etc.

Critical cases where performing TCD may delay lifesaving maneuvers.

Previous history of intracranial lesion e.g. tumor, aneurysm, etc.

The patients were subjected to:

- The patient's complete clinical history, including their height and weight.
- The same medical management techniques for TBI were applied to every patient in the trial with the goal of avoiding further brain damage.
- TCD ultrasonography was carried out in the Emergency Department (ED) within the first
- six hours following trauma, right after respiratory and hemodynamic stabilization.

The inspection was performed utilizing the S probe (3S phased array probe) and the Phillips Affinity G 50 instrument. The Philips Affiniti 50 is a midrange shared service ultrasound machine based on the premium Epiq 7 (Canada).

- The ultrasound transducer was positioned above the zygomatic arch and in front of the tragus of the ear, with a slight upward and anterior orientation (trans temporal window).
- At a depth of 40-65 mm, a red color signal indicates flow towards the probe in the ipsilateral M1 MCA. The angle and position of insonation were modified to generate the best possible Doppler signal. Tracings of the right and left middle cerebral arteries were taken for at least ten cardiac cycles.
- The ultrasound instrument measured peak systolic (PSV) and end diastolic (EDV) in centimeters per second using built-in software.
- The mean flow velocity (MFV) (in centimeters/second) was estimated using the formula (PSV+ (EDVx 2))/3.
- The pulsatility index (PI) calculates downstream cerebral vascular resistance using the formula (PSV-EDV)/MFV.
- Hypoperfusion was identified when two of the following criteria were satisfied:
  - MFV of MCA < 35 cm / sec.
  - Diastolic velocity < 20 cm / sec.
  - PI > 1.4.
  - Based on previous studies, vasospasm was diagnosed if MFV > 120 cm / sec.

Ethical approval:

This study has been approved by the Tanta Faculty of Medicine's Ethics Committee. Following receipt of all information, signed consent was provided by each participant. The study adhered to the Helsinki Declaration throughout its execution.

Statistical analysis:

SPSS version 23.0 for Microsoft Windows was used for all statistical computations. Quantitative data were presented as mean, standard deviation (SD), and range. Qualitative data were presented as frequency and percentage. Utilizing student t-test, X^2-test, linear correlation coefficient, and analysis of variance [ANOVA] tests, the current study was statistically analyzed. When it is equal to or less than 0.05, a significant p-value is taken into account.

RESULTS

Patients' sociodemographic data

We examined 60 people who had suffered a TBI (traumatic brain injury)and had been treated at Tanta University Hospital's Emergency Department.

The average age of our patients was 38 ± 13.76. They consisted of 49 (81.67%) males and 11 (18.33%) females. Fifty-one (85%) patients were the result of road traffic accidents. Only 7 (11.67%) patients had relevant past medical history **(Table 1).**

Transcranial Doppler on middle cerebral artery was done for all patients on admission, on day 7, on day 14, on day 21 and on day 28.

Table (1): Baseline characteristics of the studied patients

N= 60		
Age (years)	Mean ± SD	38 ± 13.76
	Range	18 – 66
Sex	Male	49 (81.67%)
	Female	11 (18.33%)
Mode of trauma	Road traffic accident	51 (85%)
	Fall from height	7 (11.67%)
	Local Head Trauma	2 (3.33%)
Past medical history	Negative	53 (88.33%)
	Positive	7 (11.67%)

Relationship between TCD and outcome of the studied patients:

1. Relationship between TCD and Glasgow outcome score after 28 days (GOS)

Hypoperfusion was detected in 9 patients and 4 patients showed vasospasm **(Table 2).**

Table (2): TCD in the studied patients

Normal TCD	47(78.3%)	
Abnormal TCD	**Hypoperfusion**	9(15%)
	Vasospasm	4(6.6%)

Regarding transcranial Doppler (TCD) in patients who had a favorable result, the PSV was considerably greater and exhibited a strong connection with outcome (p value 0.001). As expected, patients with a favorable prognosis had considerably greater EDVs than those with a poor outcome. For those patients who had a favorable result, the mean fluorescence velocity (MFV) was much greater, and this connection was statistically significant (p value less than 0.01) (**Figures 1-3).**

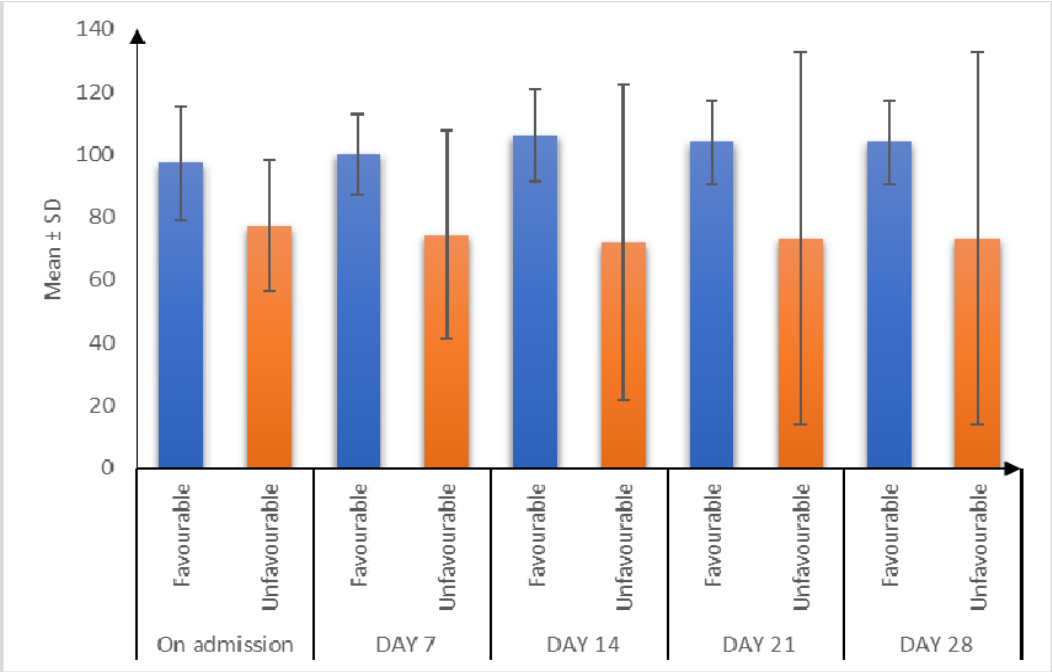

Figure (1): Relationship between PSV and outcome of the studied patients.

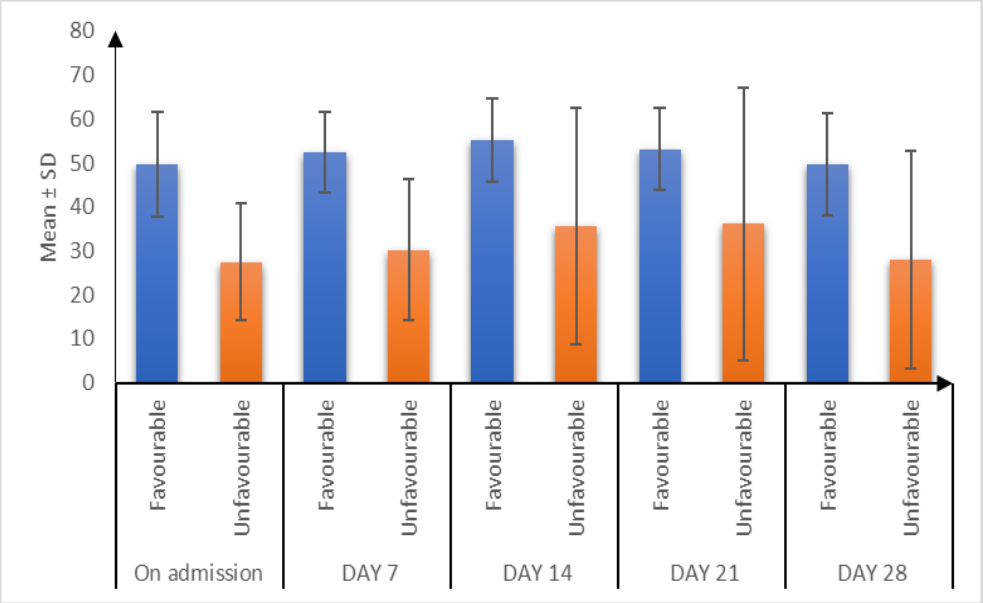

Figure (2): Relationship between EDV and outcome of the studied patients.

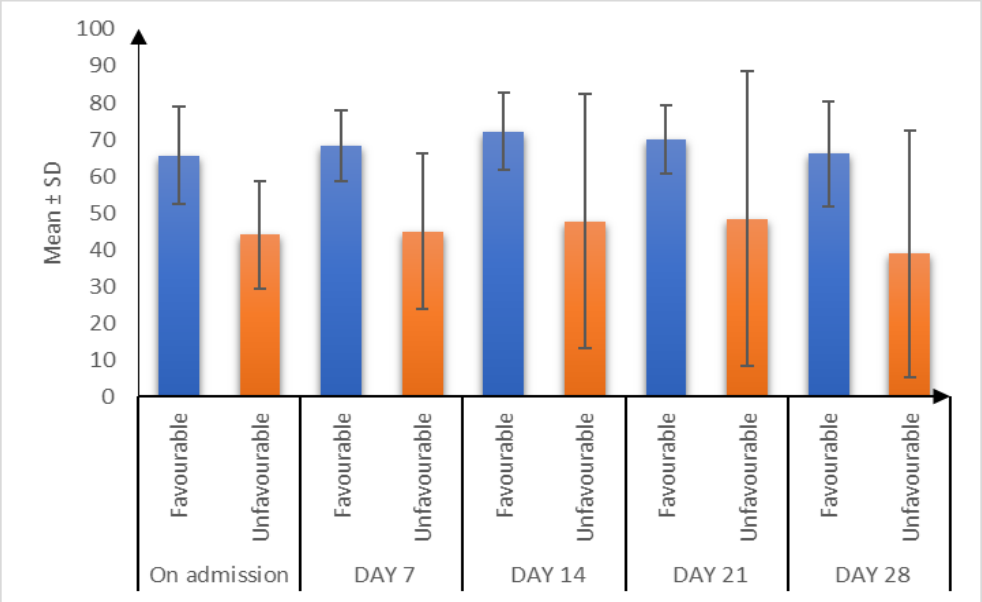

Figure (3): Relationship between MFV and outcome of the studied patients.

PI on admission, on day 21 and on day 28 was correlated with outcome with p value < 0.001, while PI on day 7 and 14 showed no correlation with outcome with p value 0.110 and 0.080 **(Table 3 and Figure 4)**.

Table (3): TCD of the studied patients

	On admission	Day 7	Day 14	Day 21	Day 28
PSV (cm/sec)	88.25 ± 21.72	93.14 ± 18.54	102.74 ± 21.98	104.04± 26.9	100 ±18.48
EDV (cm/sec)	39.67 ± 16.77	44.74 ± 14.09	52.45 ± 14.23	52.50 ± 16.01	48.88 ± 11.05
MFV (cm/sec)	55.86 ± 17.47	60.87 ± 14.8	69.21 ± 16.4	69.68 ± 18.94	65.92 ± 12.91
PI	0.95 ± 0.38	0.83 ± 0.26	0.74 ± 0.15	0.76 ± 0.2	0.79 ± 0.15

TCD: Transcranial Doppler, PSV: Peak systolic velocity, EDV: End-diastolic velocity, MFV: Mean flow velocity, PI: Pulsatility index.

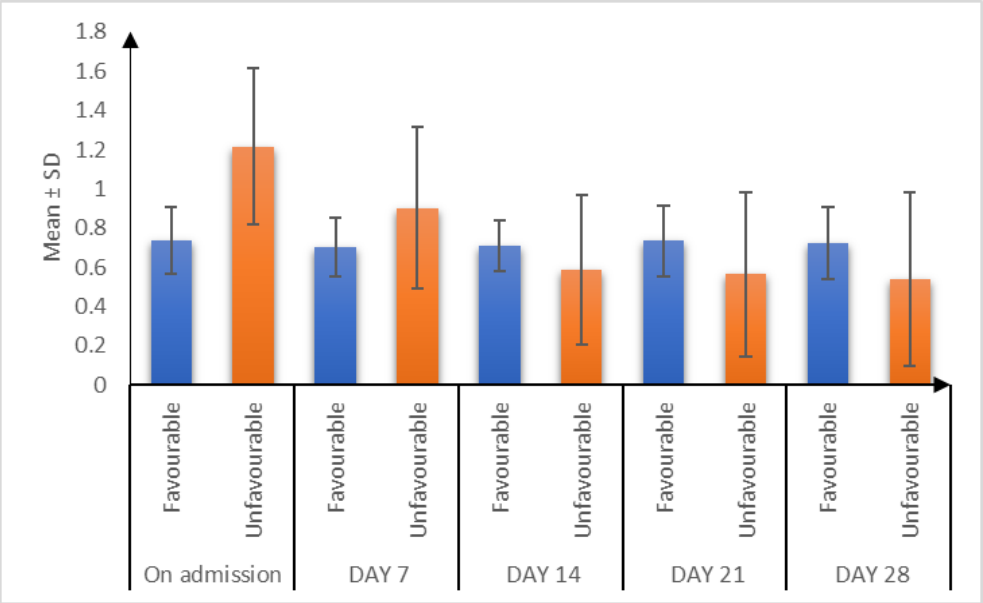

Figure (4): Relationship between PI and outcome of the studied patients.

When assessing the AU-ROC for GOS prediction using TCD measurements recorded, PSV showed sensitivity of 66.67%, specificity of 78.79%, PPV of 72% and NPV of 74.3% with best cut off value of ≤80 in predicting patients with unfavorable outcome at day 28 after trauma. EDV showed sensitivity of 74.07%, specificity of 90.91%, PPV of 87% and NPV of 81.1% with best cut off value of ≤35 in predicting patients with unfavorable outcome at day 28 after trauma (**Figure 5).**

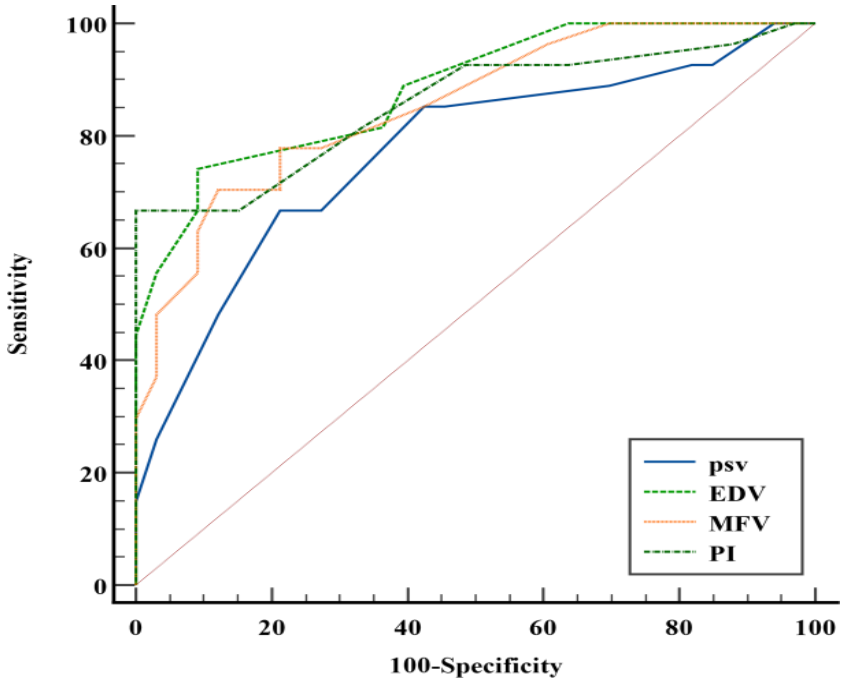

Figure (5): ROC curve for TCD parameters to predict outcome.

MFV showed sensitivity of 70.37, specificity of 87.88, PPV of 82.6% and NPV of 78.4% with best cut off value of ≤50 in predicting patients with unfavorable outcome at day 28 after trauma. PI showed sensitivity of 66.67%, specificity of 100.00%, PPV of 100% and NPV of 78.6% with best cut off value of >1 in predicting patients with unfavorable outcome at day 28 after trauma **(Table 4 and Figure 6).**

Table (4): Relationship between TCD and outcome of the studied patients

		On admission	Day 7	Day 14	Day 21	Day 28
PSV (cm/sec)	**Favorable**	97.27 ± 18.16	100 ± 12.87	106.06 ± 14.62	104.09 ± 13.37	98.94 ± 21.35
	Unfavorable	77.22 ± 20.86	74.41 ± 33.36	72.04 ± 50.52	73.15 ± 59.49	60.56 ± 51.8
	P value	< **0.001***	< **0.001***	< **0.001***	< **0.001***	< **0.001***
EDV (cm/sec)	**Favorable**	49.7 ± 11.99	52.58 ± 9.2	55.15 ± 9.56	53.18 ± 9.25	49.7 ± 11.66
	Unfavorable	27.41 ± 13.33	30.19 ± 16.02	35.56 ± 26.97	36.11 ± 31.08	27.96 ± 24.78
	P value	**< 0.001***	**< 0.001***	**< 0.001***	**0.004***	**< 0.001***
MFV (cm/sec)	**Favorable**	65.56 ± 13.27	68.38 ± 9.67	72.12 ± 10.53	70.15 ± 9.31	66.11 ± 14.37
	Unfavorable	44.01 ± 14.52	44.93 ± 21.17	47.72 ± 34.65	48.46 ± 40.29	38.83 ± 33.61
	P value	**< 0.001***	**< 0.001***	**< 0.001***	**0.004***	**< 0.001***
PI	**Favorable**	0.74 ± 0.17	0.7 ± 0.15	0.71 ± 0.13	0.73 ± 0.18	0.73 ± 0.18
	Unfavorable	1.22 ± 0.4	0.9 ± 0.41	0.59 ± 0.38	0.56 ± 0.42	0.54 ± 0.44
	P value	**< 0.001***	0.110	0.080	**0.038***	**0.032***

*: Significant

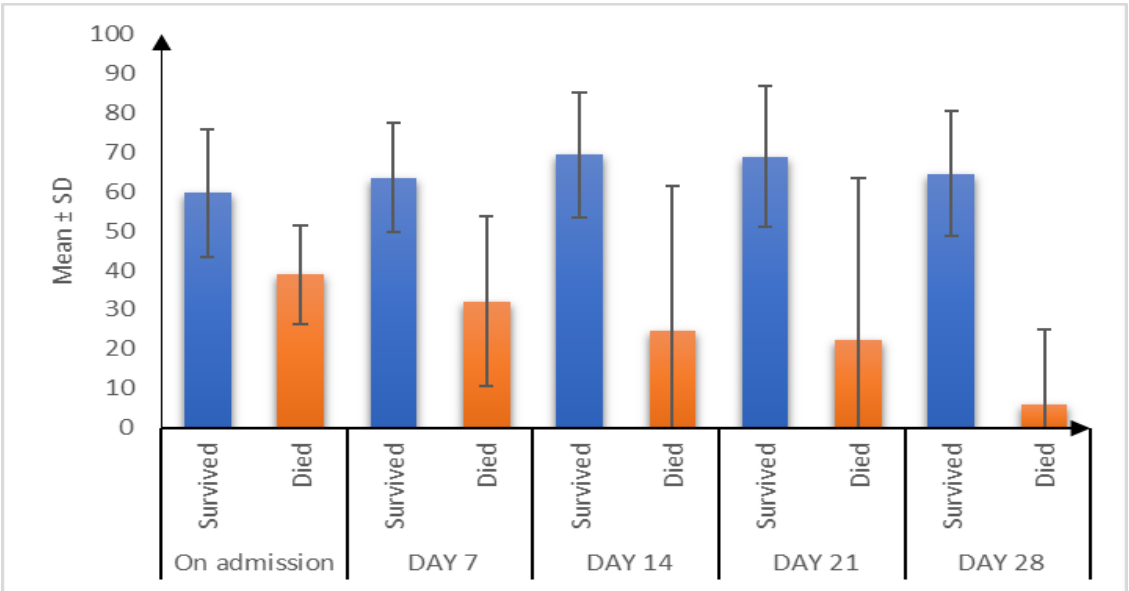

Figure (6): Relationship between MFV and mortality of the studied patients.

***2.* Relationship between TCD and mortality of the studied patients:**

PSV was significantly higher in survived patients and showed good correlation with outcome with p value< 0.001. EDV was significantly higher in survived patients showed good correlation with outcome with p value< 0.001. MFV was significantly higher in survived patients. Only PI on admission, on day 21 and on day 28 was correlated with outcome with p value < 0.001, while PI on day 7 and 14 showed no correlation with outcome with p value 0.110 and 0.080**) (Figure 9).**

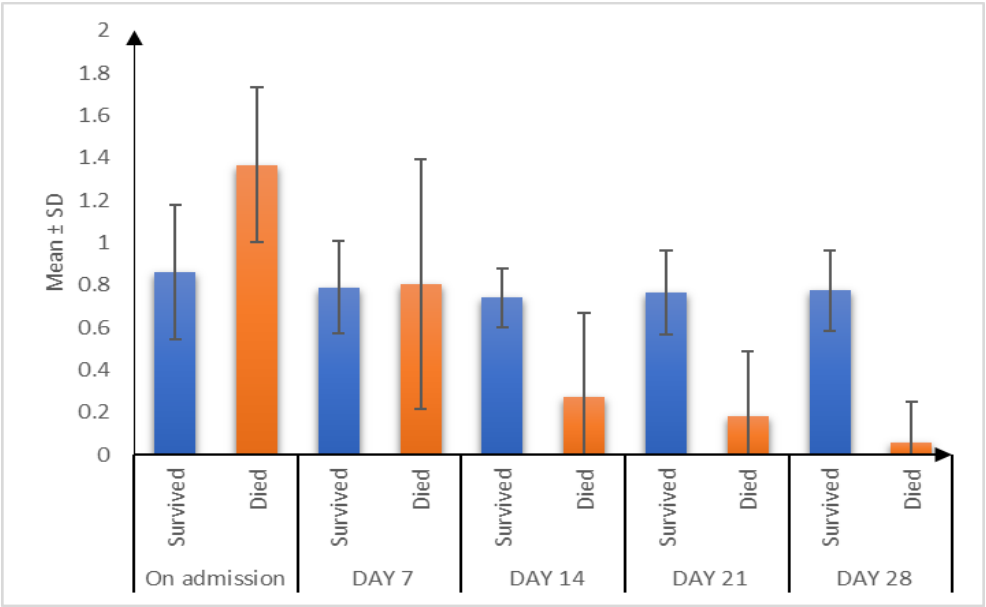

Figure (9): Relationship between PI and mortality of the studied patients

EDV showed sensitivity of 90.91%, specificity of 77.55%, PPV of 47.6% and NPV of 97.4% with best cut off value of **≤30** in predicting mortality (**Table 5 and Figures 7, 8).**

Table (5): Relationship between TCD and mortality of the studied patients

		On admission	Day 7	Day 14	Day 21	Day 28
PSV(cm/sec)	**Survived**	91.63 ± 20.29	95.92 ± 17.87	102.96 ± 21.06	103.16 ± 25.1	98.16 ± 23.33
	Died	73.18 ± 22.39	55.36 ± 37.22	36.36 ± 54.09	32.27 ± 60.47	8.18 ± 27.14
	P value	**< 0.001***	**< 0.001***	**< 0.001***	**< 0.001***	**< 0.001***
EDV (cm/sec)	**Survived**	43.67 ± 15.37	47.45 ± 12.96	52.55 ± 13.85	51.84 ± 15.43	47.86 ± 13.07
	Died	21.82 ± 9.82	20.45 ± 14.91	18.64 ± 28.29	17.27 ± 31.65	4.55 ± 15.08
	P value	**< 0.001***	**< 0.001***	**< 0.001***	**0.004***	**< 0.001***
MFV (cm/sec)	**Survived**	59.66 ± 16.18	63.61 ± 13.85	69.35 ± 15.84	68.95 ± 17.91	64.63 ± 15.98
	Died	38.94 ±12.61	32.09 ±21.64	24.55 ± 36.77	22.27 ± 41.22	5.76 ±19.1
	P value	**< 0.001***	**< 0.001***	**< 0.001***	**0.004***	**< 0.001***
PI	**Survived**	0.86 ±0.32	0.79 ±0.22	0.74 ±0.14	0.77 ±0.2	0.77 ±0.19
	Died	1.37 ± 0.37	0.81 ± 0.59	0.27 ± 0.4	0.18 ± 0.31	0.06 ± 0.19
	P value	**< 0.001***	0.110	0.080	**0.038***	**0.032***

TCD: Transcranial Doppler, PSV: Peak systolic velocity, EDV: end-diastolic velocity, MFV:Mean flow velocity, PI: Pulsatility index, * Statistically significant as P value <0.05.

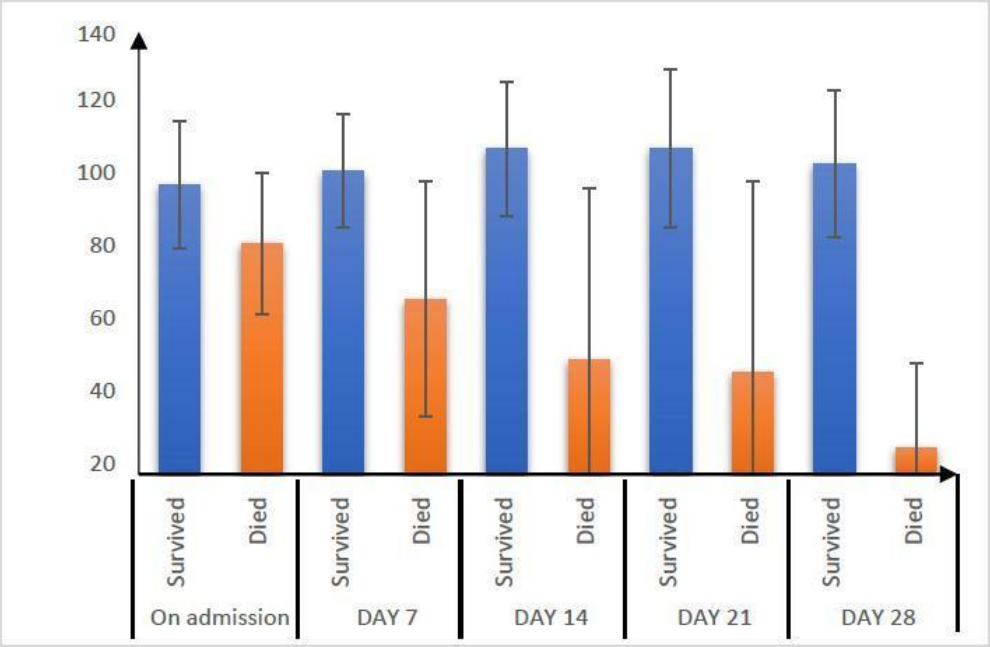

Figure (7): Relationship between PSV and mortality of the studied patients.

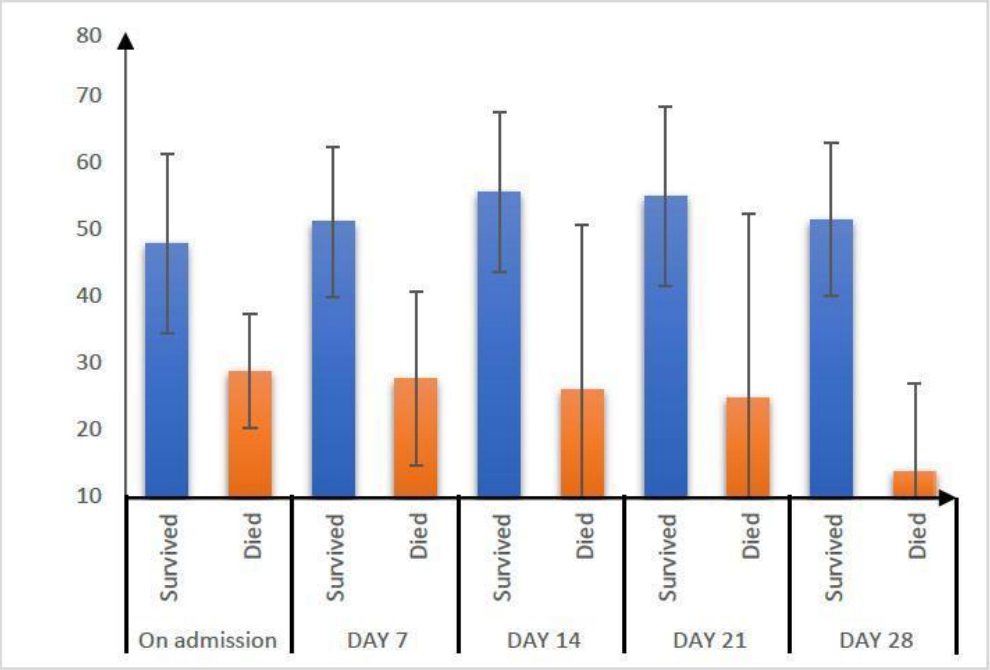

Figure (8): Relationship between EDV and mortality of the studied patients.

When gauging the AU-ability ROCs to predict death, prediction using TCD measurements recorded, PSV showed sensitivity of 72.73%, specificity of 65.31%, PPV of 29.6% and NPV of **90.9**% with best cut off value of **≤80** in predicting mortality **(Figure 10).**

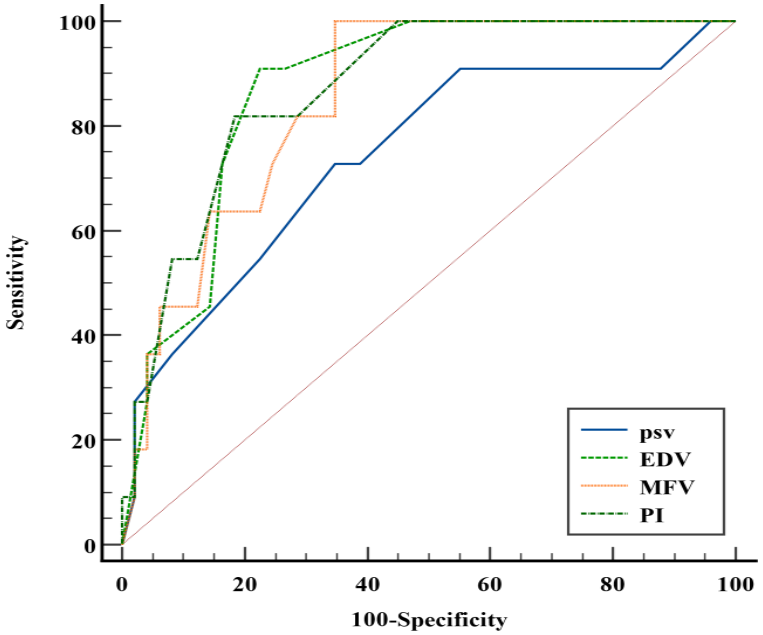

Figure (10): ROC curve for TCD parameters to predict mortality.

A 20-year-old male patient who presented to the ED after falling from height, brain CT scan was performed and revealed evidence for increased ICP (**Figure 11)**.

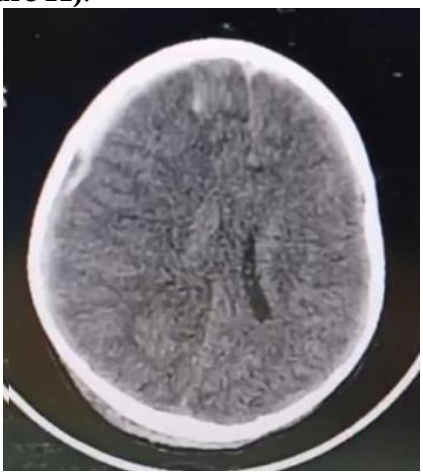

Figure (11): CT Brain showing midline shift and ventricular effacement and subarachnoid hemorrhage.

Transcranial Doppler measurements from both sides were obtained within 15 minutes after brain CT scan. TCD parameters were PSV 112 cm/s, EDV 20 cm/s, MFV 52 cm/s and PI 1,67. Those parameters suggested cerebral hypo perfusion **(Figure 12).**

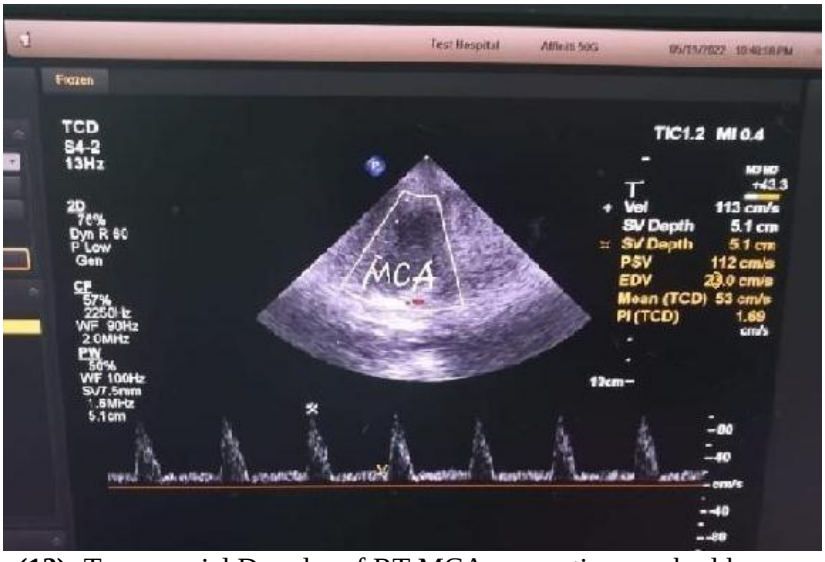

Figure (12): Transcranial Doppler of RT MCA suggesting cerebral hypoperfusion.

A 33-year-old male patient who presented to the ED after a high-speed motor vehicle collision. Brain CT scan was performed and revealed evidence of increased ICP **(Figure 13**).

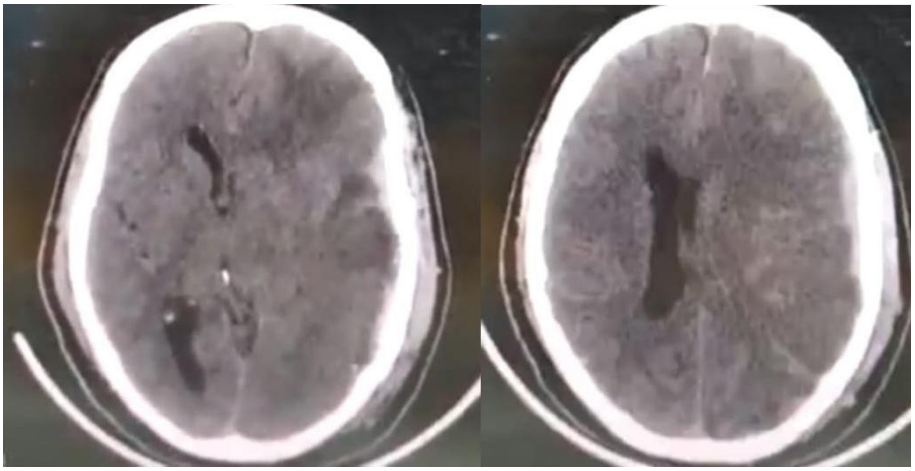

Figure (13): CT Brain showing midline shift and ventricular effacement and subarachnoid hemorrhage.

TCD on admission was done and revealed signs of cerebral hypo perfusion with PSV 111 cm/s, EDV 16 cm/s, MFV 55 cm/s and PI 1.55 **(Figure 14)**.

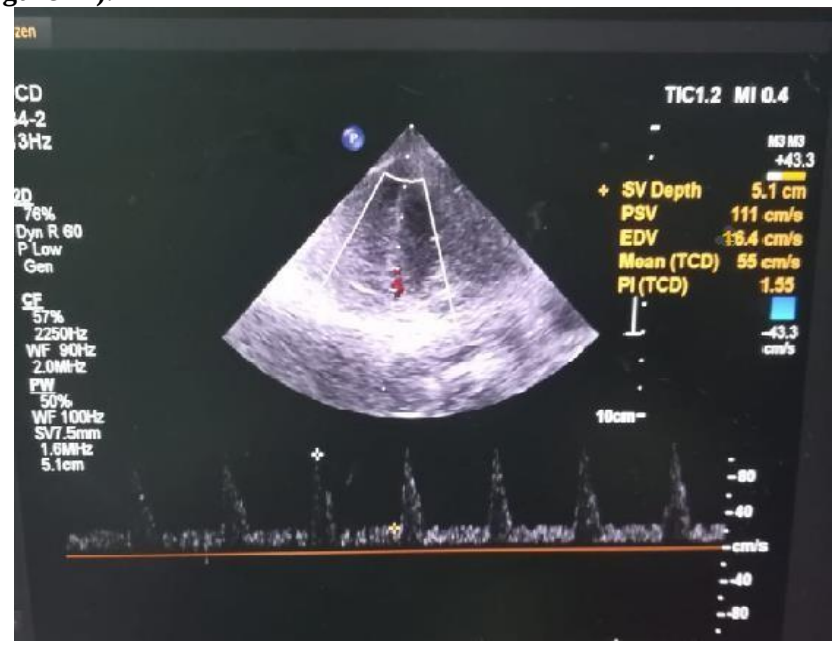

Figure (14): TCD on admission showing signs of cerebral hypoperfusion.

TCD on day 7 showed systolic spikes, diastolic circulatory arrest suggesting brain stem death **(Figure 15).**

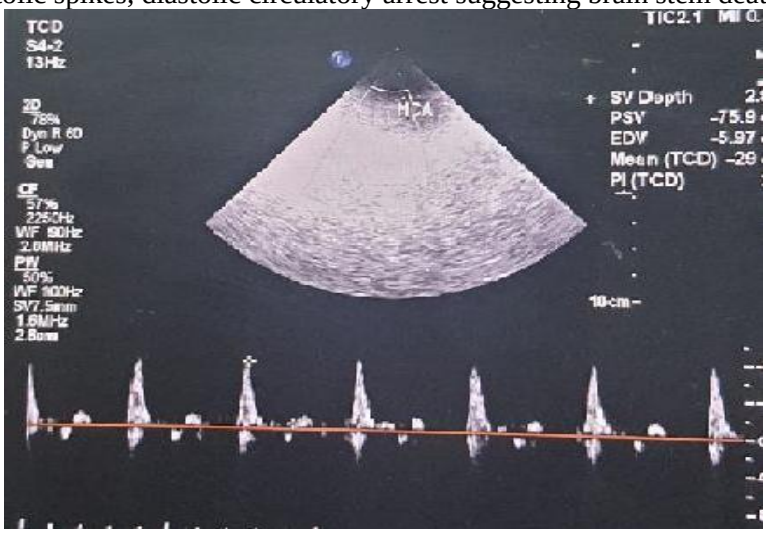

Figure (15): TCD on day 7 showing systolic spikes, diastolic circulatory arrest suggesting brain stem death.

A 47-year-old male patient who presented to the ED after a high-speed motor vehicle collision. TCD on admission was done with PSV 74 cm/s, EDV 29 cm/s MFV 45 cm/s and PI 0.99 (**Figure 16)**.

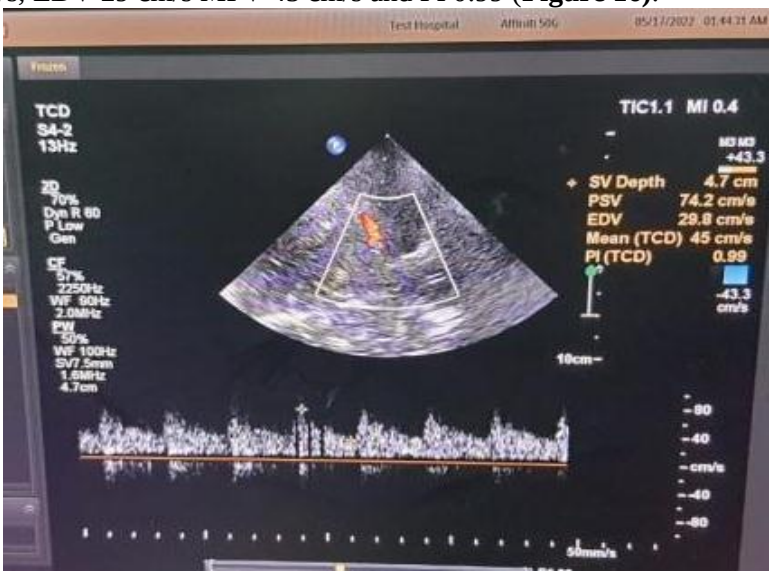

Figure (16): TCD on admission after a high-speed motor vehicle collision.

CT Brain showing midline shift and ventricular effacement and subarachnoid hemorrhage (**Figure 17).**

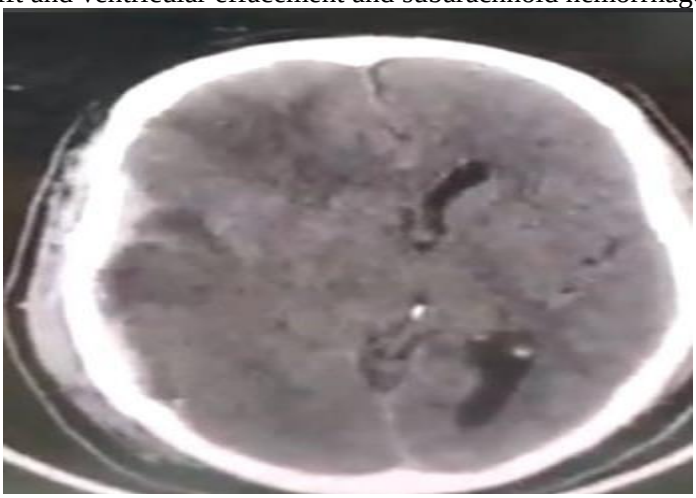

Figure (17): CT Brain showing multiple brain contusions, subdural hematoma with midline shift, ventricular effacement and subarachnoid hemorrhage. On follow up of the patient after admission GCS of the patient deteriorated.

Bedside TCD was done and revealed increased MFV 142 cm/s, PSV 138 cm/s, EDV 93cm/s and PI 1 on right side suggesting vasospasm **(Figure 18)**.

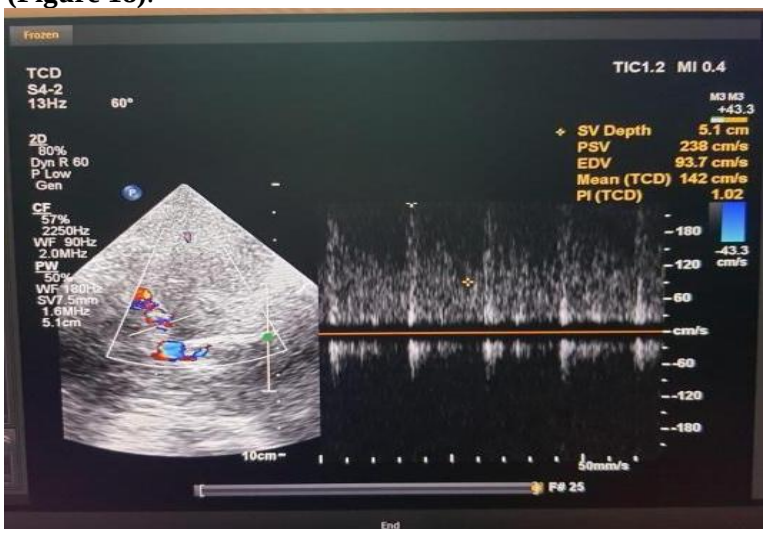

Figure (18): TCD was done suggesting vasospasm.

Follow up CT brain was done revealed right temporal infarction **(Figure 19).** The patient passed away 20 days after admission due to septicemia.

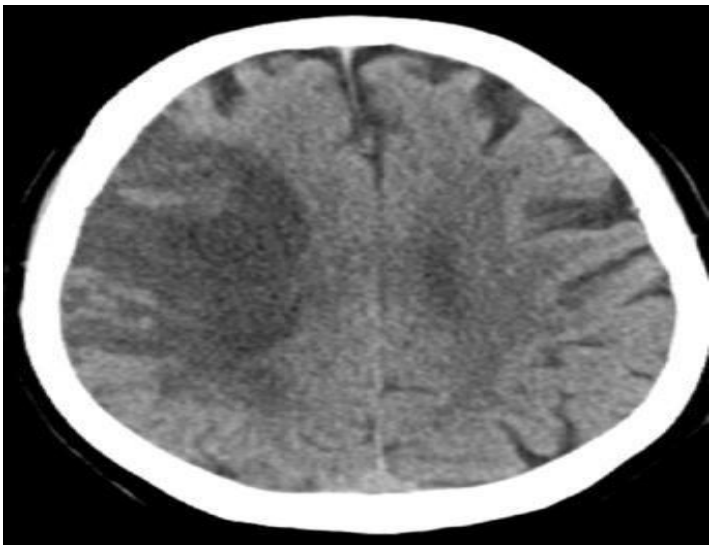

Figure (19): Follow up CT brain with right parietal infarction.

DISCUSSION

TBI is a serious socioeconomic and public health concern. It is a major global cause of mortality and disability, particularly for young adults, and many survivors have lasting disabilities [(11)]. The primary goals of contemporary TBI ICU care are the prevention and treatment of such subsequent injuries. Maintaining sufficient CBF in this situation is essential [(12)].

The cerebral blood flow velocity (CBF-V) in the main intracranial arteries is assessed using a noninvasive ultrasound (US) method termed TCD. It uses relatively narrow bone windows to insonate the basal cerebral arteries with low frequency (≤2 MHz) US waves. TCD is more convenient than other imaging techniques because it can measure CBF-V and vascular pulsatility dynamically and with a high temporal resolution [(13).]

We examined 60 people who had suffered a TBI and had been treated at Tanta University Hospital's Emergency Department.

Transcranial Doppler was repeated on day 7, 14, 21and 28 during the admission of the patients. Data of TCD were collected and compared to the final outcome of the patients.

The age of our patients varied from 18 to 66 years with an average of 38 ± 13.76. They consisted of 49 (81.67%) males and 11 (18.33%) females.

The majority of trauma studies consistently report a preponderance of men, likely because men are more susceptible to injury from social and environmental factors. About the same proportion was found in the research performed **Bahloul *et al.*[(14)]** including 437 adult TBI patients. They determined that 90% of the patients were male, whereas only 10% were female.

There was no statistically significant correlation found in this study between bad outcome of patients suffering from moderate to severe TBI, which revealed no correlation between gender and multivariate analytic outcome across nine studies.

Johannes Leitgeb *et al.* [(15)] also demonstrated that there was no correlation between gender and increased mortality rates or adverse outcomes. The greater mean age difference that contributed to the poorer results for females was the primary cause, however minor variations in GCS scores and the severity of CT findings may also have played a role.

TCD parameters were normal in 47(78.,3%), while abnormal findings were recorded in 13(21.7%) patients, as hypoperfusion was detected in 9(15%) and 4(6.6%) patients showed vasospasm, interestingly all patients with abnormal TCD measurements on admission had a poor GOS at 28 days, which reflects the poor neurological status of these patients.

TCD parameters were significantly higher in patients with favorable outcome and showed good correlation with outcome with p value< 0.001.

When GOS prediction using TCD measurements recorded, PI showed sensitivity of 66.67%, specificity of 100.00%, in predicting patients with unfavorable outcome at day 28 after trauma, as PI of patients with poor outcome was higher.

Also in this context, one study [(16)] suggested that TCD can be used for early prediction of the outcome of TBI patients when it was performed as early as possible in the first 24 hours after injury, and PI was significantly correlated to invasive ICP and CPP monitoring suggesting that TCD can be used to direct early diagnosis and management of TBI in the ED.

The outcome is similar to a research by **Splavski *et al.*[(17)]** on thirty patients who suffered from severe TBI, which found a statistically significant negative strong connection (r=-0.722, P<0.01) between PI values and outcome. Nonetheless, a weak connection (r=0.136, P<0.01) was found between the MCA flow velocity and the result. Low flow velocity state (MFV<35 and high PI) were linked to unfavorable results, according to **Santbrink *et al.*** [(18)]. **Moreno *et al.*** [(19)] found that for patients with severe TBI, the death rate was 100% for those with an index (PI) of more than 2.3.

The noted differences of results of the mentioned studies with our results can be explained by a few research have examined the function of TCD in mild and moderate TBI patients, different sample sizes, different timing of TCD monitoring, and different inclusion and exclusion criteria of the target populations and different timing of outcome measures assessment. Furthermore, still there is no standard definition of TCD parameters thresholds and cut off points of normal and abnormal TCD measurements.

Christou *et al.* [20] showed a correlation between the MCA PI and TBI outcome. There was an 83% incidence of bad outcomes at six months for individuals who were found to have PI 1.56 (GOS 4–5), compared to 71% of patients who had PI 1. Severity of the basilar artery vasospasm (BA VSP) (MFV >60 cm/s) has been linked to long-term neurological deficits. According **to Kirkpatrick *et al.*** [21] TCD is capable of detecting transitory changes in the relative CBF. CBF and FV decrease in relation to an increase in ICP.

Additionally, a number of studies have revealed that TCD might be effective in the early prediction of TBI patients' outcomes [19-22]. **Moreno *et al.*** [19] for example, studied 125 patients with severe TBI (mean GCS score of 6.02 ± 1.81) who underwent invasive ICP monitoring via intra- parenchymal catheters (mean ICP of 22.07 ± 17.29). Based on these data, they computed a mean PI of 1.26 ± 0.73 mmHg within the first 24 hours of admission. With each additional unit of ICP, the PI rose by 0.03. An increased proportion of unfavorable results (83%) was linked to PI values greater than or equal to 1.56. When the PI was more than 2.3, there was a 100% death rate.

Ract *et al.* [22] correlated TCD characteristics recorded on admission. When TCD was declared aberrant, that is, in situations where at least two of the three observed values were abnormal, as defined by the following cut offs: The GOS in 24 patients with severe TBI revealed: MFV > 30 cm/sec, FV > 20 cm/sec, and PI > 1.43. GOS was considerably worse in patients with PI 1.43 ($p < 0.006$).

Kiphuth *et al.* [23] investigated whether PI correlated with ICP and if it could serve functional prognosis in 124 individuals with an acute spontaneous, supra-tentorial intracerebral hemorrhage. Before being admitted to the hospital TCD was conducted six months after discharge, the functional result was evaluated. There was a 39.5 percent death rate in the first six months.

As a result, we can say with confidence that TCD, MFV, and PI are reliable indicators of prognosis in TBI patients. However, the variable prediction thresholds between authors, including our results, may be related to differences in the definitions of good and bad GOS groups, time of evaluation of the outcome, timing of measurement of the prediction TCD parameters, using a cut off value or the trend of the TCD parameters, and number and severity of TBI patients included in the studies.

Limitations and future directions

We studied A very limited number of people in a single location. At least 10 cardiac cycles were collected for each right and left middle cerebral artery tracing, which may have missed important peaks.

Continuous TCD monitoring through a headset during the first few hours after admission may lead to more accurate results and additional relevant insights. Assessment of patients' outcomes over longer periods, such as six months or one year following an accident, is required to corroborate the benefits of early GOS assessment.

To avoid bias and arrive at reliable correlations and results, we only looked at a tiny proportion of people who have had moderate to severe traumatic brain injuries. As a consequence, we are unable to extrapolate our findings to all patients who appear with these symptoms. The Emergency Department at our hospital does not have the capability to do invasive ICP monitoring. Therefore, that was not applicable in our study, yet using invasive ICP can add valuable information about the correlation of TCD measurements (PI) with ICP and CCP, which reinforce our findings and help better understanding of early disturbances in cerebral hemodynamics after mild and moderate TBI and how this is reflected on TCD parameters.

CONCLUSION

The primary intracranial vessels' CBF velocity can be accurately and non-invasively measured using transcranial Doppler ultrasound (TCD). In patients with a favorable result, the PSV, EDV, MFV were considerably higher and PI was within normal range. Abnormal TCD parameters either hypoperfusion or vasospasm were recorded mainly in patients with unfavorable outcome. There was a good correlation between TCD parameters and outcome in our patients.

RECOMMENDATION

- A study for a longer period should be conducted to assess the impact of longer-term outcome of severe and moderate TBI.
- TCD should be incorporated into multimodality monitoring when prognosticating traumatic brain injury victims.
- Continuous assessment TCD may have a role in the early stages of severe TBI and can provide early insight in guiding management rather than just predicting outcome.
- Patients with abnormal TCD parameters on admission and poor GOS at 1 month should be encouraged to be transferred to rehabilitation center as early as possible to give way to patients who are in need of an ICU place in facilities with limited beds.

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