# TRANSCRANIAL DOPPLER MONITORING

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***Abstract :*** *The evolution of Transcranial Doppler (TCD) as a diagnostic technique can only be surpassed by its growth and expansion as monitoring tool. The inherent characteristics of TCD, its simplicity, safety and reliability confer it the right dynamic qualities necessary for its use in the assessment of cerebral circulatory changes over period of time of variable length. The present paper is a summary of some of the basic concepts that govern the utilization of TCD for monitoring neurological patients. Examples of some of the most common clinical applications of this techniques, as well as suggestions regarding potential future roles that it will play in clinical practice are also included.*

## GENERAL CONCEPTS: TYPES OF MONITORING

Several types of TCD monitoring techniques are available, each with its own advantages and disadvantages.

## INTERMITTENT TCD MONITORING

This perhaps the one which is most commonly performed. Its principle is the repeated sampling of one or more cerebral blood vessels on multiple occasions over hours or days. Its main advantages are that it requires no specialized equipment, and that it can be performed in almost any environment, so long as the patient remains available. The obvious *disadvantage* are related to the diagnostic limitations of a short sampling period. In between sampling sessions, any changes occurring in the patient will go unnoticed. It is possible to monitor different types of patients using this technique. In fact, the earliest studies of the effects of cerebral vasospasm upon TCD measurements were conducted using this method; a technologist or a physician would record daily TCD measurements from selected brain arteries, especially the middle cerebral artery.

## CONTINUOUS DATA GENERATION

TCD monitoring, on the other hand, represents a more complex technique, requiring the utilization of specialized TCD monitoring transducers and transducer holders, in order to maintain the sampling probe in place for extended periods of time. Its basic advantage is the generation of continuous data over a single period of time, thereby reducing the risk of missing important information related to changes occurring in the patient during the sampling interval. Conversely, long-term monitoring is ideally performed in patients who are either immobile or those with limited mobility. When these conditions are not met, securing the TCD transducer in place becomes a major technical obstacle. It was this form of TCD monitoring was first utilized in the operating room to assess the effects of certain surgical procedures upon the brain circulation. Since then, it has been possible to apply it to a variety of clinical situations.

## INSTRUMENTATION

One of the characteristics of TCD that makes it such a desirable technique for monitoring is the compact and portable nature of TCD instruments. It is possible to carry the equipment almost into any environment, without occupying large amounts of space, and allowing the sonographer to operate without interfering with procedures being carried out concurrently. In general, ultrasound companies that manufacture TCD instrumentation have understood the importance of small, portable equipment. In addition, multi-channel instruments capable not only of trend analysis of the TCD data, but also of storing other types of monitoring information (e.g. blood pressure) are being introduced. Finally software that allows the detection of embolic material, as well as its characterization, is the latest link in the chain of technologic advantages that make TCD monitoring possible.

## TRANSDUCERS

As noted earlier, in order to carry out long-term continuous monitoring, the probe must be secured in place by means which preserve the spatial relationship between the Doppler sample gate and the blood vessel being monitored. Originally, elastic headbands secured with Velcro were utilized. Although capable of allowing monitoring of patients during intra-operative conditions, they were insufficient for holding the transducer in place in awake, sick, often highly mobile hospitalized patients. Several solutions were offered for this problem, including suturing the transducer holder to the skin intra-operatively. A few years ago, our group introduced a TCD transducer holder which could be "glued" to the skin with a variety of substances, including, collodion. The device could be secured and removed in a few minutes, and it allowed TCD monitoring of patients over periods of up to 72 hours. The main limitations were that electroconductive gel had to be reapplied at least every 4 hours, and that imaging procedures of the brain could not be properly carried out with the device was in place. In future, it is likely that even smaller transducers, shaped and sized like a 25 cents coin and attachable with the ease of electrocardiographic monitoring leads will be available.

## INTRA-OPERATIVE TCD MONITORING

The use of TCD monitoring during surgical procedures was first guided by the expectation of detecting hemodynamic changes that may compromise the cerebral circulation. Although this has certainly occurred, the detection of emboli is perhaps a more important finding related to the application of this technology, and one which could have an even greater impact upon the care of patients with cerebrovascular ischemic disorders. For practical purposes, the surgical procedures in which TCD monitoring has

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been most widely utilized are *carotid endarterectomy* and *cardiopulmonary* bypass grafting.

***Carotid Endarterectomy:*** The utilization of TCD monitoring during carotid artery surgery was fostered by the concern about hemodynamic complications of cross-clamping of the common carotid artery during surgical intervention. The possibility of cross-clamping resulting in cerebral ischemia (or infarction), and the need for defining parameters that would guide the surgeon about the requirement of shunting led to the use of TCD as a monitoring tool. Compared with other monitoring techniques such as electrophysiologic procedures (electroencephalography and evoked potentials), TCD provides quicker and more direct assessment of hemodynamic disturbances. In general it has been shown by multiple groups that a mean blood flow velocity (MBFV) drop of 33% or more in the middle cerebral artery during cross-clamping, is an indicator of the need for shunting. These results, in fact, are almost identical to the MBFV drop noted lobe associated with alteration of consciousness during global cerebral ischemia. Even more surprisingly, however, has been the finding of repeated embolization into the middle cerebral artery territory during carotid artery surgery.

***Cardiopulmonary Bypass Grafting:*** This is another area where TCD monitoring has allowed the identification of embolic phenomena as perhaps the most important finding during the surgical intervention. This is in contrast to the traditional idea that hemodynamic compromise results in the majority of the ischemic deficits following this type of surgical procedure. In the early years, however, TCD monitoring provided the first method for documenting the levels and effects of non pulsatile flow in the cerebral circulation, as the extra-corporeal oxygenator were being utilized.

## BEDSIDE TCD MONITORING

Perhaps the most attractive potential application of TCD monitoring has been ***performing it at the bedside***. Until TCD became available, it was practically impossible to assess on a moment-to-moment basis, the status of the cerebral circulation. In addition, issues about auto-regulation, the effects of therapeutic maneuvers or medications could now be explored fast and non-invasively. From a certain perspective, TCD monitoring could be considered the cerebral *Swan-Ganz* of the future. The application of **bedside TCD monitoring** continues to expand, to include clinical scenarios of a diverse nature. The following paragraphs will serve as a review of some of the most important.

***Ischemic Cerebrovascular Disorders :***

The moment-to-moment assessment of patients with cerebral infarction and transient ischemic attacks is perhaps one of the most exciting potential applications of TCD monitoring. The technique has allowed differentiation of hemodynamic changes which occur in eminently embolic infarction, and those secondary to lipohyalinotic occlusion of penetrating arterioles. The patterns found in the former, consistent with embolus recanalization and the evolving picture of “pseudostenosis” which often accompanies; underscores the presence of a dynamic process for which TCD appears to be a perfectly matched dynamic monitoring procedure. Furthermore, the ability of TCD to detect embolic phenomena has opened the door to the objective qualification of the effects of anti-coagulant medications upon the development of cerebral ischemic events.

***Hemorrhagic Cerebrovascular Disorders and Trauma :***The majority of the TCD data has been collected from patients with subarachnoid hemorrhage. In this context, TCD has allowed the non-invasive assessment of patients at risk, and a better planning of interventional diagnostic or therapeutic procedures. Daily TCD monitoring of patients with ruptured intracranial aneurysms has invariably shown that MBFV in the basal cerebral arteries progressively increases during the first two weeks, reaching a peak at approximately the $8^{th}$-$10^{th}$ days following the original hemorrhage. This elevation of MBFV results from the narrowing of diameter of the arterial segments being monitored. At least for the middle cerebral artery, it is possible to classify the severity of vasospasm by the degree of increment observed in the MBFV. Perhaps, more important than the detection of vasospasm, once it is present, is the ability of TCD monitoring to predict its impending occurrence, early enough to allow the clinicians to intervene before it becomes clinically symptomatic. In fact, it has been reported that an increase of over 50% in MBFV over a 24 hours period is highly indicative of the risk for symptomatic vasospasm. Furthermore, the recent introduction of cerebral balloon angioplasty as a potential tool for treating vasospasm places TCD monitoring at the top of the list of ancillary procedure that could be used to monitor the hemodynamic effectiveness of the procedure.(Table)

**Table:** *Doppler criteria for the diagnosis of spasm of the middle cerebral artery*

| MBFV (cm/sec) | MCA /ICA MBFV | Interpretation |
|---|---|---|
| <120 | <3 | Normal, non-specific elevation or distal spasm |
| >120 | 3-6 | Proximal Vasospasm |
| >200 | >6 | Severe Proximal Vasospasm |

*(Reproduced from Seiler R and Newell DW. Transcranial Doppler)*

Vasospasm is not only observed in patients who have suffered rupture of intracranial aneurysms. In fact, the most common cause of subarachnoid hemorrhage is head trauma. The incidence of vasospasm in patients with head injury has been reported to be somewhere between 5-50%, this wide range directly results from the variety of definitions utilized in the diagnosis of vasospasm, as well as the requirement of cerebral angiography in the earlier studies. Several groups of investigators have shown that it is possible to document the presence of vasospasm in the majority of individuals who have suffered closed head injuries, and that its occurrence does not necessarily correlate with the presence or absence of hemorrhage in the admission computed tomography (CT) studies. Renewed interest in the subject of post-traumatic vasospasm has promoted the inclusion of TCD monitoring among the techniques utilized in neurologic and neurosurgical critical care units. An area of particular interest is the differentiation between vasospasm and vasoparalysis, as well as the effect of certain therapeutic maneuvers upon the TCD changes observed. Finally, it is important to note that cerebral vasospasm may also occur in the context of other clinical conditions including migraine.

***Cerebral Circulatory Arrest:*** The cerebral blood flow, and therefore the cerebral blood flow velocities, depend upon cerebral perfusion pressure and cerebrovascular resistance. The latter is a result of both the vasomotor tone of the cerebral arterioles, and also of the intracranial pressure (ICP). As the ICP rises, greater resistance to flow will be encountered by the cerebral arteries. With regard to TCD monitoring, this is going to be reflected in a decrease in velocities and an increase in pulsatility. As the ICP continues to increase, resistance to flow will become even greater, to a point, where a "reverberating" waveform pattern will be noted by TCD; this pattern is associated with net blood flow, and usually implies absence of effective cerebral circulation an event associated with brain death. It is therefore possible to use TCD monitoring to detect the progression of intracranial hypertension and to document the present of cerebral circulatory arrest.

***Global Cerebral Ischemia :*** Theoretically, it is also possible to utilize TCD to monitor the effect of systemic circulatory derangements upon the brain. An example of this is the documentation of a global decrease in end diastolic blood flow velocities (EDBFV) resulting from aortic insufficiency. Even simple bradycardia will have an effect upon the EDBFW that can be measured with TCD. Several groups have studied the TCD changes occurring during syncope, showing that a drop of approximately 50% is frequently observed as patients pass out. In any case it is important to note that when systemic hypotension occurs, complete loss of EDBFV is not tolerated by the brain and is always associated with the loss of consciousness. The use of TCD monitoring during *head up tilt tests* (HUT) has introduced a new dimension in the assessment of patients according to the principal mechanism for their event, into vasovagal, vasodepressor and "cerebral" syncope. The latter is a poorly understood condition in which, for reasons yet unknown, patients seem to develop cerebral vasoconstriction and loss of consciousness.

Some groups have been also interested in assessing the effect of cardiopulmonary resuscitation upon the cerebral circulation. The use of TCD monitoring of the internal carotid artery during CPR has shown that, in spite of all maneuvers, MBFV drop progressively and relentlessly over time. This drop seems to be the direct result of a progressive increase in resistance to flow, leading to the development of "reverberating" TCD patterns; further work in this area might disclose ways in which TCD could assist in improving the outcome of patients who suffer cardiac arrest.

## DETECTION OF CEREBRAL EMBOLI

In 1990, for the first time, Spencer et al. reported the detection of asymptomatic formed emboli to the cerebral blood vessels using TCD monitoring of patients undergoing carotid endarterectomy. This report was followed by great general interest in further investigating the capability of this technique, as well as its potential clinical applications. The theoretical basis for the detection of emboli using Doppler ultrasound is actually very simple. The Doppler effect generally relies upon the frequency shift caused upon the ultrasound beam by a moving reflector, in this case the red blood cells. The intensity of the returned ultrasound depends upon the proportion of the transmitted beam that is reflected. This, in turn, depends upon the tissue through which the ultrasound passes, and the reflection from the interface between two materials. The latter is proportional to the difference in acoustic impedance compared with circulation blood, the Doppler ultrasound beam reflects readily and intensely from them, generating characteristic sounds and changes within the Doppler waveform. It is possible to utilize TCD to detect gaseous or solid embolic material. There is preliminary information to suggest that the technique may even be used to differentiate among different types of pathologic embolic material, conferring TCD monitoring a very important place in the evaluation and follow up of patients during surgical procedures, or of patients at risk of recurrent cerebral embolisation for a variety of other reasons (e.g. prosthetic heart valves, patent foramen ovale). The task of applying TCD monitoring the detection of emboli is likely to be facilitated by the development of instrumentation capable of automatically recognizing the Doppler characteristics of emboli, differentiating it from ultrasonic artifacts.

## CONCLUSION

The technique of TCD monitoring is a safe and reliable method for longitudinal assessment of the status of the cerebral circulation over time. Its applications are as diverse as the imaginative efforts of the user. In general, TCD monitoring appears to have a great future, becoming more entrenched into the daily care of patients with neurological disorders. The future is yet to see even further improvements in the instrumentation and transducer utilized for TCD monitoring, perhaps adding more potential applications of this technique.

## RECOMMENDED READING


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1. Dr. Pinnamaneni Narasimha Rao, International Award;
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BOT & CEC members and Fellows and Members of IMSA are requested to recommend names of national and international fame for delivering the above orations. The recommending persons should send biodata and achievements of the recommended persons for consideration by the Award Committee. The recommendations should reach IMSA headquarter at New Delhi by 10th May 2008.

***Secretary General IMSA***