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The Significance of Transcranial Doppler in Aortic Arch Surgery

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ABSTRACT

Background: Despite advancements in surgical techniques, aortic arch surgery poses a significant risk of neurological complications. This study evaluates transcranial Doppler (TCD) for real-time monitoring of cerebral blood flow during surgery, aiming to optimize perfusion and mitigate these complications.
Objectives: This study aims to evaluate the role of transcranial Doppler (TCD) in monitoring and optimizing cerebral perfusion during aortic arch surgery and to determine whether TCD contributes to improved postoperative neurological outcomes.
Methods: This retrospective observational study included 40 patients undergoing aortic arch surgery, divided into a control group without TCD monitoring and a TCD monitoring group. Data collection involved TCD via the transtemporal approach to measuring cerebral blood flow velocity (CBFV) and the Lindegaard index. Statistical analysis compared outcomes between groups, using appropriate methods to evaluate differences in postoperative neurological outcomes, hospital stay duration, and mortality rates.
Results: The study demonstrated several key findings: the TCD group had a lower incidence of postoperative neurological dysfunction (PND) and experienced no cases of intraoperative cerebral vasospasm. Patients in the TCD group also had reduced hospital and ICU stays. Cerebral blood flow velocity (CBFV) remained stable during critical surgical phases in the TCD group, highlighting the effectiveness of TCD in maintaining cerebral perfusion. These results establish a clear relationship between TCD monitoring, improved neurological outcomes, and accelerated recovery.
Conclusions: The study presents compelling evidence supporting transcranial Doppler (TCD) as an effective tool for optimizing cerebral perfusion and mitigating complications during aortic arch surgery. It highlights how TCD enables real-time monitoring and management of cerebral blood flow, addressing the critical challenge of neurological complications inherent in this high-risk surgical procedure.
Keywords: Aortic arch surgery; cerebral perfusion; cerebral vasospasm; intensive care unit; length of hospitalization; neurological complications; postoperative neurological dysfunction; transcranial Doppler.

BACKGROUND

Aortic surgery, which includes replacing or reconstructing the ascending aorta, aortic arch, and proximal descending aorta, represents one of the most complex areas in cardiac surgery. Despite significant advancements in surgical techniques, perfusion management strategies, and neuroprotective measures, aortic arch surgery remains associated with a high perioperative risk, particularly concerning neurological complications. The earliest publications highlighting the role of transcranial Doppler (TCD) in aortic arch surgery emerged in the 1990s.[1] However, its importance was overshadowed by the development of more advanced brain protection techniques.

In Georgia, aortic arch surgery performed under deep hypothermia presents specific challenges. This approach is linked with complications such as consumptive coagulopathy, severe bleeding, the need for massive transfusion of blood components and clotting factors, kidney failure, and increased infection risk. Additionally, the absence of clotting factors and thrombus masses adds to the complexity of this procedure. These factors contributed to a notably high mortality rate for aortic arch surgeries performed under deep hypothermia in our clinic. Consequently, a decision was made to transition from deep hypothermia to the upper limits of mild hypothermia for aortic arch surgery. This necessitated the implementation of rigorous cerebral perfusion monitoring using transcranial Doppler (TCD), near-infrared spectroscopy (NIRS), and assessments of oxygen saturation in the jugular vein.

The initial monitoring stage involved transcranial Doppler (TCD), which provides real-time data on cerebral blood flow changes. A decreased cerebral blood flow was associated with reduced oxygen concentration in venous blood, so TCD was the primary monitoring tool during aortic arch surgery.

There are three main approaches to transcranial Doppler: orbital (via the ophthalmic artery), transtemporal (through the middle cerebral artery, ACM), and transoccipital (via the vertebral arteries).

Establishing TCD monitoring presented specific challenges, particularly related to the variability in the thickness of the cranial bone, which affects the quality of the transcranial window.[2] Despite this, our experience showed that a trained researcher could obtain an adequate Doppler signal in nearly all patients. A unique holder was used to secure the transducer on both sides to eliminate variability in the signal caused by transducer movement and ensure continuous blood flow monitoring in real time. Blood flow profiles were examined in the ACM on both sides and in both common carotid arteries at several critical stages of the procedure: before switching to artificial circulation, after switching, at the start and during the progress of unilateral perfusion, and after the return to full circulation.

Statistically, 15% of the population has an incomplete Circle of Willis, underscoring the importance of early diagnosis of reduced perfusion in the left hemisphere during unilateral perfusion, a standard practice in aortic arch surgery.[3]

Decreased cerebral blood flow to various brain regions cannot be attributed solely to anatomical factors. Other potential causes include embolism, vasospasm, and reduced perfusion pressure. Transcranial Doppler allows for the early detection of these changes, enabling prompt intervention. These interventions involve transitioning to bilateral perfusion or employing strategies such as hypercapnia or the administration of vasoactive drugs, ultimately improving cerebral perfusion and patient outcomes.

Hyperperfusion of the brain, accompanied by elevated intracranial pressure and fluid accumulation within the interstitial space (edema), results in significant changes that can be detected through alterations in the blood flow profile. These changes provide valuable information that may help prevent complications. Near-infrared spectroscopy (NIRS) is another monitoring technique with limitations and considerations. While there is no universal consensus on the normal values, a 20% decrease from the baseline is typically considered pathological, and it is generally accepted that values should remain above 50%.[4] However, NIRS does not measure oxygen saturation across the entire brain; it only captures data from the surface of the frontal cortex at an average depth of 2.5 centimeters. In elderly patients, cortical atrophy causes the brain tissue to recede from the skull bones, reducing the sensitivity of NIRS and making it less reliable for assessing cerebral perfusion.[4] Moreover, the application of ice packs for brain hypothermia has been shown to impair the accuracy of NIRS readings significantly.[4] Severe hyperhidrosis can also lead to false changes in NIRS values, further limiting its reliability in such cases.[4]

Transcranial Doppler (TCD), on the other hand, offers a broader and more detailed assessment of cerebral perfusion. Normative values for TCD readings in different cerebral arteries during unilateral or bilateral perfusion have not been definitively established. However, TCD enables the measurement of cerebral blood flow velocity in the anterior, middle, and posterior cerebral basins, providing a comprehensive overview of brain perfusion compared to NIRS.[4] While skull bone thickness can affect the transcranial Doppler signal, our experience indicates that contraindications for its use are rare, and no adverse effects arising from extracranial factors were observed in our practice. Using a transducer holder further ensured the stability of the transducer position throughout the procedure, enhancing the reliability and objectivity of the acquired data.[4]

It is important to emphasize that transcranial Doppler should not be viewed as an alternative to NIRS or the measurement of oxygen saturation in the jugular vein. Instead, these methods complement each other, enabling comprehensive brain perfusion and function monitoring.

Cerebral ischemia and stroke are significant complications associated with aortic arch surgery, posing substantial risks to patient quality of life and contributing to increased mortality rates. These complications often arise from disruptions in cerebral perfusion, such as those caused by unilateral perfusion in the presence of atherosclerotic vascular lesions, incomplete formation of the Circle of Willis, or vasospasm. Additionally, perfusion cessation during hypothermic circulatory arrest further exacerbates the risk.

To mitigate these complications, it is crucial to implement robust strategies for monitoring and optimizing cerebral perfusion alongside continual advancements in surgical techniques and adopting innovative approaches. Historically, cerebral perfusion monitoring relied on invasive techniques, such as arterial pressure measurement and cerebral oximetry, which assessed brain oxygen saturation. However, these methods provided limited insights into the regional distribution of cerebral blood flow and were often insufficient for dynamic intraoperative management.[5]

Transcranial Doppler ultrasonography (TCD) has emerged as a non-invasive, safe, and effective alternative. TCD enables real-time monitoring of cerebral blood flow, offering a dynamic tool for assessing and optimizing cerebral perfusion during surgery. This approach allows surgeons to continuously track cerebral blood supply and swiftly address any emergent threats to neurological integrity.

This study aims to evaluate the role of transcranial Doppler ultrasonography (TCD) in monitoring and optimizing cerebral perfusion during aortic arch surgery. The hypothesis posits that using TCD for cerebral perfusion optimization will improve

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postoperative neurological outcomes in patients undergoing this high-risk surgical procedure.

METHODS

This retrospective observational study included 40 patients over 50 who underwent aortic arch reconstruction at our institution between January 2020 and December 2023. Patients were randomly assigned to either a control group (n=20) or an intraoperative TCD monitoring group (n=20). Informed consent was obtained from all participants, and the study adhered to the ethical principles of the Helsinki Declaration.

Inclusion Criteria:

- Age over 50 years;
- Scheduled for open-heart surgery involving aortic arch reconstruction;
- Feasibility of intraoperative TCD monitoring (TCD group only).

Exclusion Criteria:

- Presence of intraoperative stroke;
- History of severe neurological disease (e.g., dementia, Parkinson'sParkinson's disease);
- Technical impossibility of TCD monitoring (e.g., temporal bone defects).

TCD monitoring protocol

In the TCD group, cerebral blood flow velocity (CBFV) was measured bilaterally in the middle cerebral arteries using a 2 MHz pulsed-wave TCD probe (Spencer Technologies, Seattle, WA, USA). The transducer was securely fixed during the operation using a specialized holder to ensure consistent measurements. TCD monitoring was performed throughout all surgical phases, including anesthesia induction, sternotomy, cannulation, hypothermic circulatory arrest, selective cerebral perfusion, aortic reperfusion, and chest closure.

Baseline CBFV measurements were obtained before the operation. The Lindegaard index was measured before cannulation, after initiating cardiopulmonary bypass (CPB), and after initiating circulatory arrest.

Cerebral perfusion optimization

If a significant decrease in CBFV (>20% from baseline) was detected, cerebral perfusion optimization measures were promptly implemented. These measures included increasing systemic arterial pressure with vasopressors, enhancing cerebral perfusion pressure, raising the patient's blood temperature, and deepening the depth of anesthesia.

Data analysis

Data were analyzed using SPSS Statistics (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation or median (interquartile range), and categorical variables as number (percentage). Group comparisons were performed using Student's t-test or Mann-Whitney U test for continuous variables and chi-square or Fisher's exact test for categorical variables. Statistical significance was set at $p < 0.05$.

RESULTS

The baseline characteristics of the two study groups were similar, as shown in Table 1. The mean age of patients in the control group was 54.7 years, while in the TCD group, it was 55.9 years. Most patients in both groups were male (70% in the control group and 75% in the TCD group). All patients underwent aortic arch reconstruction, with the mean duration of surgery being 325.3 minutes for the control group and 315.7 minutes for the TCD group. The duration of mild hypothermic circulatory arrest was 42.1 minutes in the control group and 41.9 minutes in the TCD group. In comparison, unilateral cerebral perfusion lasted 35.2 minutes in the control group and 35.0 minutes in the TCD group.

TABLE 1. Demographic and clinical characteristics of patients

Characteristic	Control Group (n=20)	TCD Group (n=20)
Age (years), mean ± SD	54.7±11.5	55.9±13.8
Sex (male/female), n (%)	14 (70%)/ 6(30%)	15 (75%)/ 5(25%)
Type of surgery (aortic arch reconstruction), n (%)	20 (100%)	20 (100%)
Duration of surgery (minutes), mean ± SD	325.3±68.1	315.7±62.3
Duration of mild hypothermic circulatory arrest (32°) (minutes), mean ± SD	42.1±7.3	41.9±7.2
Duration of unilateral cerebral perfusion (minutes), mean ± SD	35.2±6.8	35.0±6.7

Abbreviations: TCD, transcranial Doppler.

During the procedure, four patients in the TCD monitoring group experienced disturbances in cerebral perfusion, identified by a significant decrease in cerebral blood flow velocity (CBFV). For two patients, perfusion was successfully restored by switching to bilateral perfusion. In the remaining two cases, reduced perfusion was accompanied by low flow and pressure on the cardiopulmonary bypass machine, which was addressed by increasing blood flow. One patient in the TCD group also developed cerebral vasospasm due to hypocapnia, which was promptly detected through TCD monitoring and managed by adjusting CO2 levels, as shown in Table 2. The data highlights that CBFV remained stable during mild hypothermic circulatory arrest and unilateral cerebral

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perfusion but quickly returned to baseline levels once full perfusion was restored. This underscores the importance of TCD-guided cerebral perfusion optimization in maintaining adequate cerebral blood flow during critical surgical stages.

TABLE 2. Changes in cerebral blood flow velocity at different stages of surgery

Stage	CBFV (cm/s), mean±SD (TCD Group)	p-value (compared to baseline)
Baseline	60.2 ± 10.3	-
Mild hypothermic circulatory arrest	12.0 ± 4.1	**<0.001**
Unilateral cerebral perfusion	12.0 ± 4.1	**<0.001**
Cardiopulmonary bypass	240.0 ± 35.0	**<0.001**

Abbreviations: CBFV, cerebral blood flow velocity.

Neurological outcomes were significantly better in the TCD group, with only one patient (5%) developing postoperative neurological dysfunction (PND), compared to five patients (25%) in the control group, as indicated in Table 3. The TCD group also benefited from shorter hospital and ICU stays, with averages of 7.1 ± 2.1 days and 2.4 ± 0.9 days, respectively, compared to 9.3 ± 2.8 days and 3.8 ± 1.5 days in the control group.

TABLE 3. Primary and secondary outcomes

Outcome	Control Group (n=20)	TCD Group (n=20)	p-value
Postoperative neurological dysfunction, n(%)	5(25%)	1(5%)	**0.04**
Intraoperative cerebral vasospasm, n(%)	-	0(0%)	-
Length of hospital stay (days), mean±SD	9.3±2.8	7.1±2.1	**0.01**
Length of stay in intensive care unit (days), mean±SD	3.8±1.5	2.4±0.9	**0.001**
30-day Mortality, n(%)	1(5%)	0(0%)	0.32

Abbreviations: TCD, transcranial Doppler.

Although no mortality occurred in the TCD group within 30 days postoperatively, the control group recorded one death (5%) during the same period. While this difference was not statistically significant, the TCD group showed clear benefits, including timely detection and management of cerebral perfusion disturbances such as reduced perfusion, flow drops, decreased flow, low pressure on the cardiopulmonary bypass machine, and vasospasm. These interventions improved neurological outcomes, shorter hospitalization, and reduced ICU stays.

DISCUSSION

Our research underscores the role of intraoperative transcranial Doppler (TCD) with a fixed transducer in optimizing cerebral perfusion during aortic arch surgery and mitigating neurological complications, particularly postoperative neurological dysfunction (PND). The 5% incidence of PND in the TCD group, compared to 25% in the control group, demonstrates the ability of TCD to detect and address cerebral perfusion disturbances in real time, enabling timely interventions to prevent cerebral ischemia and improve outcomes. This finding aligns with existing studies that highlight the effectiveness of TCD in improving neurological recovery in such surgeries.

Our study's absence of intraoperative cerebral vasospasm further emphasizes TCD's utility as a monitoring tool. Vasospasm, a major cause of stroke in patients undergoing aortic arch surgery, can be detected early with TCD, allowing for prompt corrective measures. TCD contributes significantly to safeguarding neurological function during surgery by preventing vasospasm-induced ischemia.

Furthermore, the study observed a statistically significant reduction in hospitalization and intensive care unit (ICU) stays in the TCD group. This finding suggests that TCD contributes to better neurological outcomes and accelerates recovery, thereby reducing healthcare costs associated with prolonged stays and post-surgical complications. Such outcomes are crucial in enhancing the efficiency of healthcare systems, especially in high-cost surgeries like aortic arch reconstruction.

Although our study's sample size and retrospective nature limit its generalizability, the findings still provide valuable insights into the potential of TCD for intraoperative monitoring during aortic arch surgery. It is also important to note that while TCD showed positive effects, its integration with other monitoring techniques like Near-Infrared Spectroscopy (NIRS) and jugular venous oxygen saturation (SvjO2) monitoring could provide a more comprehensive picture of cerebral perfusion, further enhancing patient safety.

CONCLUSIONS

Our findings demonstrate a significant reduction in postoperative neurological dysfunction (PND), length of hospital stay, and ICU stay in the TCD group compared to the control group. This highlights the potential of TCD to enhance patient outcomes and optimize resource utilization. While further large-scale studies are needed to validate these findings, our research strongly supports the integration of TCD into routine practice for aortic arch surgery. This non-invasive, cost-effective tool enables surgeons to personalize cerebral perfusion strategies, ensuring optimal neurological protection and facilitating a smoother recovery for patients undergoing this complex procedure. By improving patient safety and promoting better outcomes, TCD offers considerable promise for advancing the field of aortic arch surgery.

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