Transcranial Doppler findings during thoracic endovascular aortic repair

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Objective: **Thoracic endograft placement has become an acceptable treatment alternative to open repair of the thoracic aorta. Cerebral embolization when manipulating the aortic arch during cardiac catheterization is well described, but the influence of thoracic endovascular aortic repair (TEVAR) on this event remains poorly studied. Our aim was to quantify the number of microembolic signals (MES) detected by transcranial Doppler (TCD) during different stages of TEVAR and correlate them with landing zones, subclavian revascularization, and postoperative morbidity and mortality.**

Methods: **TCD was used to monitor 20 patients during TEVAR for the treatment of thoracic aortic aneurysms (TAAs) in 17 (85%) patients, followed by three (15%) with chronic type B aortic dissection and one (5%) Crawford type I thoracoabdominal aortic aneurysm (TAAA). Imaging and medical parameters were entered into a combined database. TCD signals were recorded digitally for the entire case. MES, velocities, and pulsatility index values were entered into a combined database.**

Results: **The total number of MES calculated for the diagnostic phase before TEVAR placement and during the treatment phase for all cases combined was 1081 and 1141, respectively. The highest MES counts were generated by the pigtail catheter placement during the diagnostic phase and by device placement during the treatment phase. Embolic count to right/left sides was equal overall. In the diagnostic phase, an average of nine MES were seen right/left, whereas during the treatment phase, 45 and 43 MES were seen, respectively, for right/left. A significant association was found between the total number of MES and postoperative stroke, transient ischemic attack ($P = .0055$), and death ($P = .0053$).**

Conclusions: TCD **can detect microemboli during TEVAR and is able to identify the procedural aspects most associated with cerebral microemboli. (J Vasc Surg 2011;54:364-9.)**

Thoracic endovascular aortic repair (TEVAR) of descending thoracic aortic aneurysms (TAAs) was first described by Volodos et al in 1991.[1] Open surgical repair of TAAs remains the historical standard but is associated with higher rates of 30-day morbidity and mortality.[2] Stroke is a particularly debilitating morbidity that occurs about 9% of the time during open procedures and at least 3% of the time during TEVAR.[3] These stroke rates are supported by previous pivotal trials for the Gore TAG (W. L. Gore and Associates, Flagstaff, Ariz) Talent (Medtronic, Minneapolis, Minn), and TX2 (Cook, Bloomington, Ind) grafts.[4-7]

Conventional computed tomography scans have been relatively insensitive in detecting small-vessel ischemic lesions, particularly those that are apparently asymptomatic.[8,9] Diffusion-weighted imaging for magnetic resonance scans provides a valuable adjunct for detecting clinically asymptomatic ischemic lesions. One study[10] documented positive findings in 16% of patients; however, this falls short of detecting all in situ microemboli during and after intervention.

Microemboli are considered the main cause of stroke after TEVAR procedures.[11] Transcranial Doppler (TCD) imaging provides an important tool for the real-time detection of emboli during manipulation of the thoracic aorta and its cerebral branches. Manipulation of the aortic arch during cardiac catheterization has likewise been identified as a source of cerebral embolization.[12] The influence of endograft placement on cerebral embolization and flow is not well studied. The aim of this study was to quantify the number of microembolic signals (MES), velocities, and pulsatility index detected by TCD during the diagnostic and deployment stages of the TEVAR and correlate these findings with landing zones, subclavian revascularization, and postoperative morbidity and mortality.

PATIENTS AND METHODS

Study design. Between February 2007 and July 2008, 20 patients underwent Gore TAG Excluder thoracic endoprosthesis placement while being monitored by TCD. All patients provided informed consent, and the Institutional Review Board at The Methodist Hospital approved this prospective study. Imaging and medical parameters were entered into a combined database. The study took place in an academic medical center with 1000 beds in a catchment area of 5 million people. It is a tertiary and quaternary referral facility.

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Study population. The study included patients with descending TAAs of more than twice the diameter of the adjacent aorta or a saccular aneurysm with a thrombus-free nonaneurysmal proximal aortic landing zone >20 mm in length and with angulation of the aortic segment of <60°. The 20 patients (11 women, 9 men) were an average age of 65 ± 22 years. Of these, 20% had hypertension, 30% had coronary artery disease, 20% had arrhythmia, 25% had peripheral arterial disease, 10% had diabetes, 10% had congestive heart failure, 20% had chronic obstructive pulmonary disease, and 25% had history of cerebral ischemia. Another 10% had renal insufficiency, with a creatinine value of >1.4 mg/dL, and 10% required hemodialysis at the time of the surgery. A history of tobacco use was prevalent in 40%, and 10% were using tobacco at the time of the procedure.

Five patients (25%) reported a history of aortic surgery, including TAA repair, arch debranching with ascending thoracic aorta replacement, and open aortobiiliac graft. At presentation, 40% of patients were symptomatic. The most common presenting symptom was chest pain (35%), followed by back pain (25%) and respiratory complaints (25%). Two patients (10%) were managed emergently. Most patients (85%) were American Society of Anesthesiology (ASA) class 4, 10% were class 3, and 5% were class 5. Patients who required left common carotid artery–left subclavian artery bypass to secure an adequate proximal landing zone were included, and all received debranching before TEVAR, and so monitoring was the same for all patients.

Methods. The procedures were performed in a hybrid operative suite with the patient placed under general anesthesia. We quantified the number of MES, velocities, and pulsatility index detected by TCD during different stages of the endograft placement and correlated them with landing zones, subclavian revascularization, and the number of devices used. Systemic heparin (1000 U/kg) was given to each patient before the treatment phase. TCD measurements were taken at access wire placement, pigtail catheter deployment, stiff wire exchange, contralateral wire placement, device advancement, device deployment, delivery system removal, device ballooning, and balloon removal.

Data were categorized into the diagnostic phase (DP), encompassing access to contralateral wire placement, and the treatment phase (TP), encompassing device deployment. In patients where we were able to monitor the bilateral middle cerebral arteries (MCAs) simultaneously, the number of MES was quantified on each side; and we used these numbers to compare MES between the right and left sides in each case.

TCD machine and software settings. Doppler parameters for our PMD100 (Spencer Technologies, Seattle, Wash) were transducer, 2 MHz; 13-mm circular probe surface; pulse repetition frequency, 8 kHz; fast Fourier transformation, 128 points; overlap, 66%; sample volume axial length, 9 mm; output power, 80%-100% (700 mW/cm^2 spatial peak temporal average intensity); filter, 125-175 Hz; noise 0-3 dB; range, 30 dB; Doppler volume, 4 dB; M-mode range, 30 dB; and sweep period, 4-16 seconds. We identified the proximal MCA bilaterally. The M-mode screen enables visualization of intracranial flow signals from depths of between 25 and 85 mm from the ultrasound probe, making it easier for the sonographer to localize the blood flow in the target vessel (Fig 1). The TCD signal was continuously recorded, and postprocedural analysis of the recording was completed for quantification of MES.

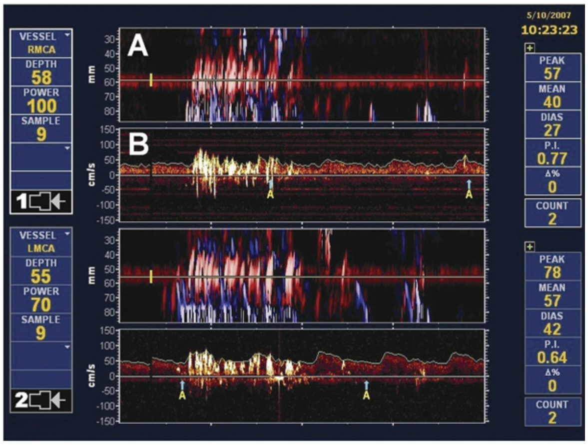

Fig 1. A, Power M-mode Doppler (PMD) screen during transcranial monitoring. **B,** Spectra. Channel 1 indicates vessel label: Right middle cerebral artery (*RMCA*); channel 2, left MCA (*LMCA; white box* on the left side of the screen). *Right side box*: velocity and emboli counting parameters. The microembolic signals recorded on the PMD screen can be tracked as they move through the intracerebral circulation.

Detection of MES. Criteria have been previously described in our study of simultaneous prefilter and postfilter TCD monitoring during carotid artery stenting,[13] based on guidelines of the Ninth International Cerebral Hemodynamic Symposium Consensus Committee.[14] The MES recorded on the power motion mode Doppler screen can be tracked as they move through the intracerebral circulation (Fig 2). An embolus traveling up the MCA would first appear in the proximal portion of the artery on power motion mode Doppler at 60 mm and then travel distally in the MCA at 40 mm. They would not be counted by the automatic embolus detection. Air emboli during contrast injection were also excluded from our analysis, but we were able to visualize and differentiate contrast injection and embolism (Fig 2).

Statistical analysis. Measured values are reported as percentages or means ± standard deviation. The Mann-Whitney *U* test was used for statistical analysis as appropriate, and association of nominal variables was tested by the Fisher exact test.

RESULTS

Isolated degenerative TAAs were present in 17 patients (85%), followed by chronic type B aortic dissection in three (15%) and one Crawford type I thoracoabdominal aortic

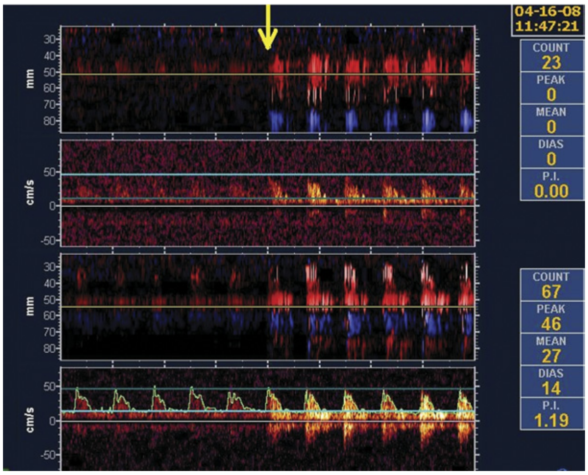

Fig 2. Transcranial Doppler screen: Bilateral middle cerebral artery (MCA) monitoring. Brightness changes at *yellow arrow* indicate contrast media arrival into both MCAs at the same time.

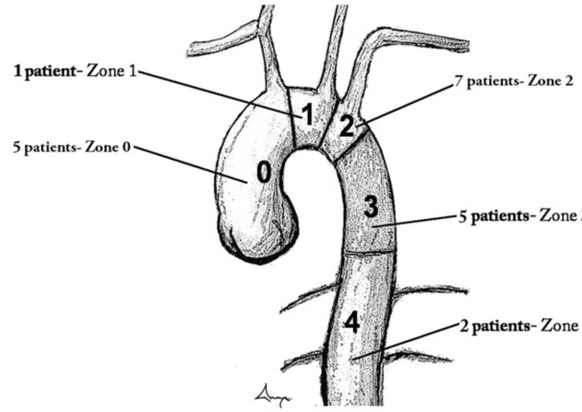

Fig 3. Number of patients per landing zone in this series.

Table I. Monitoring of the vessels among the 20 patients included in this series

Monitoring	*Patients, No.*
Bilateral MCA	15
Left MCA[a]	3
Right MCA	2

MCA, Middle cerebral artery.
[a]With simultaneous left vertebral artery monitoring.

aneurysm (TAAA; 5%). In 10% of patients, arch aneurysms involved the ascending aorta or a descending TAAA involved the visceral vessels. Among patients with TAA, 13 were isolated to descending, and four involved the arch. Arch type 2 was present in six patients, followed by type 3 in five, and type 1 in three.

A hybrid repair with open aortic debranching was required in 11 patients (55%), with five patients (35%) managed through a staged approach. All debranching procedures were limited to the aortic arch, requiring a sternotomy in five patients, a supraclavicular approach in three, and a right anterior minithoracotomy in three. Three women required a conduit secondary to difficult iliac anatomy. Prophylactic spinal drainage was based on operator preference and patient safety (length of covered aorta and coagulopathy) and was used in 50% of patients. The mean operative length was 204 ± 132 minutes.

There was 100% technical success with TCD monitoring during the diagnostic and treatment phases of endograft placement. An average of two devices (range, 1-6 devices) were deployed per patient. The left subclavian artery orifice was covered in 70% of the patients, and 79% of these individuals underwent left common carotid artery–left subclavian artery bypass. This corresponded to proximal fixation at landing zone 0 in five patients, zone 1 in one patient, zone 2 in seven patients, zone 3 in five patients, and zone 4 in two patients (Fig 3).

Intraoperative endoleak occurred in four patients (20%) and was corrected immediately with ballooning or deployment of an additional cuff. Seven (35%) patients required an intraoperative blood transfusion. Intraoperative hypotension occurred in 65% of the patients. One instance of moderate hypotension (<80 mm Hg) lasted 3 minutes, and one instance of severe hypotension (<70 mm Hg) persisted for 15 minutes.

There were no intraoperative deaths, and the 30-day postoperative mortality was 5% (one patient). One late death occurred in a patient who died of cardiac arrest. All remaining patients were alive at a mean follow-up of 24.2 months. Four patients (20%) presented with a postoperative cerebrovascular accident (CVA) or transient ischemic attack (TIA).

TCD findings. Bilateral MCA monitoring was used in 15 patients, left MCA monitoring was used in three, and two of those also had simultaneous left vertebral artery monitoring. In two patients, only the right MCA was monitored (Table I). Although TCD probe placement does not require significant time, bilateral monitoring is difficult to perform during emergencies or in situations where there is a lack of space near the patient's head.

The total number of MES calculated for the DP before TEVAR placement and during TP for all cases combined was 1081 and 1141, respectively. The highest MES counts were generated by the pigtail catheter during the DP and by device deployment during TP. Embolic counts to the right/left sides were the same overall. An average of nine MES were seen right/left in DP, whereas during TP, 45 and 43 MES were seen, respectively, for right and left.

A significantly greater number of MES were counted when the device was deployed at landing zone 1 than in landing zones 2 and 3 or 4. When analyzing the entire TP separately, devices deployed in landing zones 0 to 2 released more MES than those in landing zones 3 or 4. Furthermore, in the TP, landing zones 0 to 2 were associated with more MES than landing zones 3 and 4

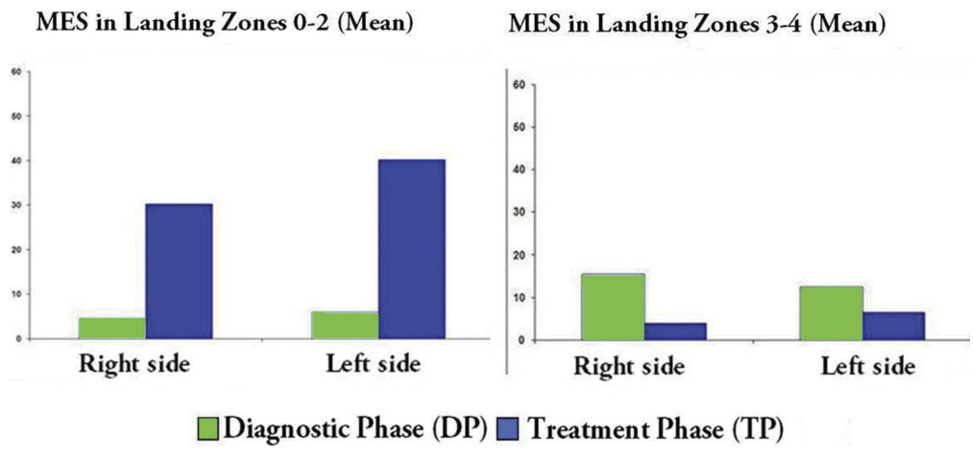

Fig 4. Microembolic signals (*MES*) during the diagnostic phase (*green bars*) and treatment phase (*blue bars*). When the entire treatment phase (*TP*) was analyzed separately, devices deployed in landing zones 0 to 2 released more MES than those in landing zones 3 or 4 ($P = .027$).

Table II. Number of microembolic signals associated with landing zones 0 to 2 during device deployment

Landing zone	*MES, No. (mean ± SD)*
Zone 0	20 ± 4
Zone 1	54 ± 9
Zone 2	12 ± 4

MES, Microembolic signals; *SD,* standard deviation.

($P = .027$; Fig 4). There was no difference in numbers of MES related to arch type. Interestingly, we noted a greater number of MES associated with zone 1 (54 ± 9), followed by zone 0 (20 ± 4) and zone 2 (12 ± 4), particularly during the device deployment (Table II).

When treatment of thoracic aortic pathology required coverage of the left subclavian artery orifice, no more MES were noted than when the left subclavian artery was not covered. Analysis within the subgroup for whom the left subclavian artery was covered by the endograft revealed that increased numbers of MES were observed specifically during the device deployment phase over elements within the DP ($P = .001$). This was not the case when the left subclavian artery was not covered. Debranching the left subclavian artery did not lead to any more MES outside of the differences already observed to be associated with the landing zone.

Although the Tri-Lobe Balloon (W. L. Gore and Associates) offers continuous flow and decreases the "windsock" effect,[15] we observed significant variation in blood flow velocity ($P = .0144$) and pulsatility index ($P = .0001$) through the MCA and during balloon inflations, with significant decrease (below baseline) at deflation ($P < .05$; Fig 5). Significant association was found between the total number of MES and postoperative stroke, TIA ($P = .0055$), and death ($P = .0053$).

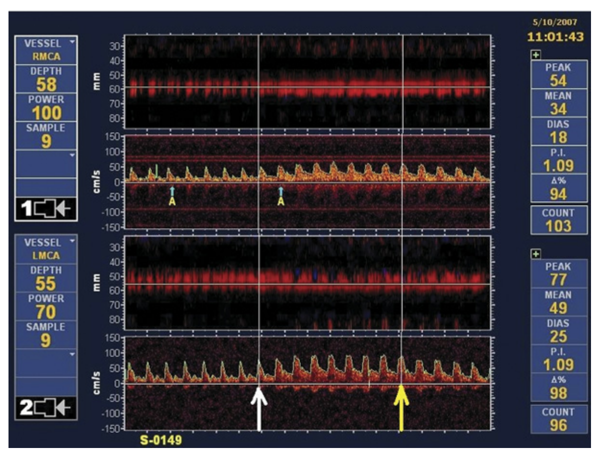

Fig 5. Transcranial Doppler screen: Bilateral middle cerebral artery (*MCA*) monitoring during balloon in/deflation. Nine seconds of inflation/deflation shows waveform and velocity changes on both sides (*white arrow*: inflation starts, *yellow*: deflation starts, balloon was inflated for 6 seconds equals the time frame between the two arrows).

DISCUSSION

This study indicates that cerebral ischemia from intraoperative emboli is a significant and often unrecognized morbidity during aortic repair near the aortic arch. The use of thoracic endoprosthesis to treat a variety of thoracic aortic pathologies has rapidly increased, primarily to its relative ease of application and decreased initial morbidity. Although TEVAR has succeeded in decreasing perioperative morbidity and mortality, stroke rates remain relatively unchanged.

Benefits of TCD. Emboli from the aortic arch and its branches can come in a variety of sizes, from grains visible to the naked eye to debris <60 μm, less than the pore size in current filter devices.[16] TCD allows real-time monitor-

ing of MES during TEVAR and reports ongoing changes in flow velocities in the intracerebral circulation due to the manipulation of the aortic arch and branches. TCD can also provide a functional assessment of contralateral circulations. We observed MES during various phases of diagnosis and treatment. TCD also has the potential to support research initiatives as we try to develop new products, as well as test the embolic potential in current devices. Sauren et al[17] demonstrated the feasibility of the EmBlocker ultrasonic device (Neurosonix Ltd, Or-Yehuda, Israel) to deflect microemboli from the cerebral vasculature using TCD-based quantification of MES.[17]

Risk of CVA during aortic arch manipulation. Feezor et al[18] reported the relative occurrence of perioperative stroke with TEVAR and noted that the incidence of CVA was highest with TAAs (44.4%), followed by penetrating ulcers (33.3%) and then dissections (22.2%). They also reported increased CVA occurrence if the distribution of pathology involved the descending thoracic aorta, particularly zone 2 (35%) and zone 4 (33%).[18]

The prevalence of aneurysmal disease and paucity of dissections and penetrating ulcers in our patient population prevented adequate statistical analysis of MES associated with aortic pathology. The number of MES associated with coverage was higher during device deployment but was not significantly greater than the MES observed when the left subclavian was not covered. We did not find any association of MES with debranching (carotid-subclavian bypass). Peterson et al[19] reviewed the literature on outcomes of TEVAR when comparing coverage of the left subclavian artery vs carotid-subclavian bypass and found eight times more neurologic events associated with subclavian coverage vs bypass (24% vs 3%). This analysis was supported by subsequent studies using the Cook TX2 endograft and the Valiant graft, which both reported increased stroke with placements of the graft in the descending thoracic aorta and without revascularization of the subclavian artery.[20,21] Although our numbers are relatively small, our analysis indicated that landing zones may be a potential predictor of significant MES. Other reports have not demonstrated any significant difference in stroke rate predicated on the landing zone.[22]

Holzer et al[23] attempted to assess the value of TCD in predicting clinical outcome after TIA. They reported that 38.9% of patients with abnormal TCD findings went on to have a new cerebral ischemic event. TCD used to monitor cerebral integrity during single-stage TAAA repair implied the feasibility of TCD-mediated monitoring of cerebral blood flow.[24]

Our data indicate that there is significant variation in the velocity of blood flow through the MCA before, during, or after ballooning the stent graft and support assertions that the Gore TAG and Trilobe Balloon Catheter facilitate the maintenance of cerebral blood flow during device deployment and ballooning. Our focus was on monitoring embolization, but velocity changes during the entire surgery could be studied in the future for hemodynamic correlation with blood pressure management and anesthesia efforts. These findings support the use of TCD to monitor emboli and cerebral blood flow during procedures involving the aortic arch.

Limitations of TCD. TCD is confined by the same limitations associated with other ultrasound-based imaging modalities. It is operator-dependent and sometimes limited by suboptimal bone windows in up to 16% of cases.[25] In the present series, we used one experienced operator for all the cases. Power M mode TCD improved embolus detection by 40% compared with previous single-channel methods.[26] Also, the machine has only two channels; thus, if we were interested in monitoring one of the vertebral arteries, we had to forego the MCA monitoring. Another limitation is that this device is not able to differentiate between air and solid particles.[27]

True significance of microemboli. It is essential to establish a correlation between the number of emboli and microinfarction and stroke. Several studies have specifically addressed this issue, indicating that a general count of 50 MES places a patient at significantly greater risk of clinical stroke.[28,29] There are also reports indicating the cumulative effect of microemboli may be an etiology of cognitive changes in memory and processing as we age. Therefore, the prevention of emboli may pay dividends in the functional status of our quickly aging population that are not immediately apparent, even on postoperative diffusion-weighted imaging. However, as recent studies have supported, microemboli are not the only factor in cognitive impairment. Cerebral protection devices used to significantly reduce MES as monitored by TCD during cardiothoracic surgery, particularly aortic and mitral valve replacements, did not affect rates of cognitive dysfunction.[30,31] It remains to be seen what the long-term sequelae of subclinical embolic events on cognitive function will be. Nevertheless, it seems intuitive that we should do our best during procedures involving the aortic arch, specifically TEVARs, to diminish the number of emboli that escape into the cerebral circulation. Not surprisingly, our findings support focusing on the device deployment phase of endograft placement.

CONCLUSIONS

The ability of TCD to detect cerebral emboli and alterations in blood flow patterns is important to elucidate which steps of TEVAR or other procedures are most likely to provoke hemodynamic changes and embolic events. It also has a potential to compare endografts and their different capacities to generate emboli. We propose that further use of TCD monitoring during TEVAR provides meaningful information about the risk of potential hazardous flow pattern changes and not just the embolization rates. Monitoring of the left vertebral artery specifically might provide more information about the need for left subclavian artery coverage.

AUTHOR CONTRIBUTIONS

Conception and design: JB, ZG, AL, MD
Analysis and interpretation: JB, ZG, MD

Data collection: JB, ZG, JA, JN, EP
Writing the article: JB, ZG, JA
Critical revision of the article: JN, AL, EP, HE, MD
Final approval of the article: MD, AL, JB
Statistical analysis: JB, ZG, JA, MD
Obtained funding: Not applicable
Overall responsibility: JB

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