Cerebral Microemboli During Hip Fracture Fixation: A Prospective Study

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BACKGROUND: Recent studies have shown that cerebral fat microembolism takes place during surgery for hip or knee replacement. In this study, we examined the occurrence of cerebral microembolism, solid or gas, during a standard procedure of hip fracture fixation.

METHODS: This was a prospective study of patients who underwent urgent surgery with a dynamic hip screw for hip fracture fixation. During surgery, patients were monitored with transcranial Doppler for detection of microemboli from right and left middle cerebral arteries.

RESULTS: Twenty-two patients were included in the study; their median age was 82 yr (range, 51–97 yr). In nine (41%) patients, high intensity transient signals were recorded, indicating microemboli passage in the middle cerebral arteries. All nine patients had signals of both solid and gas emboli. One of these nine patients had a postoperative cerebrovascular accident.

CONCLUSIONS: The incidence of cerebral microemboli during urgent surgery for hip fracture fixation is considerable. This phenomenon is not confined to hip or knee replacement surgery. The clinical implications of this finding require further investigation.

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The occurrence of cerebral microembolism has been demonstrated by transcranial Doppler (TCD) during operations for knee or hip replacement in several studies.[1–3] Solid microembolism was attributed to various causes, such as tourniquet usage in total knee replacement, and pressurization of the medullary cavity of the bone in total hip replacement.[4–6] Emboli, which probably contain fat, fibrin and cell debris, thrombi or air, travel in the venous circulation from the leg, pass through the cardiac or pulmonary right to left shunt, enter the systemic circulation, and reach the brain. The clinical significance of this phenomenon is under investigation.[7]

In the current study, we monitored cerebral blood flow for signals of solid or gas microemboli in operations for hip fracture fixation. There is no tourniquet use or bone reaming in these procedures, nevertheless the long bone, the femur, is drilled. Our hypothesis is that the cerebral microembolism phenomenon is more widespread than admitted, and not limited to knee or hip replacement. However, there may be procedures in which embolization risk is higher than others, such as long, extensive surgery, and when bones are operated. TCD signals indicate the immersing of particles, solid as well as gas, into the brain. This event may have clinical consequences, because the brain is highly susceptible to ischemic injury and may contribute to the patient's postoperative early or late neurocognitive deterioration, which is frequent after hip fracture fixation in the elderly.

METHODS

This study was conducted in the operating rooms of Rambam Health Care Campus from February to July 2007. After approval of the local Ethics Committee, we conducted a prospective study of adult patients who underwent urgent surgery in our hospital for fixation of an intertrochanteric hip fracture. Signed informed consent was obtained from each patient who agreed to participate in the study. All the patients underwent surgery within 24 h of arrival at the emergency room. The surgery was dynamic hip screw insertion whose duration is 1–2 h, does not involve bone reaming and does not require tourniquet use. In the operating room reception room, all patients were tested for temporal "acoustic windows" that enable detection of cerebral arteries blood flow using the TCD. Those without appropriate acoustic windows were excluded. Other exclusion criteria were: non-sinus rhythm, known pathology of the carotid artery, known intracranial disease, preoperative diagnosis of dementia or delirium.

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Table 1. Patient Data

Patient	Age (yr)	Gender	Rt MCA		Lt MCA		Time (min)
			Solid	Gas	Solid	Gas	
1	89	M	11	14	3	15	17
2	51	M	14	10	9	3	9
3	74	M	0	0	0	0	
4	97	M	232	174	75	62	6
5	92	M	464	479	228	140	22
6	63	F	9	2	0	0	18
7	73	F	6	4	13	7	13
8	82	F	0	0	0	0	
9	57	M	0	0	0	0	
10	89	F	0	0	0	0	
11	84	F	0	0	0	0	
12	63	M	7	5	3	1	14
13	82	F	0	0	0	0	
14	82	F	0	0	0	0	
15	77	F	0	0	0	0	
16	85	M	0	0	0	0	
17	94	M	0	0	0	0	
18	91	F	10	8	NA	NA	11
19	85	M	0	0	0	0	
20	74	F	0	0	0	0	
21	58	F	NA	NA	4	3	10
22	74	F	0	0	0	0	

M = male; F = female; Rt MCA = right middle cerebral artery; Lt MCA = left middle cerebral artery; NA = the transcranial Doppler (TCD) probe could not detect pulse wave from the middle cerebral artery of that side; Time = the time period between skin incision and first high intensity transient signals (HITS) appearance.

In the operating room, each patient was monitored with noninvasive arterial blood pressure, electrocardiogram and pulse oximeter, and IV access was established. A facemask with oxygen was applied and spinal anesthesia was performed using pencil point needle and 12 mg bupivacaine 0.5% with 0.02 mg fentanyl. After placing the patient on the operating table, the TCD headset was placed to detect signals from the right and left cerebral arteries for about 15 min before the beginning of the surgery (skin incision). This period was the baseline recording data for each patient. Signals were recorded from that time until the application of wound bandage. After surgery, the patient was transferred to the postanesthesia care unit for a few hours and then returned to the orthopedic department. In the orthopedic department, every patient was tested daily for neurological deficits by the department physician, who consulted a specialized neurologist in case of abnormal examination. Both physicians were blinded to the study results. Complications during the patients' stay in the orthopedic department were recorded. After 5–8 days in the ward, if uneventful, the patient was discharged and transferred for rehabilitation to another institution. All the patients received a letter with the study findings for their primary physicians, recommending further investigation with echocardiography in case of TCD signals. Information about the results was not included in the study.

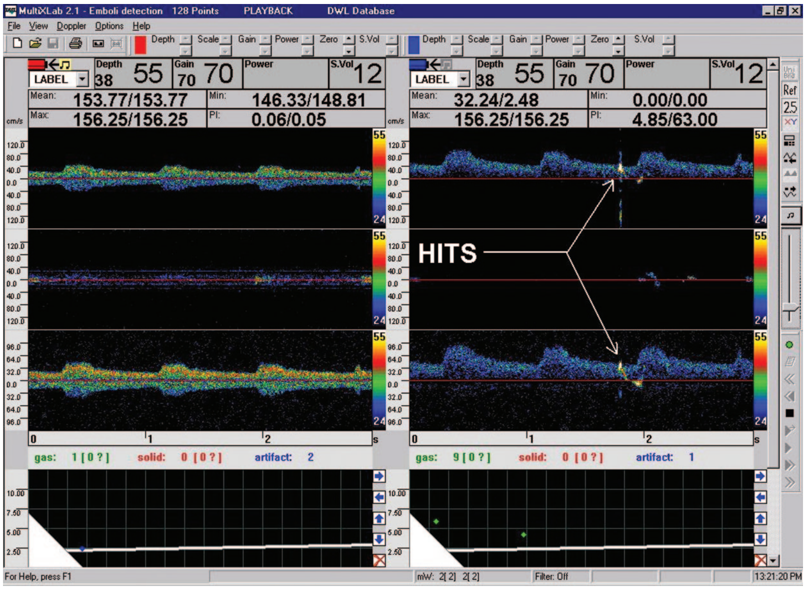
Bilateral middle cerebral arteries were monitored for microemboli using a multifrequency TCD system (Embodop, DWL Compumedics, GmbH, Hamburg, Germany). The current device has dual frequency technology for automatic emboli signal differentiation and artifact rejection online, which has been described previously.[8,9] Dual frequency probes (2.0 and 2.5 MHz) were used simultaneously; insonation depth was set between 45 and 60 mm with a sample volume of 12 mm, the filter setting was 200 Hz, power was 188 mW, and scale was 150/120. The detection threshold for microemboli was a Doppler energy increase of 28 dB·ms or more. The measurement of each patient was recorded on the computer and the high intensity transient signals (HITS) were analyzed and summed. All the measurements were conducted by the same investigator (M.K., a physician trained by the TCD company instructor), who followed the TCD screen during the surgery and verified the results off-line.

RESULTS

During the study period, 40 patients underwent urgent surgery for hip fracture fixation. Nine patients were excluded because of dementia, seven did not have an acoustic window, one was excluded for rapid atrial fibrillation, and one refused to participate in the study. Of the 22 remaining patients, 10 were males and 12 were females, with a median age of 82 yr (range, 51–97 yr).

The intraoperative period was uneventful for all patients, during which the mean arterial blood pressure was within a range of 25% of the patient's baseline, and oxygen saturation was above 90%. HITS in the cerebral circulation were recorded in 9 (41%) of the 22 patients. All nine had signals of both solid and gas emboli (Table 1). The signals typically appeared as

Figure 1. Transcranial Doppler (TCD) screen shows normal pulsation of the right and left middle cerebral arteries. Arrow points at signal (HITS = high intensity transient signal) indicate microemboli passing.



soon as the bone was drilled, yet did not stop after fixation. In two patients, the TCD detected arterial waves from the middle cerebral artery on one side only (Patients 18 and 21, Table 1). The HITS as seen on the TCD screen are shown in Figure 1.

One patient suffered from hemiparesis 4 days after surgery, and the diagnosis of a cerebrovascular accident was confirmed by computerized tomography (Patient 1, Table 1); no other major neurologic complications were recorded.

DISCUSSION

The main results of this study are that 41% of the patients who underwent an urgent operation for hip fracture fixation had detectable cerebral solid and gas microemboli. Several studies have described microemboli detected with TCD during hip and knee replacement surgery.[1–6] Sulek et al.[2] used TCD during total knee arthroplasty in 22 patients and found cerebral emboli in 60%. In their study, cerebral microembolism occurred frequently during tourniquet release. Similar findings were published by Edmonds et al.[5] In 40% of their 20 patients undergoing total hip arthroplasty, embolic signals were detected by TCD, all during impaction of cemented components or after relocation of the hip. In a more recent study, Koch et al.[7] found signals of cerebral microemboli in all the patients undergoing hip or knee replacement surgery. This high rate of cerebral microemboli suggests that better technology may detect events that were not discovered in the past. Moreover, it implies that the transfer of particles from the venous to the systemic circulation is more frequent than heretofore thought. In addition, the TCD-detected HITS measures microemboli arriving at the cerebral circulation, which is about 20% of the cardiac output and probably indicates that a larger number of microemboli were trapped in the pulmonary circulation or in organs other than the brain.

Several explanations were suggested for microembolism during orthopedic surgery. The mechanism of fat microembolism has been primarily linked to pressurization of the medullary cavity during orthopedic procedures.[10] This is distinctly different from the mechanism after tourniquet release, where thromboembolism is responsible.[4] During hip fracture fixation, the medullary cavity is breached, thus enabling fat, and probably air, embolization. The timing of the microemboli found in this study strongly suggests that the pressurization of the medullary cavity is the primary source of microemboli (both solid and gas), because the signals appeared as soon as the bone was drilled. This is consistent with the video microscopic studies reported in an animal model.[11] Our study differs from the earlier clinical studies in several aspects. The first difference is the type of operation. Previously, only surgeries for hip or knee replacement were studied. We chose a standard, routine, orthopedic procedure which is performed without cement impaction, tourniquet use, or bone reaming. According to our findings, cerebral microemboli are not limited to hip or knee replacement, although it is reasonable to believe that cement impaction, use of tourniquet and bone reaming may intensify the incidence of microembolism. Indeed, it has been established that changing the surgical maneuver may reduce the TCD signals of cerebral emboli.[6] Kalairajah et al.[6] showed that, in computer-assisted total knee arthroplasty, which is performed without breeching the intramedullary cavities, there is a significantly lower rate of TCD-detected cerebral emboli than in conventional knee replacement surgery. The commercial advent of devices to reduce reaming should be considered while studying the subject. However, it would be interesting to test other, non-orthopedic procedures for the occurrence of cerebral microemboli, as the orthopedic procedure *per se* may not entirely explain the microemboli phenomenon.

Previously published studies reported solid microembolism, whereas we also detected gas emboli in the cerebral blood flow during surgery. It was believed that fat from bone marrow passes into the bloodstream after bone drilling, and that blood clot, foreign bodies, and cement are released after tourniquet deflation.[2,4] The source of gas microemboli is not yet identified. Air bubbles may enter open blood vessels in the surgical field or originate in the solutions that are transfused IV during the surgery. In addition, there is no consensus about the capability of the current technology, as sophisticated as it is, in differentiating between solid and gas microemboli. Russell and Brucher[8] demonstrated differentiation of gas and solid emboli by multifrequency TCD. Their results were challenged by Markus and Punter[12] and Schoenburg et al.[13] in two similar studies. Both concluded that dual frequency TCD showed ambiguous identification of microembolic signals and insufficient artifact rejection, thus the EmboDop system, in its present form, is not accurate enough for differentiating between solid and gaseous particles. Answering these comments, Russell and Brucher[14] published their explanation for these arguments, focusing on the technical aspects of the current improved TCD. Without discussing technical issues, we admit that our results are reliant on dual frequency TCD validation. Moreover, lipid microemboli that are detected as solid with the TCD are liquid at body temperature. This may further complicate the differentiation subject. From a clinical point of view, however, the end result of microemboli, gas as well as solid, in the brain, is detrimental and should be avoided.

The weakness of our study is that we could not test the clinical effect of the miocroemboli event. Although both hip and knee replacements are elective procedures, surgery for a hip fracture is urgent. The patients in our study arrived at the operating room in the acute stage of fracture, aching, and anxious, and we could not compare preoperative with postoperative neurologic and cognitive status. Koch et al.[7] found no correlation between the number of HITS and cognitive decline; nevertheless, cerebral microemboli could have a potentially deleterious effect on brain functions. Another problem is the possibility that some of the patients in our study, considering their age, had undiagnosed carotid artery disease or other non-surgical causes for these emboli. One may hypothesize that the very large number of emboli which were detected in two patients (Patients 4 and 5, Table 1) may suggest a non-surgical cause for the HITS. Our baseline recording before the beginning of the surgery and the time course of emboli occurrence during surgery could support the theory that attributes the emboli to surgery.

Microemboli from the leg reach cerebral circulation by traversing from venous circulation to the arterial circulation and cause organ ischemia. This is termed paradoxical embolism,[15] and there are few mechanisms by which it may occur. One is passage of emboli through the physiologic shunt (2%–5% of cardiac output); another is passage through cardiac right-to-left shunt. The prevalence of cardiac shunt ranges between 15% and 40% in various studies,[16,17] usually as a result of patent foramen ovale, but may be caused by other cardiac anatomical anomalies. A right-to-left shunt might also be extra-cardiac, for example, an intrapulmonary shunt caused from dilation of pulmonary vessels. In most cases, the existence of such a shunt is unknown to the patient or physician, and the risk of paradoxical embolism is not considered. In this study, we did not have echocardiography results for the patients. Correlation of cardiac shunt with our findings could have provided more insight about microeboli origin and their course.

Neurological or mental decline after anesthesia and surgery has been well known for decades.[18–20] Clinical symptoms range from transient postoperative delirium, confusion or somnolence, to long-term, persistent deterioration of mental qualifications, currently referred to as postoperative cognitive dysfunction, all of which are most prominent in the elderly population.[21] The difficulty of measuring cognitive changes consistently postoperatively and the acknowledged multiple factors which potentially contribute to postoperative neurological changes provide significant challenges. Many factors affect the patient's postoperative neurological and mental status, such as age, low baseline cognition, severe metabolic derangement, hypoxia, hypotension, alcohol abuse, and unfamiliar environment.[22–24] This is attributed generally to the effect of drugs used during and after anesthesia, although the superiority of regional anesthesia over general anesthesia in maintaining neuro-mental capacity has not been established.[25] The incidence of postoperative delirium in older adults after general anesthesia is 5%–15%.[26] However, patients undergoing surgery for hip fractures have a higher rate of postoperative delirium, ranging from 16% to 62%, with an average of 35% across 12 studies of 1823 patients.[27] No single drug or surgical regimen has been proven to be preventive, and the exact pathophysiology remains unclear.[24] We believe that cerebral microembolism is another cause of the patient's neurological deterioration; not only directly by obstructing the blood flow in brain microcirculation, but also indirectly by interrupting pulmonary circulation, thus reducing oxygenation and contributing to brain anoxia, during and mainly after surgery.

Continuing improvement in TCD technology will facilitate better inspection of the intraoperative cerebral microemboli phenomenon. Further research is required to evaluate the clinical importance of this event.

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