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Cerebral Microembolism Diagnosed by Transcranial Doppler during Total Knee Arthroplasty

Correlation with Transesophageal Echocardiography

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Background: **Tourniquet deflation following total knee arthroplasty (TKA) frequently results in release of emboli into the pulmonary circulation. Small emboli may gain access to the systemic circulation *via* a transpulmonary route or through a patent foramen ovale. This study examined the incidence of cerebral microembolism after tourniquet release by transcranial Doppler (TCD) ultrasonography and its correlation with echogenic material detected in the left atrium.**

Methods: **Twenty-two adult patients (9 men, 13 women) undergoing TKA were studied with simultaneous TCD ultrasonography and transesophageal echocardiography. Data were recorded after anesthesia induction and tourniquet inflation and during tourniquet deflation. Emboli counts were performed manually off-line. Echogenic material in the left atrium was qualitatively assessed and correlated with TCD data. Patients were examined postoperatively for focal neurologic deficits.**

Results: **Fifteen patients had unilateral TKA (six left, nine right) and seven had bilateral TKA. Cerebral emboli were detected in 9 of 15 patients (60%) with unilateral TKA and in 4 of 7 patients (57%) with bilateral TKA. Echogenic material was identified in the left atrium in eight patients (two through a patent foramen ovale and six from the pulmonary veins). Emboli counts were significantly higher in patients with bilateral TKA compared with those with unilateral TKA ($P < 0.05$). Duration of tourniquet time in patients with emboli was longer only during bilateral TKA ($P < 0.05$). All patients with echogenic material in the left atrium detected by transesophageal echocardiography had emboli as assessed by TCD ultrasonography. No focal neurologic deficits were identified.**

Conclusions: **Cerebral microembolism occurs frequently during tourniquet release, even in the absence of a patient foramen ovale. This passage most likely occurs through the pulmonary capillaries or the opening of recruitable pulmonary vessels. (Key words: Blood clots; brain; heart; orthopedics.)**

TOTAL knee arthroplasty (TKA) is usually performed under tourniquet-induced ischemia to provide a bloodless field. Embolism to the pulmonary circulation occurs frequently following deflation of tourniquets.[1,2] Most patients tolerate the embolic load without any clinical deterioration; however, some develop clinical manifestations of fat embolism syndrome (FES) with respiratory compromise and central nervous system symptomatology.[3–5] Occasionally during TKA, transatrial passage of emboli through a patent foramen ovale (PFO) can occur, resulting in major neurologic deficit.[6] We have observed that echogenic material occasionally appear in the left atrium during tourniquet release, in the absence of a PFO, and thus may pose a risk of cerebral microembolization. The objective of this study was to monitor for the presence of cerebral embolism following tourniquet release with transcranial Doppler (TCD) ultrasonography and to establish any possible correlation with echogenic material seen in the left atrium.

Material and Methods

We obtained informed consent from 30 adult patients with American Society of Anesthesiologists physical status II or III after approval from an institutional review board. Eight patients were excluded because of either inability to insonate the middle cerebral arteries (n = 4) or contraindications for transesophageal echocardiography (TEE) (difficulty swallowing, n = 3, and/or documented esophageal stricture, n = 1). The remaining 22 patients (9 men and 13 women) were studied. All sub-

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jects underwent general anesthesia with isoflurane, oxygen/air mixture, fentanyl, and vecuronium. Twelve patients had epidural catheters placed prior to anesthetic induction for postoperative analgesia.

After the induction of anesthesia, a 2-MHz pulsed Doppler ultrasound device (Neuroguard, Freemont, CA) with two probes was used to insonate the middle cerebral arteries (MCAs) bilaterally from the posterior temporal window above the zygomatic arch. Simultaneous recordings were made from bilateral MCAs in a continuous fashion. The anterior cerebral arteries and MCAs were identified bilaterally, and depth was adjusted to obtain signals from the proximal MCA. Every effort was made to obtain the best possible acoustic window by adjustment of gain, sample volume, and power of ultrasound. A head strap ensured constant position of the ultrasound probes. Transesophageal echocardiography was performed with an omniplane probe (Hewlett Packard, Andover, MA) and was positioned to monitor both atria with emphasis on the interatrial septum. A contrast echo examination was performed prior to surgical incision to identify a PFO.[7] Ten milliliters of agitated saline was rapidly injected through a free-running peripheral cannula following the release of a 20 cm H_20 end-inspiratory hold. Injection was considered satisfactory if opacification of the right heart chambers and leftward deviation of the atrial septum occurred. The left heart chambers were observed for the passage of echogenic material through the interatrial septum.

The lower extremity tourniquet was inflated to a pressure of 300 mmHg after exsanguination of the leg with an elastic bandage. The femoral component of the prosthesis was placed using a nonvented intramedullary alignment guide, and the tibial components were aligned extramedullarly. Transcranial Doppler spectral flow and TEE images of the four-chamber view were recorded on digitized videotape following induction, after tourniquet inflation, and prior to tourniquet deflation until 10 min after release or disappearance of echogenic signals for at least 1 min. Those patients with bilateral joint disease underwent sequential bilateral TKA with a 15-min interval between deflation of the first tourniquet and deflation of the contralateral tourniquet. Muscle relaxation was reversed, and the patients emerged from anesthesia. A basic neurologic examination including muscle strength, sensation (pinprick, light touch), orientation (person, place, time), and response to complex commands was performed by one of the investigators blinded to the TCD and TEE results. All patients were examined preoperatively and prior to discharge from the post anesthesia care unit.

Statistical Analysis

Emboli counts on TCD ultrasonography were analyzed manually off-line by two independent observers. The number of emboli recorded were a summation of the right and left MCAs for each patient. The criteria for cerebral emboli detection included the following: (1) high amplitude signal $>$ 3 dB higher than background blood flow signal; (2) unidirectional sign; (3) transient signal lasting $<$ 0.3 s; (4) visual appearance on spectral display; and (5) characteristic chirping sound. Echogenic mobile material in the left atrium was assessed qualitatively (present or absent). Demographic data between groups were analyzed with a Student *t* test. The number of emboli during left, right, and bilateral TKA was analyzed with repeated-measures analysis of variance and Student–Newman–Keuls test. The correlation with echogenic material in the left atrium was analyzed with a chi-square test. Blood pressure and end-tidal carbon dioxide values before and after tourniquet deflation were analyzed with one-way analysis of variance. A P value $\leq$ 0.05 was considered significant.

Results

All patients underwent TKA for the first time. Unilateral TKA was performed on 15 patients (six left and nine right), and seven had bilateral TKA. A PFO was identified in two patients. Adequate TEE images of the interatrial septum were obtained in all patients. TCD embolic signals were detected in 9 (60%) of 15 patients after single TKA and four (57%) of seven patients after bilateral TKA. Patients with bilateral TKA were no more likely to have emboli than patients with single TKA ($P = 0.79$); however, the average number of emboli was significantly higher in those with bilateral TKA (right TKA, 31 $\pm$ 23; left TKA, 56 $\pm$ 44 *vs.* bilateral TKA 87 $\pm$ 20) ($P < 0.05$; fig. 1). No significant demographic differences were found in patients with and without emboli (table 1). Intraoperatively, the duration of tourniquet time in patients with emboli was significantly longer only during bilateral TKA (230 $\pm$ 17 min *vs.* 198 $\pm$ 22) ($P < 0.05$; fig. 2). Tourniquet time for bilateral TKA reflected the sum of left and right knee deflations. Following tourniquet release, there was a small but statistically significant decrease in blood pressure and simultaneous increase in end-tidal carbon dioxide in both groups (table 2). Echo-

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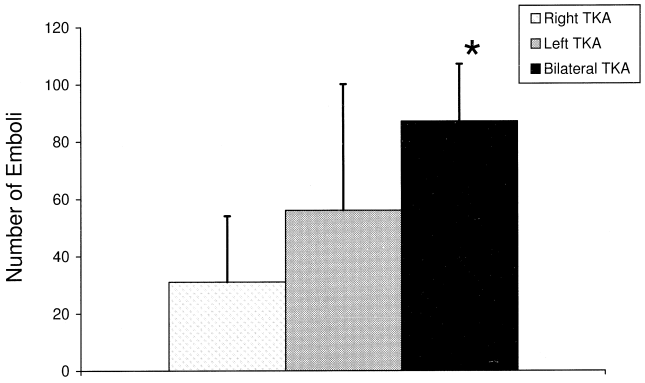

Fig. 1. Cerebral emboli counts (sum of left and right sides) following tourniquet deflation during unilateral and bilateral total knee arthroplasty (TKA). Values expressed as mean ± SD. *$P < 0.05$ compared with right and left unilateral TKA groups.

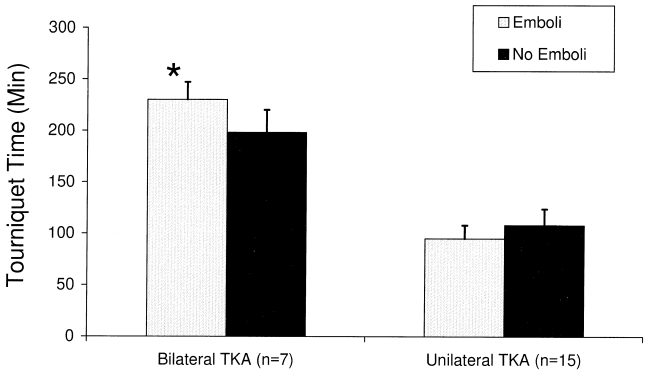

Fig. 2. Association between tourniquet time (in minutes) for the surgical procedure and presence or absence of cerebral emboli detected by transcranial Doppler ultrasonography. Tourniquet times in patients with and without emboli: unilateral total knee arthrplasty (TKA) 95 ± 13 *vs.* 108 ± 16 (not significant); bilateral TKA 230 ± 17 *vs.* 198 ± 22. Values expressed as mean ± SD. *$P < 0.05$ compared with bilateral TKA group without emboli.

genic material was detected by TEE in the left atrium in eight patients. In the two patients with preexisting PFO, transatrial passage of embolic material was demonstrated. In the other six patients, the echogenic material appeared through the pulmonary veins. All patients with TEE evidence of emboli had emboli by TCD. One patient with severe aortic stenosis had congestive heart failure after surgery and remained intubated for 12 h. There was no clinical or laboratory evidence of FES. The patient was diuresed and subsequently extubated without sequelae. All other patients were discharged from the postanesthesia care unit without obvious motor weakness or sensory deficit, and all were oriented to person, place, and time (as tested by physical examination).

Discussion

Embolic material in the venous circulation is noted frequently following TKA.[1,2] The causes include cement, foreign bodies, blood clots, and fat tissue from the bone marrow.[8,9] During tourniquet deflation, the absorption of bone marrow, fat, and surgical debris into the medullary sinusoids results in a sudden embolic load to the lungs. Studies using TEE have demonstrated echogenic material in the right heart chambers in most patients following tourniquet deflation during TKA;[1] however, clinical symptomatology is rare. If fully manifested, embolism from the lower extremities is associated with acute pulmonary hypertension and right-sided heart failure.[10,11] If fat is predominantly involved, the FES develops.[11–13] Pulmonary manifestations vary from mild hypoxemia to florid pulmonary edema.[14] Neurologic abnormalities are present in up to 80% of patients with FES and range from mild disorientation to stupor and coma.[4] Focal lesions can manifest as motor or sensory deficits or ataxia.[4,15] Ozelsel *et al.*[16] recently reported two patients who developed major neurologic dysfunction 2–3 h after uneventful total hip arthroplasty that was attributed to FES. None of our patients developed major neurologic deficits; however, longer follow-up of the patients may have revealed more subtle neurological dysfunction.

Table 1. Demographic Analysis

	Emboli (n = 13)	No Emboli (n = 9)
Age (yr)	62 ± 3	65 ± 4
Gender	8(F), 5(M)	5(F), 4(M)
Hypertension	7	5
Diabetes	3	4
CAD	1	2
Weight (kg)	84 ± 12	88 ± 9

Values are mean ± SD.

CAD = coronary artery disease.

Although mechanical and biochemical pathways can produce pulmonary damage, the neurologic manifestations of FES are more difficult to explain, even if hypoxemia and hypercapnia are taken into account. Paradoxic embolism through a PFO is one possible explanation.[6] During tourniquet release, transient pulmonary hypertension may ensue with increased right heart strain, whereas the sudden opening of a previously nonperfused vascular bed may result in systemic hypotension. The combination of increased right and decreased left heart pressures predisposes to paradoxic embolism. Au-

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Table 2. Blood Pressure and End-tidal CO_2 following Tourniquet Release

	Pre-SBP	Post-SBP	Pre-DBP	Post-DBP	Pre-ET_{CO_2}	Post-ET_{CO_2}
Group 1 (no emboli; n = 9)	136 ± 10	124 ± 9*	74 ± 9	70 ± 7*	35 ± 2	42 ± 3*
Group II (emboli; n = 13)	142 ± 10	132 ± 8*†	86 ± 10†	76 ± 8*	33 ± 2	40 ± 2*

Values are mean ± SD.

SBP = systolic blood pressure (mmHg); DBP = diastolic blood pressure (mmHg); ET_{CO_2} = end-tidal carbon dioxide (mmHg).

* $P < 0.05$ versus prior to tourniquet release.

† $P < 0.05$ among groups.

topsy series performed in adults without congenital heart disease report a 20% incidence of PFO, and its presence in the general population is considered a risk for cerebral embolism.[17–19] Another possibility is the passage of multiple small emboli through the pulmonary microcirculation, particularly in a zone with little or no ventilation (zone III of West). This phenomenon has been reproduced experimentally and has been observed clinically.[20,21] Alternatively, release of free fatty acids from bone marrow triglycerides or by pulmonary lipase may induce platelet aggregates in the systemic circulation and contribute to cerebral microembolism.[5,11]

Clinical manifestations of embolism following TKA are uncommon but do occur.[3,10] Risk factors include (1) nonvented intramedullary rods that "push" marrow contents into the sinusoids; (2) performance of simultaneous bilateral TKA; and (3) arterial tourniquet.[22] The majority of patients undergoing TKA tolerate the changes associated with tourniquet release without any evidence of clinical decompensation. Williams-Russo *et al.*[23,24] evaluated the incidence of postoperative delirium and long-term cognitive dysfunction after TKA. Acute delirium was documented in 41% of patients, and 5% had long-term cognitive dysfunction. There was no difference in neuropsychologic outcome based upon intraoperative anesthetic technique or postoperative analgesic regimen. Factors such as age, concomitant medical illnesses, alcohol use, type of procedure (bilateral *vs.* unilateral TKA), and hospital environment were suggested as etiologic factors. However, the possibility of cerebral microembolism was not considered. The role of cerebral microembolism as a contributing factor to postoperative neuropsychological dysfunction is now widely recognized in patients undergoing open heart surgery.[25,26] The incidence of neuropsychological deficits varies from 30–80%, and the number of microemboli detected correlates with postoperative cognitive dysfunction.[25]

TEE is the most sensitive monitor available to detect embolic material in the heart during orthopedic and trauma surgery.[14,27] TEE remains the intraoperative gold standard for the detection of intracardiac shunts.[28] In our study, cerebral emboli were detected by TCD ultrasonography in 13 patients, whereas only eight patients had echogenic material seen in the left atrium by TEE. In some patients, only part of the left atrium was visualized, because we were interested mostly in monitoring the interatrial septum to detect paradoxical emboli. A small number of patients had transatrial passage of emboli. A traditional four-chamber view or monitoring the left-ventricular outflow tract may increase the sensitivity of systemic emboli detection.

Our study strongly suggests that microembolism to the brain occurs in a significant percentage of patients after tourniquet release following TKA. These emboli most likely occur as a result of transit through recruitable pulmonary vascular beds into the left atrium. In a small group of patients, microembolism is caused by transatrial passage. The clinical impact of cerebral microembolism in this patient population is currently unknown but deserves further investigation.

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