ABSTRACT

BACKGROUND
Diffusion-weighted (DW) imaging abnormalities often develop in patients after invasive procedures associated with cerebral microembolism. Cerebral microembolism has recently been shown during orthopedic surgery. We here examine the effects of intraoperative microembolism on acute magnetic resonance (MR) imaging in patients undergoing hip and knee replacement.

METHODS
We enrolled 24 patients, at least 65 years old, requiring elective knee or hip replacement surgery. MR with DW and axial fluid-attenuated inversion recovery (FLAIR) imaging was performed pre- and postoperatively. All patients were monitored intraoperatively for microemboli.

RESULTS
The mean age of patients was 74 years. All patients had intraoperative microemboli. The mean number of emboli detected was 9.9 ± 18 per surgery. MR imaging was obtained a mean of 3.5 days postoperatively. No DW imaging abnormalities were found after surgery. One patient had new findings on postoperative FLAIR imaging.

CONCLUSION
Intraoperative microembolism occurred universally, but did not lead to acute DW imaging abnormalities following knee and hip replacement. Acute imaging abnormalities on FLAIR imaging are rare but may occasionally occur after joint surgery.
single-shot echo planar imaging [TR / TE 3896 / 135], acquisition matrix 256 × 256, slice thickness of 5 mm with 1.5 mm gap at b values of 0, 500 and 1,000 s/mm². Diffusion gradients were applied in the x, y and z directions. Patient head positioning was standardized using the orbitomeatal line as reference to facilitate study comparison.

A neuroradiologist unaware of study objective and protocol reviewed all images. All DW imaging studies were examined individually for any acute ischemic lesions. Pre- and postoperative FLAIR sequences were compared side by side for any changes in white matter lesions. The reviewer was blinded to the timing of the two FLAIR studies. Individual images did not include a date which may have led to unblinding.

**Intraoperative Monitoring**

All patients were monitored intraoperatively with TCD. Studies were performed with a Nicolet Pioneer TC 4040 using a 2-MHz Doppler probe. Either the right or left middle cerebral artery was insonated unilaterally at a depth of 5-6 cm starting at the time of incision to wound closing. Signals suspicious for microembolism were saved by an experienced technician and reviewed offline. Microembolic signals were defined in accordance with consensus criteria as random, unidirectional, less than 100 ms duration and associated with a chirping sound. A higher intensity threshold of 6 dB was used. The number of microemboli per surgery and the size (intensity over background signal) of all microembolic signals was determined by an investigator blinded to clinical features.

**Surgical Procedure**

Knee and hip replacements were performed according to standard surgical practice. During knee replacement surgery a lower extremity tourniquet was inflated prior to skin incision. Cemented knee prosthesis was routinely used for knee surgeries. Hip replacement was performed uncemented.

**Statistical Analysis**

Data are expressed as mean and standard deviation. Emboli counts of patients with and without a PFO were examined with nonparametric statistics (Mann-Whitney U Test) and differences in emboli sizes were analyzed with independent samples T-test. All P values are two-tailed at .05 level of significance.

**Results**

Mean age of the 24 enrolled patients was 74 ± 6 years and 10 (42%) were men. Baseline characteristics of the study population are depicted in Table 1. Cognitive decline was present in 10/22 (45%) patients at 3 months.

**Intraoperative Monitoring**

All patients had emboli during surgery. The mean duration of monitoring was 91 ± 26 minutes. The average number of emboli per surgery was 9.9 ± 18 (range 1-84). The average size of emboli was 12 ± 5 dB (range 6-51 dB). Patients with a venous-arterial shunt had larger (9.6 ± 1.5 vs. 13.6 ± 6.9, P = .076) and more emboli (4.4 ± 3.5 vs. 15.4 ± 23.7, P = .222) but this was not statistically significant.

**Neuroimaging Data**

Baseline MR imaging showed subcortical lacunar infarction in 3 patients. No patient had acute DW imaging abnormalities prior to surgery. Follow-up MRI was performed a mean of 3.5 ± 1.8 days after surgery. Postoperatively no acute DW imaging changes were detected. Only one patient was noted to have an increase in subcortical white matter lesion on postoperative FLAIR imaging (Fig 1).

**Discussion**

We found intraoperative microembolism in all patients undergoing joint replacement. Despite the high prevalence of microembolism during surgery, acute MR imaging abnormalities are rare but may occasionally be seen after joint replacement.

In neuropathological studies cerebral fat embolism has been referred to as a microembolic state characterized by numerous cerebral microinfarcts. DW imaging in patients with the fat embolism syndrome shows multiple punctuate hyperintensities, consistent with restricted motion of water and cytotoxic edema, confirming a process of diffuse microembolism. MR changes may be transient, but persist in a subset of patients.

It is likely that the emboli detected in the present study are fat microemboli. However, we cannot be certain. During joint replacement surgery aspiration of right atrial blood has largely shown fat globules and transesophageal echocardiography has revealed that large masses consisting of fat traverse a patent foramen ovale. However, some emboli may also include platelet aggregates, bone marrow cells or air microbubbles.

Imaging abnormalities, particularly on DW imaging, frequently develop in patients undergoing invasive procedures which may produce cerebral microembolism. At 3 months 45% of our study population showed cognitive decline. Therefore in a setting of diffuse microembolism and continued cognitive dysfunction we anticipated acute brain MR imaging abnormalities following joint replacement surgery. Detecting

<table>
<thead>
<tr>
<th>Study Population</th>
<th>All patients</th>
<th>Male, n (%)</th>
<th>Hypertension</th>
<th>Diabetes</th>
<th>Knee replacement</th>
<th>Hip replacement</th>
<th>Duration of surgery, min</th>
<th>Number of emboli</th>
<th>Size of emboli, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>74 ± 6</td>
<td>10 (41)</td>
<td>15 (62)</td>
<td>5 (21)</td>
<td>18 (75)</td>
<td>6 (25)</td>
<td>91 ± 25</td>
<td>9.9 ± 18</td>
<td>12 ± 5</td>
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Values are shown as means ± SD or number (%).
ischemic injury of this nature would have allowed greater insight into the etiology of cognitive decline following orthopedic surgery. Our findings do not suggest that ischemia is a likely cause.

To the best of our knowledge this is the first study to examine acute imaging abnormalities in patients undergoing orthopedic surgery. The lack of more frequent imaging abnormalities is surprising given the high frequency of intraoperative embolism. Our study showed a relatively low number of emboli with a mean of 10 emboli per surgery. During cardiac surgery emboli detection rates are often in the hundreds. It is possible that the low embolic burden did not cause imaging abnormalities or was below the resolution of the imaging techniques used. Our imaging protocol used a slice thickness of 5 mm and may have missed smaller-sized lesions.

However, we performed studies on a 1.5 T magnet using sequences most sensitive to cerebral ischemia and edema. Alternatively the effects of microembolism may have been transient and could have resolved by the time of postoperative imaging. Postoperative imaging was completed on average 3.5 days after surgery. In a cat model of intracarotid fat injection brain MR, including DW, abnormalities significantly improved 24 hours and resolved 4 days after injection.20

In summary, intraoperative microembolism occurs with a high incidence during knee and hip surgery. We found no DW imaging abnormalities and only one case of FLAIR changes after joint replacement surgery.

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References


