Background and Purpose—Paresis of the upper extremity after stroke limits the overall function of patients. However, existing therapies do not effectively address this problem. We introduce a new approach using mental imagery training combined with electromyography-triggered electric stimulation (MIT–EMG) to improve paretic upper extremity motor function in patients with chronic stroke.

The intervention consists of mental imagery training with electromyography (EMG)-triggered stimulation to assist in carrying out mental imagery. In practice, the process is achieved using an instrument equipped with EMG. At the time of performing mental activities, electric potentials from the brain arrive at the paretic extremity and are detected by the instrument. When the potentials reach a preset threshold, an electric stimulation induces muscle contraction. During this process, the subject’s mental imagery efforts are reinforced by somatosensory feedback through timed electric stimulation and visual feedback from instrument screen displays.

The aim of this study was to investigate whether MIT–EMG improved paretic extremity motor function. We also tested whether the intervention induced cortical reorganization in patients with chronic stroke through brain 18F-fluorodeoxyglucose positron emission tomography.

Materials and Methods
This study was an open, parallel-group randomized controlled trial with recruitment from a university hospital rehabilitation center. Fourteen subjects were enrolled and allocated to 2 groups by block randomization. For randomization, sealed envelopes containing a
code specifying the group were used. Inclusion and exclusion criteria are in Figure 1.

This study was approved by the local Institutional Review Board, and informed consent was obtained from all subjects.

A Mentamove (Mentamove Deutschland GmbH) was used for MIT-EMG and a Microstim (Medel GmbH) for functional electric stimulation (FES). The same method was used to attach electrodes on the forearm extensor muscles for the 2 different interventions. Both interventions were carried out 2 20-minute sessions a day 5 days a week for 4 weeks, and usual treatment was permitted.

MIT-EMG was in 3 stages: mental imagery (maximum 12 seconds), stimulation (6 seconds), and relaxation (12 seconds). Each stage proceeded according to the working menu indicated on the monitor of the instrument. The mental imagery used in this study was a simple movement (vigorous waving of the entire arm). This imagery was selected because it could be executed easily by subjects.

To define the electric potentials detected by the instrument during MIT-EMG, a diagnostic electromyograph (Medelec Synergy system, Version 11) using surface electrodes (20-mm diameter disk; Hurev) was used. During mental imagery, several small waveforms with amplitudes under 50 μV were observed on the EMG screen. We reasoned that the potentials were due to the end-plate potential, not to the motor unit action potential related to voluntary muscle contraction.

FES consisted of cycles of contraction and rest by preset, automatic electric stimulation. Biphasic pulses with a frequency of 35 Hz and a pulse width of 200 μS were applied for 12 seconds.

The primary outcome measure was the upper extremity component of the Fugl-Meyer Motor Assessment. Secondary measures were the Amount of Use and Quality of Movement of the Motor Activity Log, the modified Ashworth Scale, and the modified Barthel Index. Each measurement was completed before and after intervention by 2 occupational therapists blinded to the intervention.

Positron mission tomography images were obtained from all patients before and after interventions using a Gemini TF16 positron mission tomography scanner (Phillips Healthcare). At 1 hour after an intravenous injection of 185 MBq of 18F-fluorodeoxyglucose, emission scanning was performed for 10 minutes.

**Statistical Analysis**

The Mann–Whitney U test was conducted to compare the 2 groups before the intervention and the changes in scores after the intervention. The Wilcoxon signed-ranks test was used to compare measures before and after the intervention in each group. Data were analyzed using SPSS Version 18.0 for Windows. Results were considered significant at $P<0.05$.

Statistical analysis of positron mission tomography images was performed using statistical parametric mapping software (SPM2; Institute of Neurology, University College London, UK). The lesioned hemisphere side was standardized to the left so that the final output was a set of single hemispheric lesions located in the "left" hemisphere.

**Results**

Completing the intervention were 14 enrolled subjects with baseline characteristics in Figure 1.

No measures showed significant differences between the 2 groups before intervention. The upper extremity component of the Fugl-Meyer Motor Assessment scores increased for the MIT-EMG group after intervention ($P<0.05$). This was caused by a noticeable increase in the upper extremity...
component of the Fugl-Meyer Motor Assessment shoulder and wrist scales. However, this parameter did not show a significant change in the FES group after intervention. The difference in score changes between the 2 groups was significant (Table).

The modified Ashworth Scale improved for the MIT-EMG group after intervention, but it did not for the FES group. The modified Ashworth Scale, Amount of Use and Quality of Movement of the Motor Activity Log, the modified Ashworth Scale, and the modified Barthel Index showed no significant differences in changes in scores between the 2 groups.

SPM analyses showed significantly increased cerebral glucose metabolism after 4 weeks in the supplementary motor (coordinate x, y, z=14, 18, 10; P<0.001), precentral (coordinate x, y, z=52, 2, 10; P<0.001), and postcentral gyri (coordinate x, y, z=18, −52, 78; P=0.001) of the contralateral hemisphere in the MIT-EMG group compared to baseline. Cerebral glucose metabolism in the FES group did not change (Figure 2).

Table. Gains in Outcome Measures After Intervention

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>FES (n=7)</th>
<th>MIT-EMG (n=7)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMM-UE</td>
<td>27 (18–33)</td>
<td>0 (0–3)</td>
<td>29 (22–33)</td>
</tr>
<tr>
<td>AOU</td>
<td>9 (5–18)</td>
<td>1 (0–3)</td>
<td>15 (9–19)</td>
</tr>
<tr>
<td>QOM</td>
<td>10 (7–16)</td>
<td>1 (0–1)</td>
<td>20 (10–22)</td>
</tr>
<tr>
<td>MAS</td>
<td>2 (2–3)</td>
<td>0 (0–1)</td>
<td>3 (2–3)</td>
</tr>
<tr>
<td>MBI</td>
<td>72 (58–89)</td>
<td>0 (0–3)</td>
<td>91 (88–93)</td>
</tr>
</tbody>
</table>

FES indicates functional electrical stimulation; MIT-EMG, mental imagery training combined with electromyography-triggered electrical stimulation; Before, score before intervention; Change, change in score in each group; FMM-UE, upper extremity component of the Fugl-Meyer Motor Assessment; AOU, Amount of Use; QOM, Quality of Movement; MAS, modified Ashworth Scale; MBI, modified Barthel Index.

*P<0.05 of comparison between before and after intervention within each group; P, results compared between groups. All values except P are the median and interquartile range of measures.

Discussion

MIT-EMG showed a greater improvement in motor function of the paretic upper extremity than FES. Also, MIT-EMG increased cerebral glucose metabolism in the supplementary motor, precentral, and postcentral gyri of the contralateral hemisphere, whereas FES showed no significant differences.

MIT-EMG is similar to generalized EMG-triggered electric stimulation in that electric potentials generated by a subject are used as a trigger to induce electric stimulation. However, MIT-EMG uses electric potentials generated by mental imagery without real motion or observable muscle contractions, and EMG-triggered electric stimulation applies signals generated through voluntary muscle contractions.

The advantage of MIT-EMG is that it can be used in patients with early or chronic stroke who have Medical Research Council Grade 1 muscle strength. In comparison, generalized EMG-triggered electric stimulation or constraint-
induced movement therapy are universally applicable in patients with Medical Research Council Grade 2 or greater muscle strength. Thus, these findings suggest that MIT-EMG can be recommended as a tool to improve motor function of paretic extremities in stroke patients before other interventions.

In this study, the improvement of motor function in the paretic upper extremity by MIT-EMG was associated with increased metabolism in the contralesional supplementary motor area, postcentral and precentral gyri, and superior parietal area. These results suggested that MIT-EMG activated the contralesional sensory and motor cortex. That is, intervention improved the paretic extremity motor function, giving rise to activation in areas not activated by movements of the nonparetic extremity such as the contralesional somatosensory motor cortex, superior parietal cortex, premotor area, and supplementary motor area.

In conclusion, MIT-EMG improved motor function of the paretic extremity in patients with chronic stroke and increased metabolism in the contralesional motor–sensory cortex.

Disclosures
None.

References
Cortical Changes After Mental Imagery Training Combined With Electromyography-Triggered Electrical Stimulation in Patients With Chronic Stroke
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