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Brief Report

The prediction of need of using ankle-foot orthoses in stroke patients based on findings of a transcranial magnetic stimulation study

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Ankle-foot orthoses (AFOs) are widely prescribed for stroke rehabilitation. We investigated the potential of transcranial magnetic stimulation (TMS) at an early stage, after stroke, to predict the need of using AFOs in stroke patients. We recruited 35 patients who could walk with intermittent support of one person or independently 3 months after onset of stroke. The patients included in the study were classified into two groups: a TMS (+) group (n = 10), in which motor-evoked potential (MEP) in the affected tibialis anterior (TA) was present, and a TMS (-) group (n = 25), in which the MEP in the affected TA was absent. Three months after the onset of stroke, we investigated whether patients were using AFOs or not. We also checked the motor function of the affected lower extremity using the Medical Research Council (MRC) scale. After 3 months of onset of stroke in the TMS (+) group, 4 patients (40%) were using an AFO during ambulation. In the TMS (-) group, 21 patients (84%) were using an AFO. The probability of using AFOs in the 2 groups were significantly different. Additionally, 3 months after the onset of stroke, the MRC scores of ankle dorsiflexor power, on the affected side, were significantly higher in the TMS (+) group. Early TMS evaluation of the corticospinal tract to the TA appears to be useful for predicting the need of using AFOs in stroke patients during the recovery phase.

Keywords

Transcranial magnetic stimulation; Ankle-foot orthosis; Stroke; Prediction; Motor function

1. Introduction

Stroke is a common disorder which can result in a functional deficit in humans [1–3]. Motor impairment after stroke is one of the most disabling sequelae, which can hinder patients' independent living and decrease their quality of life [2, 4, 5]. Motor impairment, in the lower limb especially, disturbs gait function, and approximately 54% to 80% of patients are reported to have walking problems 3 months after the onset of stroke [6].

Impaired function of muscles around the ankle is a major cause of gait disturbance after stroke, resulting in instability of the ankle during stance phase and reduced clearance during swing phase [7–9]. An ankle-foot orthosis (AFO) can provide medial-lateral stability at the ankle during stance phase, and aid clearance during swing phase by keeping the foot in a neutral plantigrade position [2, 6, 10–14]. Therefore, AFOs are widely prescribed within stroke rehabilitation. It was reported that 39% of stroke inpatients needed an AFO at discharge from rehabilitation [10, 15–18].

However, in clinical practice, the following scenario frequently occurs. In a patient with weakness of ankle dorsiflexors (Medical Research Council [MRC]: grade 1-2), one month after stroke, the clinician prescribes an AFO. However, the dorsiflexors may quickly improve to MRC 4. In this case, further application of an AFO may not be necessary. Accordingly, the prediction of the need of using an AFO would be useful in early stroke rehabilitation.

The corticospinal tract (CST) is one of the most important neural tracts for motor function in the human brain [19–21]. The CST mainly controls the distal musculature; thus, injury of the CST frequently results in weakness of ankle dorsiflexors [19, 22, 23]. Patients in whom the CST innervating the tibialis anterior (TA) muscle is disrupted, show poor outcome for the recovery of the ankle dorsiflexor and need to wear an AFO while walking, whereas patients who have a preserved CST to the TA muscle have a good recovery outcome and do not need to wear an AFO [22, 24]. The recovery of motor weakness in the TA is correlated with the need of using an AFO. Transcranial magnetic stimulation (TMS) is a useful tool for evaluating the state of the CST and predicting the motor outcome in stroke patients [20, 22, 25]. Therefore, by evaluating the status of the CST using TMS, clinicians can predict motor outcome and the need of using an AFO early on. This can allow for appropriate planning of the rehabilitation strategy for stroke patients, leading to a good therapeutic outcome.

In the current study, we evaluated the potential of TMS to reliably predict the need of using AFOs in stroke patients.

2. Methods

2.1 Subjects

Thirty-five consecutive patients (24 males and 11 females; 58.1 ± 8.9 years of age; range was 37-70 years of age) were retrospectively recruited from patients admitted for rehabilitation at the Department of Physical Medicine and Rehabilitation in a university hospital during Jan 2016 to Apr 2019 according to the following criteria: (1) first ever stroke, (2) admitted to the Department of Physical Medicine and Rehabilitation at an early stage (8-30 days) after the onset of stroke, (3) at the time of admission to the Department of Physical Medicine and Rehabilitation, severe weakness of the ankle dorsiflexor of the affected side graded less than 2 on the MRC scale, (4) a scheduled TMS study within 8-30 days of onset, (5) the absence of serious medical complications, such as pneumonia or cardiac problems, during the interval from the stroke onset to the final evaluation, (6) nonuse of medication that could influence the motor-evoked potential (MEP), such as muscle relaxants or anticonvulsants at the time of TMS, (7) at the follow-up evaluation (3 months after onset), gait was possible with intermittent support of one person or independently (functional ambulation category [FAC] $\geq$ 2). We excluded patients with severe cognitive deficit or severe apraxia. The custom hinged AFOs, applied to patients, were constructed from a 4 mm thick polypropylene with a 90° plantar flexion stop, free dorsiflexion, and a full-length foot plate. The calf shells of the AFOs were extended proximally 2.5 cm distal to the fibular head. The AFOs were prescribed by a physician and made by a qualified orthotist. The study was approved by the institutional research board of the university hospital. The requirement for informed consent was waived because this was a retrospective study.

2.2 Clinical evaluation

Three months after the onset of stroke, we investigated whether patients were using the AFOs or not. We also checked the motor function of the affected lower extremity using the MRC scale, and the walking ability using the FAC. The FAC score consists of six categories as follows: 0, non-ambulatory; 1, a need for continuous support from one person; 2, a need for intermittent support from one person; 3, a requirement for verbal supervision only; 4, help required on stairs and uneven surfaces; and 5, able to walk independently anywhere. Its reliability and validity were well established.

2.3 Transcranial magnetic stimulation

A Magstim Novametrix 200 magnetic stimulator with a 9 cm diameter circular coil (Novametrix, Woburn, MA, USA) was used for TMS. Cortical stimulation was performed with the coil held tangentially over the vertex. A cloth marked with 1 cm spacing and Cz referenced to the intersection of the midsagittal and interaural lines was placed on the scalp. Stimulation of the left hemisphere was provided by a counterclockwise current and stimulation of the right hemisphere was provided by a clockwise current. MEPs were obtained from the TA muscle in a relaxed state. The motor threshold was defined as the minimum stimulus required to elicit a MEP with a peak-to-peak amplitude of 50 μV or greater in two out of four attempts. Stimulation intensity was set at the motor threshold plus 20% when the motor threshold was below 80%, or 100% of the simulator output when the motor threshold was more than 80%. Each site at 1-cm intervals was stimulated 4 times with a minimum interval of 10 s. Patients were classified into two groups according to the presence of a MEP in the affected TA (Fig. 1): the TMS (+) group with patients who showed a MEP in the affected TA and the TMS (-) group consisting of patients who did not show a MEP in the affected TA.

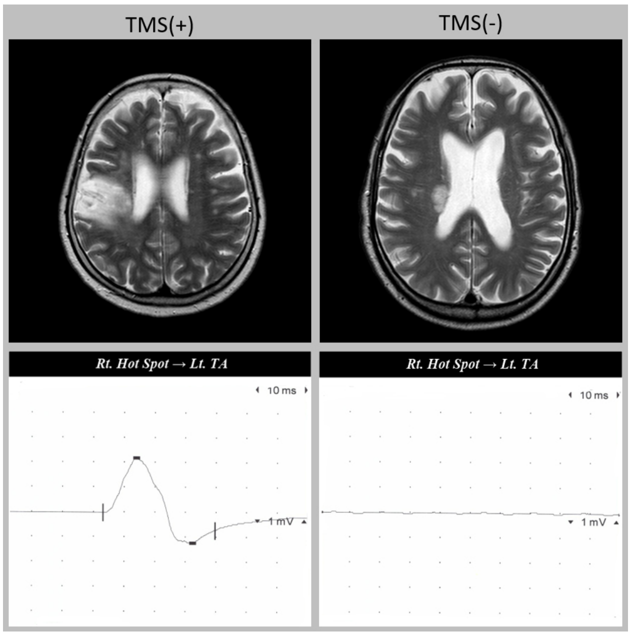

Fig. 1. Classification according to the results of transcranial magnetic stimulation (TMS) study of the corticospinal tract to tibialis anterior (TA). Axial T2-weighted magnetic resonance images (top panel) and the results of the TMS study (bottom panel) are presented. In the TMS (+) group, motor evoked potential (MEP) appeared in the affected TA; in the TMS (-) group, MEP was not evoked in the affected TA.

2.4 Statistical analysis

We used SPSS version 23.0 software (SPSS, Chicago, IL, USA) for statistical analysis. The Fisher's exact was used for evaluating intergroup differences in use of the AFO, stroke type, and sex distribution. The Mann-Whiney test was used to analyze the intergroup differences of age, time from stroke onset to the TMS study, and motor function. Statistical significance was set at $P < 0.05$.

3. Results

The number of patients in the TMS (+) group was 10, and that in the TMS (-) group was 25. The type of stroke, age of the patient, time to TMS evaluation, and MRC and FAC at admission to the Department of Physical Medicine and Re-

Table 1. Demographic data of TMS (+) and TMS (-) group.

	TMS (+) group (n = 10)	TMS (-) group (n = 25)	*P*
Stroke type (infarct: hemorrhage), n	7 : 3	14 : 11	0.704
Sex (male: female), n	6 : 4	18 : 7	0.689
Age, years	57.9 ± 6.0	58.1 ± 9.9	0.706
Time point from stroke onset to the TMS study, in days	13.0 ± 6.1	15.2 ± 7.4	0.339
Motor function at admission to PM & R			
MRC (hip flexor)	1.7 ± 1.1	1.4 ± 1.1	0.439
MRC (knee extensor)	1.4 ± 1.5	1.5 ± 1.4	0.872
MRC (ankle dorsiflexor)	0.5 ± 0.5	0.3 ± 0.6	0.788
FAC	0.3 ± 0.7	0.4 ± 0.9	0.900

FAC, functional ambulation category; MRC, Medical Research Council; PM & R, department of physical medicine and rehabilitation; TMS, transcranial magnetic stimulation.

habilitation were not significantly different between the two groups ($P > 0.05$) (Table 1). At 3 months after the onset of stroke, in the TMS (+) group, 4 patients (40%) out of 10 were using an AFO during ambulation (Table 2). In the TMS (-) group, 21 patients (84%) out of 25 were using an AFO. The rate of using AFOs in the 2 groups were significantly different ($P = 0.016$). Additionally, 3 months after the onset of stroke, the MRC scores of the ankle dorsiflexor of the affected side and the FAC scores were significantly higher in the TMS (+) group ($P < 0.05$).

4. Discussion

In the current study, we evaluated whether a TMS study during the early stage of recovery from stroke can help predict the need of using AFOs.

The most characteristic abnormal walking pattern after stroke is impairment of ankle dorsiflexion or hyper-plantarflexion in the swing phase and the genu recurvatum due to hyperextension of the knee while in the stance phase [6]. These abnormal gait patterns are explained by the loss of optimal muscle control, muscle strength, and a sense of balance [7, 16, 26]. The application of an AFO improves the gait-pattern and gait-stability of stroke patients by inhibiting hyper-plantarflexion in the swing phase and the genu recurvatum in the stance phase [6, 11, 17, 26–28]. An AFO is most frequently prescribed for orthosis in stroke patients [10, 15–17, 27], but sometimes motor recovery during recovery phase eliminates the need for AFOs [15, 29]. Because the preservation of CST is the most important factor that affects motor recovery [23, 24], we tried to assess the ability of a TMS study to predict the need of using AFOs. We evaluated for the presence of MEP in the CST of the affected TA because the functional state of the TA (ankle dorsiflexor) is a decisive factor for the application of AFOs. The presence of MEP indicates that the CST innervating the affected TA is preserved after stroke. In contrast, if MEP is not evoked from the affected TA, it indicates that the CST to the TA is interrupted.

In patients whose CST to the TA is preserved, 40% of them needed to apply an AFO during ambulation at 3 months after stroke onset. However, when CST was interrupted, 84% applied an AFO during ambulation. The ratio of using AFO at 3 months after the onset of stroke was significantly higher in patients with interrupted CST to the TA. The intergroup difference of these ratios seems to result from the recovery of motor weakness of the ankle dorsiflexor. The mean MRC score of the ankle dorsiflexor of patients with preserved CST was 2.7 at 3 months after the onset, whereas that of patients with interrupted CST was 1.3. An MRC score of 1.3 implies that patients cannot perform ankle dorsiflexion against gravity; these patients need an AFO during ambulation to prevent the toe dragging on the ground. In addition, an improvement of medial-lateral stability at the ankle by an AFO helps the patients to walk stably and gait pattern to be normalized.

Considering the results that 40% of patients with preserved CST used an AFO and 16% of patients with interrupted CST did not use an AFO at the 3-month follow-up, we believe that it would be difficult for clinicians to clearly decide to apply AFOs to patients with severe weakness of the ankle dorsiflexor based on the findings of MEP. However, when MEP on the affected TA is present at an early stage after the onset of stroke, clinicians can delay the decision of application of AFOs while observing the motor recovery even if the weakness of the ankle dorsiflexor is severe. In addition, when clinicians apply AFOs to the stroke patients, the patients would be able to provide detailed information about the possibility of throwing away the AFO at a later stage.

In addition, we observed that the motor function of hip flexor, knee extensor, and ankle dorsiflexor muscles was additionally improved when MEP to the affected TA was present. This result corresponded to the results of several previous studies. Chang *et al.* [30] assessed the presence of MEP to the affected TA in 14 stroke patients within 7-28 days of onset. The motor function of lower limb at 6 months after onset was better in patients with preserved MEP, compared to patients with interrupted MEP. Thus, TMS evaluation at an early stage is useful for predicting recovery of motor function of lower limb in stroke patients.

Table 2. Clinical data 3 months after the onset of stroke.

	TMS (+) group (n = 10)	TMS (-) group (n = 25)	*P*
Use of AFO, n (%)	4 (40%)	21 (84%)	**0.016**
Motor function			
MRC (hip flexor)	3.1 ± 0.7	2.9 ± 0.9	0.512
MRC (knee extensor)	3.2 ± 0.6	3.0 ± 1.0	0.723
MRC (ankle dorsiflexor)	2.7 ± 1.3	1.3 ± 1.2	**0.005**
FAC	3.2 ± 0.6	2.6 ± 0.9	**0.047**

AFO, ankle-foot orthosis; FAC, functional ambulation category; MRC, Medical Research Council; TMS, transcranial magnetic stimulation; Bold values denote statistical significance at the $P < 0.05$ level.

Regarding the prediction of necessity of using AFO, in 2001, Teasell *et al.* [31] investigated factors associated with AFO use in 423 stroke patients. They found that patients with lower upper and lower limb functions at admission were more likely to need an AFO at discharge.

Our study has some limitations. First, this study was conducted retrospectively. Second, the number of recruited patients was relatively small. Third, AFOs may affect the lower limb in various ways; however, this study has primarily considered AFOs role in compensation for ankle dorsiflexion weakness only. Further studies complementing these limitations should be conducted in the future.

5. Conclusions

We suggest that a TMS study is beneficial for deciding whether clinicians apply AFOs to stroke patients during the recovery phase or not, which could optimize outcomes and make the most efficient use of resources. In addition, this study adds to the literature on motor recovery which will inform clinical practice and future research in this area.

Abbreviations

AFO, Ankle-foot orthosis; CST, corticospinal tract; FAC, functional ambulation category; MEP, motor-evoked potential; MRC, Medical Research Council; TA, tibialis anterior; TMS, transcranial magnetic stimulation.

Author contributions

Y.J.C., J.K. and M.C.C. conceived and designed the experiments; Y.J.C. and M.C.C. performed the experiments; Y.J.C. and M.C.C. analyzed the data; Y.J.C., J.K. and M.C.C. wrote the paper.

Ethics approval and consent to participate

This research was retrospectively conducted without randomization or blinding, and approved by the institutional review board of Yeungnam University Hospital (YUMC 2019-10-046).

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Conflict of interest

The authors declare no conflict of interest.

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