Enhancement of walking ability using a custom-made hinged knee brace in patients who experienced ambient stroke and are in the acute phase

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Abstract. [Purpose] In this study, we investigated the immediate effect on walking using a custom-made hinged knee brace with adjustable knee flexion and extension support (support brace) in patients in the acute phase of stroke. [Participants and Methods] Thirteen patients (56.8 ± 6.8 years) who experienced stroke and who were able to walk independently participated in the study. The walking speed and mean knee extension strength were evaluated under three conditions: no brace, general brace, and support brace. [Results] The walking speed of patients while using the support brace was significantly faster (0.60 ± 0.11 m/s) than that without brace (0.45 ± 0.16 m/s) and with general brace (0.52 ± 0.14 m/s). The fastest walking speed among all 8 patterns (no brace, general brace, and the support brace with six different patterns of support) was with the support brace. The mean knee extension strength while wearing a support brace (1.01 ± 0.24 Nm/kg) was significantly greater than that without wearing a brace (0.82 ± 0.28 Nm/kg). [Conclusion] The support brace, which allows for customizable adjustment of the flexion and extension strength, enhanced the walking ability of patients who experienced ambient stroke and were in the acute phase.

Key words: Custom-made hinged knee brace, Gait, Stroke

INTRODUCTION

In the acute phase of stroke, walking speed decreases because of abnormal movement patterns, such as knee instability in the stance phase and inadequate knee mobility in the swing phase1, 2). Custom-made ankle-foot orthoses (AFOs)3) and articulated AFOs4) are useful for improving knee instability in the stance phase and knee mobility in the swing phase5). These previously reported orthoses, however, cannot be adjusted according to the individual patient’s abilities during the stance and swing phases.

Ota et al. reported a custom-made hinged knee brace with adjustable knee flexion strength for patients with knee osteoarthritis that, compared with the hinged knee brace, allows for a greater knee flexion angle during the swing phase6). Findings from that study revealed that knee joint motion during the swing phase is improved by the orthosis, suggesting its potential usefulness for patients with stroke. The support brace was originally designed for knee osteoarthritis and not applied to patients with stroke. The support brace not only has adjustable knee flexion strength during the swing phase, but also adjustable extension strength during the stance phase that can be individualized for each stroke patient.

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The purpose of the present study was to investigate the immediate effects of the support brace on walking ability of ambient stroke patients in the acute phase.

PARTICIPANTS AND METHODS

Participants were enrolled patients able to walk at least 50 m and whose leg function was in Brunnstrom recovery stage IV to VI on admission due to acute phase of stroke (cerebral infarction and cerebral hemorrhage) at Toyohashi Municipal Hospital from April, 2013 to March, 2015. Brunnstrom Recovery Stage can be transformed into an interval-level measure that could be useful for quantifying the extent of post-stroke motor function, changes in motor function, and differences in motor functions in patients with stroke7). Exclusion criteria were inability to obey orders because of dementia or decreased conscious level and modified Rankin Scale grade 4 to 5 (inability to walk independently) before admission. Thirteen patients (8 males, 5 females; 56.8 ± 6.8 years of age, height: 161.0 ± 11.2 cm, body weight: 64.8 ± 11.6 kg) participated in the study. The mean time interval between stroke onset and the experiment day was 12.2 days. This study was approved by the ethics committee of Toyohashi Municipal Hospital (No. 108), and all patients provided written informed consent.

The support brace was constructed from a general hinged knee brace (Japan Sigmax Co., Ltd., Tokyo, Japan) with metal struts on the medial and lateral sides of the knee and additional rubber tubing (Fig. 1). The rubber tubes crossing at the tibial tuberosity supports knee extension, and the rubber tubes running parallel on the lateral sides of the lower extremity support knee flexion. The tension generated by extending the rubber tubes from their length at rest to the upper and lower hooks (21 cm) was either 1 kgf, 2 kgf, or 3 kgf. All three types of tubes were used for flexion support, and only the 1 and 2 kgf tubes were used for extension support because the 3 kgf tube could not be fixed at the tibial tuberosity. The knee flexion and extension moment in each of the support tube strength combinations at 0, 15, 30, 45 degrees was determined using a spring scale and details were provided in Table 1.

First, walking times were measured when patients walked between parallel bars (2.2 m) in one direction under eight conditions (without brace, with the general brace, and with the support brace with each of six different tube combinations). Measurements were first obtained twice in the no brace condition, and then twice for each of the remaining seven conditions, the order of which was randomly selected. The faster walking speed from the two trials of each condition was determined; the support brace configuration in which the walking speed was the fastest was selected as the optimal configuration; and the tube combination associated with the fastest walking time for each individual was selected.

Second, knee extension strength of isometric contraction was measured three times using a handheld dynamometer (Japan Medix Co., Ltd., Tokyo, Japan) with patients in the sitting position and with the knee flexed 90° in each of three conditions (no brace, general brace, and optimal support brace tube configuration). The mean knee extension strength, normalized by multiplying the length of lower thigh divided by body weight (Nm/kg), was measured in each condition.

Data are presented as the mean and standard deviation (SD). The Shapiro-Wilk test was used to confirm that the data were normally distributed. The walking speed and the mean knee extension strength (no brace, general brace, and optimal support combination) were analyzed using a one-way ANOVA for the three conditions. Because all of the data were normally distributed, paired t-tests with Bonferroni’s correction for multiple comparisons were used to compare the differences among the three conditions. The level of significance was set to p-value less than 0.05. Data were analyzed using SPSS, version 22.0 (IBM Inc., Tokyo, Japan).

![Fig. 1. The lateral view of the support brace is shown. The support brace was constructed from a general hinged knee brace (Japan Sigmax Co., Ltd., Tokyo, Japan) with metal struts on the medial and lateral sides of the knee and additional rubber tubing. Tubes cross at the tibial tuberosity at the top, and run parallel down the lateral side of the lower leg. The crossed tubes support knee extension, and the parallel tubes support knee flexion.](image)

Table 1. Moment (Nm) of each support brace’s tube strength combination (rubber tube force: flexion/extension)

| Brace’s angle (°) | F1/E1 | F1/E2 | F2/E1 | F2/E2 | F3/E1 | F3/E2 |
|------------------|-------|-------|-------|-------|-------|-------|
| 0°               | 1.29  | 1.94  | 0.00  | 1.62  | −0.60 | 0.00  |
| 15°              | 1.94  | 2.48  | 1.08  | 2.16  | 0.00  | 1.62  |
| 30°              | 2.37  | 3.13  | 1.29  | 2.70  | 0.00  | 2.16  |
| 45°              | 2.91  | 3.67  | 1.83  | 2.91  | 1.29  | 2.48  |

Positive value indicates knee extension moment.
F1/E1: Flexion 1 kgf/Extension 1 kgf.
RESULTS

The tubing support combination that provided the fastest walking speed, however, varied among patients (flexion: F/ex-
tension: E; kgf) as follows: 2 patients, 3F/2E; 4 patients, 3F/1E; 3 patients, 2F/2E; 4 patients, 1E/2F. All the patients exhibited
their fastest walk while wearing the support brace. The walking speed under the conditions of the optimal support brace tube
configuration (0.60 ± 0.11 m/s) was significantly faster compared to no brace (0.45 ± 0.16 m/s; p<0.01) and compared to the
general brace (0.52 ± 0.14 m/s; p<0.01, Table 2). The walking speed while wearing the general brace (0.52 ± 0.14 m/s) was
significantly greater than that while not wearing a brace (0.45 ± 0.16 m/s; p<0.01). The mean knee extension strength under
the condition of the optimal support brace tube configuration (1.01 ± 0.24 Nm/kg) was significantly greater compared with
that when no brace was worn (0.82 ± 0.28 Nm/kg; p<0.01), but not compared with the general brace (0.93 ± 0.28 Nm/kg).
The mean knee extension strength while wearing the general brace (0.93 ± 0.28 Nm/kg) was significantly greater than that
while not wearing a brace (0.82 ± 0.28 Nm/kg; p<0.01).

DISCUSSION

The findings of the present study revealed that wearing the support brace under the conditions of the optimal support brace
tube configuration enhanced walking ability of ambient stroke patients in the acute phase compared with no brace and with
the general brace. Furthermore, the mean knee extension strength of the optimal support brace configuration was significantly
larger than those obtained while not wearing a brace.

During the acute phase of stroke, muscle weakness on the affected side results in decreased walking speed due to a lack
of knee joint motion in the swing phase and impaired knee joint stability in the stance phase1, 2). Therefore, patients in the
acute phase of stroke need sufficient muscle power not only for the swing phase but also for the stance phase, which may be
supplied by orthoses designed to support knee function.

In the present study, the tubing crossing at the tibial tuberosity might help the patient to regain co-contraction of the
quadriceps and hamstrings, thereby reducing instability during the stance phase (particularly in the loading response) on the
affected side, and the compression supplied by the brace may enhance proprioception8 by supplying more sensory input9).
These actions may improve not only the knee extension strength, but also walking speed, as some reports suggest strong
associations between the isometric knee extension strength of the affected side and walking speed in stroke patients10, 11). The
walking condition is not directly associated with muscle strength, however, because the knee tube strength depends on the
knee flexion angle. During the swing phase, parallel tubes that support flexion strength might help smooth knee joint motion.

On the other hand, a feature of the support brace is that six combinations of tubes with different strengths can be used, and
thus the tube combinations can be adjusted for each individual patient’s particular disability. In this study, the fastest walking
speed was obtained with the use of the support brace compared with the general brace or no brace conditions. It is not clear
which of the tubing combinations is optimal because it varied among patients, and the number of patients in this study was
relatively small. This finding suggests the importance of adjusting the brace for each individual patient’s ability. Moreover,
the support brace is easy to put on and take off because it comprises only a general hinged knee brace and rubber tubes.
Additionally, because it does not prevent wearing an AFO, both the support brace and an AFO can be used at the same time.
Therefore, the support brace is easy to use by patients in the acute phase of stroke.

The present study has some limitations. First, six characteristics of the support brace could not be evaluated under general
walking conditions, because obtaining the measurements for eight combinations (total=16 times) was too exhausting for

Table 2. Maximum walking speed (m/s) for each condition (rubber tube force: flexion/extension)

| Participant | No brace | General brace | Support brace | Selected combination |
|-------------|----------|---------------|---------------|----------------------|
| 1           | 0.34     | 0.44          | 0.60          | F3/E1                |
| 2           | 0.14     | 0.31          | 0.39          | F1/E2                |
| 3           | 0.66     | 0.71          | 0.75          | F3/E1                |
| 4           | 0.72     | 0.84          | 0.85          | F3/E1                |
| 5           | 0.35     | 0.47          | 0.55          | F2/E2                |
| 6           | 0.38     | 0.42          | 0.50          | F2/E2                |
| 7           | 0.42     | 0.37          | 0.51          | F1/E2                |
| 8           | 0.55     | 0.49          | 0.56          | F3/E1                |
| 9           | 0.43     | 0.61          | 0.70          | F1/E2                |
| 10          | 0.38     | 0.47          | 0.61          | F1/E2                |
| 11          | 0.63     | 0.60          | 0.63          | F3/E2                |
| 12          | 0.48     | 0.50          | 0.55          | F2/E2                |
| 13          | 0.32     | 0.60          | 0.61          | F3/E2                |

Average ± SD 0.45 ± 0.16 0.52* ± 0.14 0.60* † ± 0.11

*p<0.01, vs. no brace; †p<0.01 vs. general brace.
F1/1:E Flexion 1 kgf/Extension 1 kgf.
patients in the acute phase of stroke and was thus measured with the patients walking one way between parallel bars. Second, because the sample numbers for each of the optimal tube combinations were small, each optimal combination’s effect cannot be discussed in detail. Third, evaluation of the effects of an AFO could not be performed because none of the participants in the present study required an AFO for walking.

In conclusion, the support brace, in which flexion and extension strength can be adjusted according to each individual, enhanced walking ability of ambulant stroke patients in the acute phase.

Funding and Conflict of interest

There is no conflict of interest.

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