Research Report

The Effect of Casting Combined With Stretching on Passive Ankle Dorsiflexion in Adults With Traumatic Head Injuries

Background and Purpose. Ankle plantar-flexion contractures are a common problem following traumatic head injury. Although serial casting is used to correct and prevent ankle plantar-flexion contractures, treatment efficacy has not been evaluated using an experimental design. The aim of this research was to establish the effect of a regimen of casting combined with stretching on passive ankle dorsiflexion motion. **Subjects.** Nine people who had sustained traumatic closed head injuries and had limited dorsiflexion motion participated in the study. **Methods.** A crossover design was used in the study. Subjects were assigned to both experimental and control groups. Torque-controlled measurements of passive ankle dorsiflexion motion were obtained for all subjects before and after 1 week of casting combined with stretching, as well as before and after a 1-week control period. The order of the experimental and control conditions was randomized. **Results.** Passive ankle dorsiflexion increased by a mean of 13.5 degrees (SD=9.3) during the experimental condition, as compared with a mean decrease of 1.9 degrees (SD=10.2) during the control condition. The difference between the experimental and control conditions was statistically significant. **Conclusion and Discussion.** These findings suggest that casting combined with stretching is an effective method of correcting ankle plantar-flexion contractures in patients with traumatic head injuries. [Moseley AM. The effect of casting combined with stretching on passive ankle dorsiflexion in adults with traumatic head injuries. *Phys Ther.* 1997;77:240–247.]

Key Words: *Ankle, Contracture, Head injuries, Physical therapy, Rehabilitation.*

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Plantar-flexion contractures are a common problem following traumatic head injury (THI). The prevalence of restricted passive ankle dorsiflexion in persons with THI admitted for rehabilitation has been reported to be as high as 76%.[1] Plantar-flexion contractures develop in response to the altered mechanical environment imposed on soft tissues when physical activity changes following THI. In experimental animals, morphological adaptations that accompany immobilization of muscle in a shortened position include a decrease in muscle,[2–4] tendon,[5] or muscle-tendon[6] length; a decrease in the number of sarcomeres in series[2–4]; an increase in the proportion of connective tissue to muscle fiber within the muscle[3,7]; and alterations in the orientation of intramuscular connective tissue.[7] Immobilization also causes a decrease in extensibility of periarticular connective tissue.[8] Similar adaptations are probably the cause of contractures in the population with THI.

Plantar-flexion contractures can be quantified by measuring ankle angle while known torques are applied to passively dorsiflex the ankle. Two types of measurement systems have been used to quantify contractures. The more sophisticated system uses a footplate instrumented with a load cell and a potentiometer.[9] Torque and angle measurements are collected simultaneously as the ankle is passively dorsiflexed through its whole range. The simpler system, which may be more suitable for clinical practice, records the ankle angle (with photography or a goniometer) obtained from the application of a single known torque (which can be quantified using a dynamometer or a spring balance).[10] A passive torque versus angular displacement curve is produced with the sophisticated system, whereas only one point from that curve is recorded with the simpler system. The leg muscles must not be actively generating force (ie, by voluntary contraction or reflex activity) during the measurement procedure. To achieve this absence of muscle activity, subjects are instructed to relax their muscles while the ankle is slowly and passively dorsiflexed. The absence of muscle activity can be confirmed using electromyography.[9]

Plantar-flexion contractures can interfere with the performance of functional tasks by increasing the plantarflexor moment when the ankle is in dorsiflexed positions. This increased plantar-flexor moment can cause a range of changes in the gait pattern of people with THI, including decreased peak hip extension in late stance phase, knee hyperextension during the stance phase, and decreased ankle dorsiflexion during the swing phase.[11,12] The contribution of the soft tissues that passively limit dorsiflexion to the muscle moment developed about the ankle during the stance phase of walking has been quantified in a small number of subjects. In a patient with a "mild" ankle plantar-flexion contracture following a cerebrovascular accident[13] and in a group of children with cerebral palsy who toe-walked,[14] passive moments contributed up to 43% of the internal moment about the ankle during the stance phase. In comparison, the contribution of the passive moment to the total internal moment was less than 14.4% in subjects without known neurological impairment.[13,14]

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This study was approved by the Lidcombe Hospital Ethics Committee.

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Table 1.
Subject Characteristics (N=9)

	$\bar{X}$	Range	SD
Age (y)	29.1	16–50	11.0
Time postinjury (d)	72.2	29–106	27.1
Duration of LOC[a] (d)	19.6	12–42	12.6

[a] Values for duration of loss of consciousness (LOC) are based on data from 5 subjects only, as duration of LOC was unknown for 2 subjects and 2 subjects were unconscious at the time of casting.

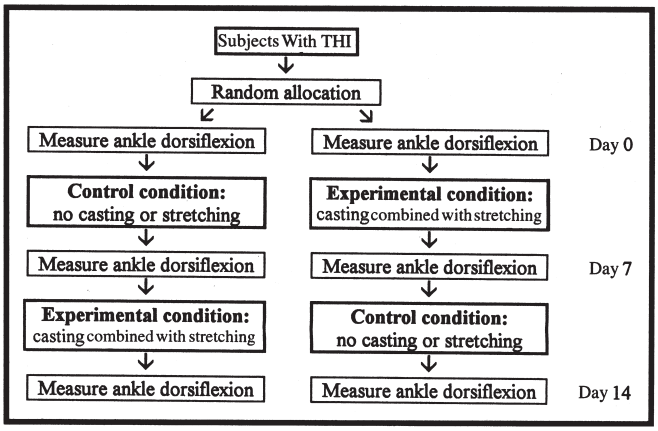

Figure 1.
Study design. A crossover design in which each subject underwent both the control and experimental conditions (in random order) was used. THI=traumatic head injury.

Serial casting has been used to prevent or correct plantar-flexion contractures in adults with THI undergoing medical care during the acute phase of their injury[15–17] and during rehabilitation.[18–23] Below-knee casts can be used to immobilize the soft tissues that passively limit dorsiflexion in the lengthened position or to apply a prolonged stretch. The gastrocnemius muscle can be further stretched by positioning the knee in extension.[24] Casts are usually applied serially, with the ankle placed in slightly more dorsiflexion with each cast. In animals, immobilization of muscle in a lengthened position is associated with an increase in the number of sarcomeres in series and an increase in muscle length.[2] It is likely that similar adaptations occur with serial casting in humans.

Serial casting has been reported to increase passive ankle dorsiflexion movement in subjects with THI who have plantar-flexion contractures.[15–19,22] For example, passive ankle dorsiflexion increased by an average of 10.4 degrees with a below-knee cast applied for a period of 7 days[22] and by an average of 20 degrees with a series of five casts applied over a period of 1 month.[15,17] Unfortunately, there have been no randomized trials investigating the effectiveness of serial casting. Most published studies have used nonexperimental designs in which precasting and postcasting measurements were compared[15,18,19,22] or in which historical controls were used.[17] These designs do not, in general, provide control of confounding factors, such as the effects of natural recovery or concurrent treatment.[25] Randomized trials provide the most rigorous way of differentiating effects due to casting from those attributable to other factors.

The aim of this study was to evaluate the effect of a regimen of casting and stretching on passive ankle dorsiflexion movement in a group of subjects with THI who had plantar-flexion contractures.

Method and Materials

Subjects

Ten people who had sustained THI and were admitted to the Brain Injury Rehabilitation Unit of Liverpool Health Service (Liverpool, New South Wales, Australia) for inpatient rehabilitation participated in the study. Subjects were selected using the following criteria: (1) presence of restricted passive ankle dorsiflexion (either unilateral or bilateral) that prevented the heel(s) from touching the ground when standing with the hips extended, (2) no evidence of generally accepted contraindications to casting (including marked edema, open sores, skin grafting, or vascular disorders), and (3) ability to lie prone for plaster application. Written informed consent was obtained from the subjects or their legal guardian. One subject withdrew due to discomfort experienced while the cast was in place and has been excluded from all subsequent analysis. The results of the 9 subjects who completed the entire experimental procedure are described.

One female subject and 8 male subjects completed the trial. Road traffic accidents were the cause of injuries for eight subjects, and a fall from a cliff was the cause of the injury for the remaining subject. Six subjects had casts applied bilaterally. Subject age, duration of loss of consciousness (LOC), and delay before casting are detailed in Table 1. The duration of LOC was unknown for two subjects, and two subjects were unconscious at the time of casting. These subjects' data were excluded from the LOC data in Table 1.

The majority of subjects were unable to stand up or walk at the time of casting. The distribution of scores for the standing-up and walking items of the Motor Assessment Scale (MAS)[26] illustrates the severe degree of disability. All subjects scored "0" for the walking item of the MAS (ie, they were unable to step forward with their unaffected lower extremity). Seven subjects scored "0" (ie, required the assistance of more than one person to stand up) and two subjects scored "1" (ie, achieved standing with help from therapist) for the standing-up item of the MAS.

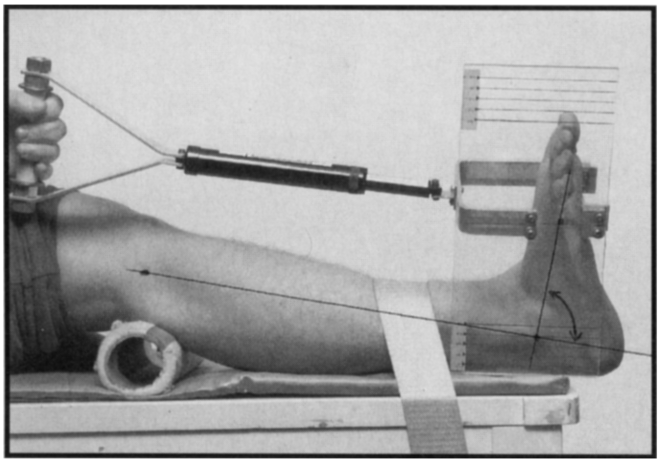

Figure 2.
The torque-controlled measurement procedure. A known torque is applied to produce passive ankle dorsiflexion in a standardized testing position. Ankle angle is measured using skin surface markers and photography. The angle measured from the photograph is indicated by arrows.

Procedure and Data Analysis

A crossover design in which each subject underwent both experimental and control conditions was used (Fig. 1). Subjects wore a below-knee cast and stretched for 7 days in the experimental condition, whereas subjects were not casted and did not stretch in the control condition. The experimental and control conditions occurred in random order. Passive ankle dorsiflexion motion was measured on days 0, 7, and 14, that is, at the commencement, crossover, and conclusion of the study. Measurements were taken after the casts were removed at the end of the experimental condition. For the six subjects who had casts applied bilaterally, the average dorsiflexion angle of both ankles was used so that the assumption of independence of data points would not be violated.

A torque-controlled measurement procedure was developed (Fig. 2), and its reliability was tested prior to the study.[10] Long-lasting dye was used to mark the skin overlying the head of the fifth metatarsal, the lateral malleolus, and the head of the fibula for the duration of the study. Each subject was positioned supine with the knee of the affected lower extremity extended. A strap placed over the shank and a 10-cm-diameter cylinder placed under the knee were used to minimize changes in gastrocnemius muscle length associated with knee position[24] by keeping the knee at a constant angle for each subject. A template (consisting of a clear plastic sheet and a spring balance attached to a footplate) was used to apply a known torque to dorsiflex the ankle. I applied a 120-N force, as measured with a spring balance, to the subject's ankle via a footplate at the level of the head of the fifth metatarsal. The perpendicular distance between the line of force and the ankle joint (ie, the lateral

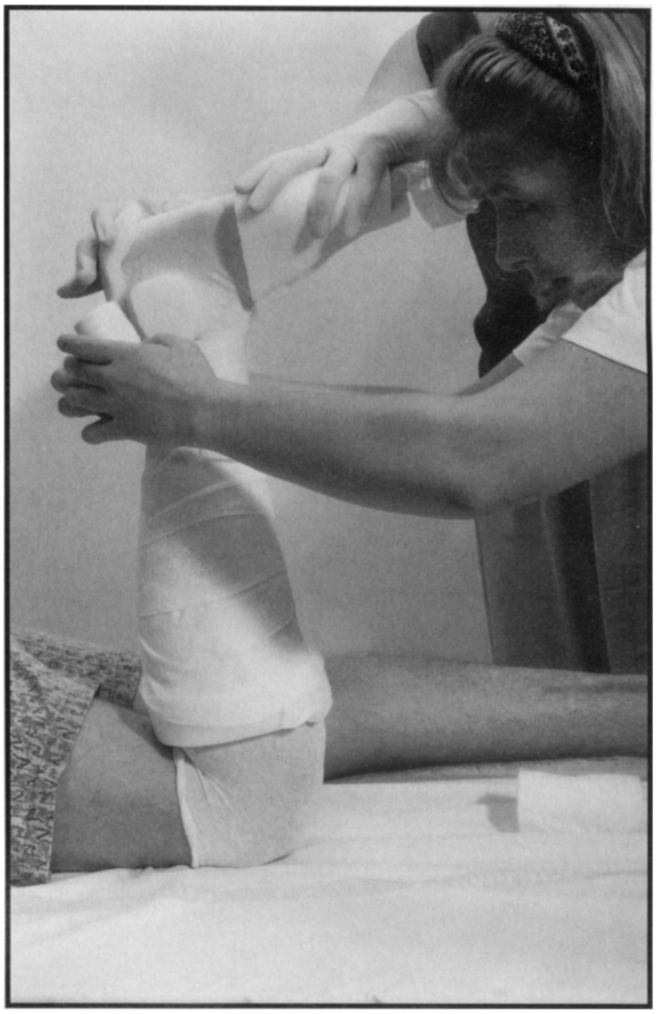

Figure 3.
Application of padding over bony and tendinous prominences on the foot and shank prior to casting.

malleolus skin marker) was measured using the parallel lines ruled on the plastic sheet. The magnitude of the torque applied ranged from 12 to 16.8 N·m among subjects because of their different foot lengths, but it was held constant within subjects. This level of torque was selected because it corresponds with the relatively steep portion of the curve representing passive torque versus angular displacement. The dorsiflexion torque was applied slowly and then maintained at the target value while a photograph was taken. This procedure usually took about 30 seconds. The photograph was taken to record the positions of the three skin markers, and I measured the ankle angle (ie, the angle subtended by the lines connecting the head of fibula and lateral malleolus markers and the lateral malleolus and head of fifth metatarsal markers, as indicated in Fig. 2) from the photograph using a protractor.

The measurements obtained with this procedure have high interrater reliability.[10] Reliability was previously

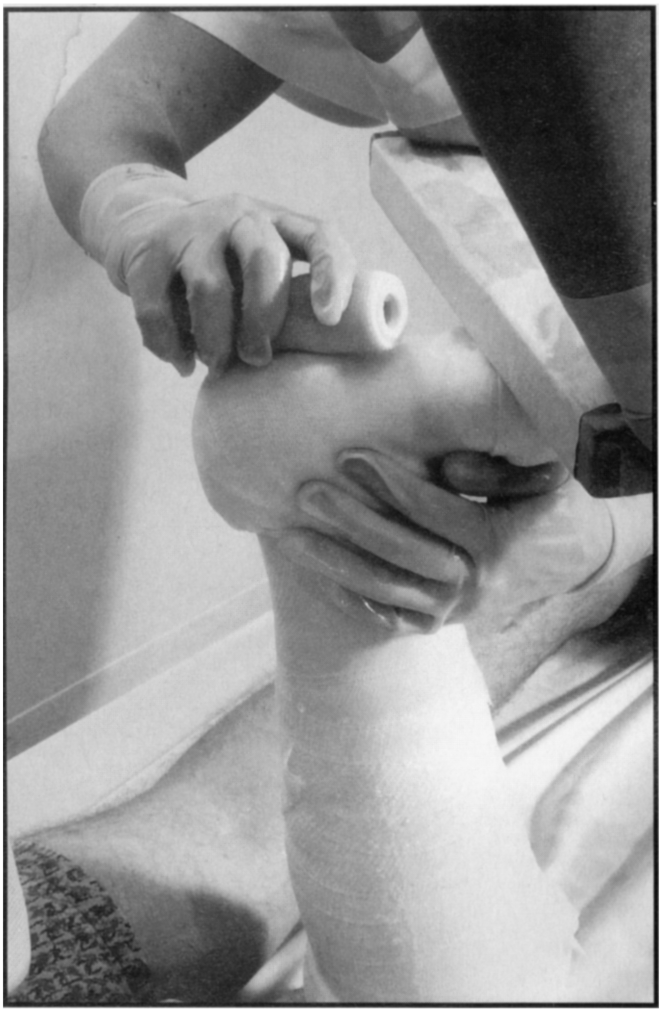

Figure 4.
Application of fiberglass casting tape with the ankle positioned in maximum obtainable dorsiflexion. (Reprinted with permission from Moseley AM. The effect of a regimen of casting and prolonged stretching on passive ankle dorsiflexion in traumatic head-injured adults. *Physiotherapy Theory and Practice*. 1993;9:219).

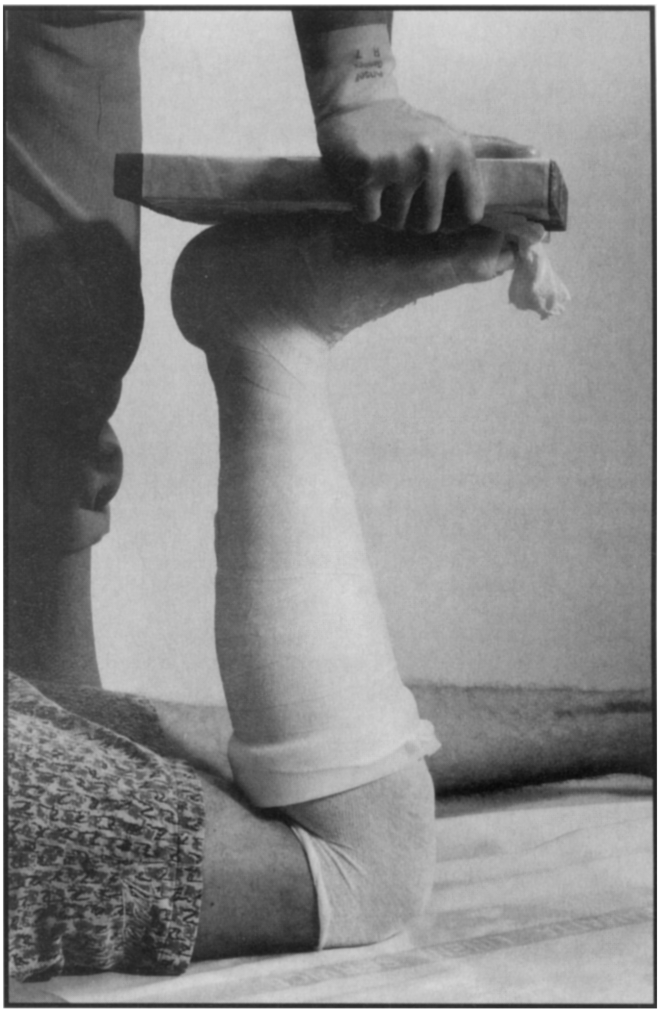

Figure 5.
The soleus muscle is stretched into maximum obtainable dorsiflexion using a board placed on the plantar aspect of the foot and immobilized in this position using fiberglass casting tape.

evaluated by having five testers each measure 15 subjects (5 subjects without known neurological impairment, 5 subjects who had sustained a cerebrovascular accident, and 5 subjects with THI).[10] Each tester measured the subject once, with measurements separated by about 5 minutes. Intraclass correlation coefficients (2,1) were .98 for the subjects with THI, .91 for the subjects without known neurological impairment, .94 for the subjects who had undergone a cerebrovascular accident, and .97 for the combined group data.

During the experimental condition, below-knee casts were applied using the protocol described by Ada and Scott.[18] The skin was protected with a layer of stockinette, and a small amount of padding was placed over bony and tendinous prominences (Fig. 3). The subject was then positioned prone with the knee flexed, the soleus muscle was stretched into maximum obtainable dorsiflexion using a board placed on the plantar aspect of the foot, and the ankle was immobilized in this position using fiberglass casting materials (Figs. 4 and 5). As part of the standard clinical procedure for casting, seven of the subjects were sedated with 10 to 20 mg of Valium®* (administered orally) prior to casting to facilitate cast application by decreasing agitation. When used, this medication was administered after completion of the measurement procedure. Once the cast was in place, the gastrocnemius muscle was stretched by positioning the subject's knee in extension for prolonged periods of time (subjects either stood on a tilt table or sat with their knee extended by placing their leg on a chair for at least 1 hour each day). In contrast, no casting or passive stretching was applied to the ankle joint over the 7-day control period.

* Roche Products Inc, Manati, PR 00674.

Table 2.
Change in Passive Ankle Dorsiflexion Motion for the Experimental (Casting Combined With Stretching) and Control Conditions for the Group Casted First, the Group Casted Second, and All Subjects

Condition[a]	Change in Passive Dorsiflexion (°) Group Casted First (n=4)	Group Casted Second (n=5)	All Subjects (N=9)
Experimental			
$\bar{X}$	13.8	13.3	13.5
SD	14.1	4.8	9.3
95% CI	−8.7–36.2	7.3–19.3	6.4–20.7
Control			
$\bar{X}$	−3.0	−1.0	−1.9
SD	10.3	11.3	10.2
95% CI	−19.4–13.4	−15.1–13.1	−9.8–6.0
Difference (experimental-control)			
$\bar{X}$	16.8	14.3	15.4
SD	18.6	14.8	
SE			5.6

[a] CI = confidence interval, SE=standard error.

During both the experimental and control conditions, each subject participated in an individually designed motor training program aimed at improving performance in a range of everyday tasks (including standing up from a sitting position, standing, and walking). All training was based on the principles of motor learning and biomechanical analysis, as described by Carr and Shepherd.[27] The amount and type of training depended on the subject's motor problems and ability to practice and were consistent between the experimental and control conditions.

Change in passive ankle dorsiflexion in the experimental and control conditions were compared using a two-tailed one-sample *t* test based on the procedure described by Hills and Armitage[28] and using Minitab statistical software.[†] A statistic with a probability of less than .05 under the null hypothesis was considered significant. Order effects were evaluated by comparing the mean and 95% confidence limits for change in passive ankle dorsiflexion during the experimental and control conditions for the group casted first and the group casted second.

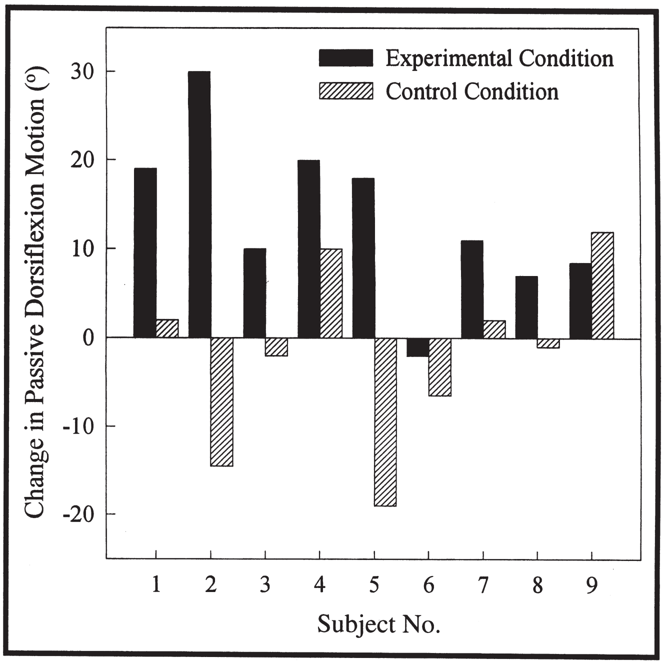

Figure 6.
Change in passive dorsiflexion motion during the experimental (casting combined with stretching) and control conditions for each subject.

Results

Based on the data from all subjects (Tab. 2), the mean increase in passive ankle dorsiflexion movement associated with the experimental condition was 13.5 degrees (SD=9.3). Mean passive ankle dorsiflexion was 44.5 degrees (SD=9.2) prior to casting compared with 58.0 degrees (SD=15.6) after casting. During the control condition, passive ankle dorsiflexion decreased by a mean of 1.9 degrees (SD=10.2), changing from a mean of 51.2 degrees (SD=18.8) to a mean of 49.3 degrees (SD=16.3). There was a mean difference between the experimental and control conditions of 15.4 degrees (SE=5.6) ($t_{observed}$=2.798, $t_{critical}$=2.365, $P<.05$).

The order of the experimental and control conditions was well balanced in that four subjects (three of whom had bilateral contractures) had the experimental condition followed by the control condition and five subjects (three of whom had bilateral contractures) had the control condition followed by the experimental condition. Mean (with standard deviation and 95% confi-

[†] Minitab Inc, 3081 Enterprise Dr, State College, PA 16801-2756.

dence limits) change in passive ankle dorsiflexion during the experimental and control conditions for the group casted first, the group casted second, and all subjects is detailed in Table 2. The order of the conditions did not appear to affect the magnitude of the change in passive ankle dorsiflexion.

The change in passive ankle dorsiflexion during the experimental and control conditions is illustrated in Figure 6 for each subject. During the experimental condition, eight subjects demonstrated an increase in passive ankle dorsiflexion, which ranged between 7.0 and 30.0 degrees. Passive ankle dorsiflexion decreased by 2.0 degrees in the other subject. In contrast, in the control condition, five subjects demonstrated a decrease in passive ankle dorsiflexion, ranging between 1.0 and 19.0 degrees, and dorsiflexion increased by 2.0 to 12.0 degrees in four subjects.

Discussion

The main finding of this study was that casting combined with stretching increases passive ankle dorsiflexion in persons with THI. Casting combined with stretching for a period of 7 days was associated with a greater increase in passive ankle dorsiflexion than a control period of 7 days in which subjects were not casted and did not stretch. The mean increase in passive ankle dorsiflexion associated with 7 days of casting combined with stretching was 13.5 degrees. This rate of increase in passive ankle dorsiflexion compares favorably with those of other published studies that demonstrated a change in passive dorsiflexion of between 4 degrees[15,17] and 10.4 degrees,[22] on average, per cast.

There was considerable variability in individual responses to casting combined with stretching. Both the ankle position attained during cast application and the amount of active task practice performed by individual subjects could contribute to the between-subject variability observed. Three factors that may affect cast application are the degree of plantar-flexion contracture, coexisting musculoskeletal adaptations, and the use of medications prior to casting. Severe degrees of ankle plantar-flexion contracture and the presence of musculoskeletal adaptations that limit passive knee flexion could interfere with the positioning of the foot during cast application using the experimental protocol, as the ankle must be relatively dorsiflexed and the knee must be flexed to greater than 90 degrees in order to apply a sufficiently strong dorsiflexion force (Fig. 5). Further research is needed to determine the optimum variables for patient selection and cast application.

In this study, passive stretching was controlled while the subjects continued to actively practice functional tasks. The amount of practice each subject performed with his or her calf muscles placed in the lengthened position (eg, rising from a sitting position to a standing position and stepping forward) will also contribute to the total amount of ankle stretching and may account for the increase in passive dorsiflexion demonstrated by some subjects during the control condition. Studies that manipulate the amount of active stretching (ie, task practice with the calf muscles in the lengthened position) as well as the amount of passive stretching (ie, prolonged low-load stretches and casting) are needed to evaluate the relative effects of both forms of treatment.

One potential threat to the validity of the study was the use of a nonblinded measurer. The measurer (AMM) was aware of both the experimental condition and crossover point for all subjects. I do not consider this to be a major problem as the measurement procedure used was relatively impervious to observer bias.

The nature of the soft tissue adaptations associated with stretching could not be determined from this study because only a single point from the passive torque versus angular displacement curve was measured. More sophisticated measures of contracture are needed to evaluate the passive mechanical properties of the ankle. The use of an instrumented footplate to measure torque and angle as the ankle is passively dorsiflexed throughout the range of motion would enable the quantification of passive ankle torque and stiffness (ie, the slope of the torque versus angle curve) for a range of ankle angles.[9] Furthermore, diagnostic ultrasound could be used concurrently to measure gastrocnemius muscle fiber length[29] and thus to deduce the location and extent of soft tissue adaptations.

Measures of passive ankle dorsiflexion motion were used to determine the short-term effects of casting combined with stretching in this study. In addition to measures of the passive mechanical properties of the ankle, measures of reflex activity and the ability to perform functional tasks are needed for a more comprehensive evaluation of both the immediate and long-term benefits of serial casting and other stretching interventions.

Conclusion

Limited passive ankle dorsiflexion motion, a common sequela following THI, interferes with functional tasks such as standing up from a sitting position and walking. This study demonstrated that plantar-flexion contractures can be reduced with casting combined with stretching in individuals with THI, resulting in a greater range of dorsiflexion motion. The use of this treatment regimen, therefore, can improve rehabilitation outcomes.

Acknowledgments

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