The purpose of this study was to evaluate the effects of two intensities (5 and 10 kg) of continuous and intermittent Achilles tendon pressure on the H-reflex in eight hemiparetic subjects. A decrease in the H-reflex was interpreted as a depression in motoneuron excitability, a condition conducive for reducing muscle tone. The H-reflex measurements were obtained before, during, immediately after, and 2.5 minutes after tendon pressure application. Piecewise linear regression equations were used to evaluate the effects of four pressure conditions. The mean of the midpoints of the lines for each pressure condition was compared with prepressure baseline values by t tests and with the other pressure conditions by an analysis of variance. All four pressure conditions demonstrated H-reflexes less than prepressure baseline values, with three of the four conditions (5 and 10 kg of intermittent pressure and 5 kg of continuous pressure) being significantly less than prepressure baseline values (p < .05). The analysis of variance revealed a significant difference among pressure conditions. Scheffé post hoc contrast comparisons revealed significant differences between intermittent and continuous pressure but not between 5 and 10 kg of pressure. The results of this study indicate that in these hemiparetic subjects, the H-reflex was depressed during both continuous and intermittent tendon pressure. Intermittent pressure was more effective than continuous, but 10 kg of pressure had no greater effect than 5 kg of pressure. The effects of pressure lasted only as long as the stimulus was present. Therapeutic techniques that might take advantage of this decrease in motoneuron excitability include stretching of shortened musculotendinous units, strengthening of antagonists, and improving lower extremity bed and wheelchair positioning.

Key Words: Hemiplegia, general; Muscle performance, lower extremity; Muscle tonus; Neurophysiology/neuroanatomy.
TABLE 1 Description of Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Side of Cerebrovascular Accident</th>
<th>Age (yr)</th>
<th>Duration Since Onset of Hemiparesis (mo)</th>
<th>Direction of Face During Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>right</td>
<td>18</td>
<td>2.5</td>
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</tr>
<tr>
<td>2</td>
<td>F</td>
<td>right</td>
<td>46</td>
<td>4.0</td>
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<tr>
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<td>M</td>
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<td>59</td>
<td>5.5</td>
<td>right</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
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<td>44</td>
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<td>F</td>
<td>right</td>
<td>55</td>
<td>21.0</td>
<td>midline</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>left</td>
<td>42</td>
<td>8.0</td>
<td>midline</td>
</tr>
</tbody>
</table>

mined by a brief history. The mean time between onset of hemiparesis and this study was 8 months with a range of 2.5 to 21 months. All subjects signed informed consent statements. Guidelines for subject participation were approved by The University of Iowa Human Subjects Committee.

Procedure

Subjects were positioned prone with the foot of their affected side stabilized by a footplate in a resting position of about 15 degrees of plantar flexion and their head turned to the side of most comfort. Six subjects positioned their head to their affected side, one subject positioned his head away from the affected side, and one subject kept his head in the midline. Evoked H and M responses were recorded from the soleus muscle using a pair of 5-mm diameter silver-silver chloride surface electrodes imbedded with an on-site preamplifier in an epoxy mount. The electrodes were secured in the midline of the subjects' calf according to accepted guidelines. The evoked responses were further amplified with a high impedance differential amplifier. The entire system was frequency limited below 40 Hz and above 5 kHz. We used a Hewlett-Packard eight-channel FM tape recorder to store the data. The H- and M-wave amplitudes were measured using a Tektronix 5110 digital oscilloscope with a resolution of up to 20 μV. Single square wave, 1-msec cathodal pulses were delivered to the tibial nerve in the popliteal fossa using a Grass S88 stimulator§ coupled to a Grass SIU5 stimulus isolation unit. The cathode was housed in a specially designed assembly that provided optimal stability and positioning for stimulation. Proper cathode positioning was determined by the ability to elicit an H-reflex without a direct muscle response (M response); M and H waves displaying the same configuration; and no change in M-amplitude for repeated, constant, submaximal stimulus intensities.

We used a Genisco load cell mounted on to a modified drill press to apply standardized pressure to the triceps surae tendon. The pressure was applied over an area of about 4.4 cm² located 0.5 in proximal to a line bisecting the lateral and medial malleoli. Because the area of the force applicator remained constant throughout the experiment, pressure was expressed in kilograms.

Calibration of a standardized pressure of either 5 or 10 kg was performed before each of the four trials. The load cell was connected to one of two inputs of a comparator circuit. The second input of the circuit received a reference voltage. This reference voltage was established before each trial by placing either a 5- or 10-kg weight on the load cell and then nulling its effect on the circuit with a DC adjustment. When the load cell was pressed onto the tendon, it produced a voltage that was compared to this reference voltage. When the two voltages were equal, that is, had a pressure intensity of either 5 or 10 kg, the comparator emitted a pulse that was used to trigger the stimulator via a Digitimer D100. An adjustable stop on the drill press was then set to this calibrated pressure.

We selected 5 and 10 kg as the minimal and moderate intensities, respectively, that might be used in a clinical setting. Intermittent pressure was applied at a rate of 1 application/sec and was synchronized manually using an audio cue to the investigator (J.A.L.) derived from the Digitimer D100 connected to a Grass AM7 audio amplifier. With both intermittent and continuous pressure, stimulation began one second after the desired tendon pressure was reached.

The experimental protocol consisted of delivering four types of tendon pressure—intensities of 5 and 10 kg of both continuous and intermittent pressure—to each subject. Eight different orders of presentation for the four pressure conditions were determined by alternating between intermittent and continuous conditions and randomizing the two pressure intensities. Each subject, therefore, received one of eight different orders of presentation. Figure 1 is a flow diagram of the general sequence in which data were gathered for each subject. Ten H-reflexes (baseline measurements) were obtained at the beginning of the experiment. The first pressure condition was then delivered, during which the next 10 H-reflexes were generated. This series of reflexes was followed immediately by 10 postpressure H-reflexes and 2.5 minutes later by 10 final postpressure H-reflexes. The H-reflexes in each series were generated at 5-second intervals. The 2.5-minute postpressure series was used as the prepressure baseline for the next pressure condition. Stability of stimulating conditions was verified by the maintenance of a consistent minimum M wave (<10% of H wave) throughout the experiment.

Data Analysis

The median of the first 10 prepressure H-reflex peak-to-peak amplitudes was used as a baseline from which to compare each pressure and postpressure test. Each pressure, immediate postpressure, and 2.5-minute postpressure H-reflex amplitude was adjusted by dividing it by the median of the prepressure test and subtracting 1. Adjustment of data allowed for quantitative comparisons among tests and facilitated assessment of the positive and negative effects of pressure. Zero or near-zero adjusted values signified no effect. Positive adjusted pressure terms signified reflex values greater than the prepressure baseline median (excitation), and negative terms signified pressure values less than prepressure baseline medians (inhibition). The absolute value for the adjusted pressure data, when multiplied by 100, provided the percentage change in the reflex amplitude.

* Therapeutics Unlimited, 2835 Friendship St, Iowa City, IA 52240.
† Model 3968A, Hewlett-Packard Co, 1501 Page Mill Rd, Palo Alto, CA 94304.
‡ Tektronix, Inc, PO Box 500, Beaverton, OR 97077.
§ Grass Instrument Co, 101 Old Colony Ave, Quincy, MA 02169.
‖ Model AWU-50, Genisco Technology Corp, 650 Easy St, Simi Valley, CA 93065.
*1 in = 2.54 cm.

** Medical Systems Corp, 239 Great Neck Rd, Great Neck, NY 11021.
Piecewise linear regression equations were used to evaluate tendon pressure effects over time, both during and after pressure application. During pressure application, the first reflex generated (time designated 0 seconds, or \( t = 0 \)) was readily observed to be uncharacteristic and, therefore, was analyzed separately. The slope, intercept, and midpoint (time designated 25 seconds, or \( t = 25 \)) of the line were determined for the remaining nine adjusted H-reflex values. The mean of the midpoints of the lines for each pressure condition was compared with prepressure baseline medians using \( t \) tests. The time courses of the linear regression models constructed from the adjusted pressure values (excluding \( t = 0 \)) were evaluated using individual \( t \) tests for comparing each slope to zero.

Variability of the H-reflex measurement was assessed by calculating the coefficients of variability (CVs) for each subject-test condition. The coefficient of variability has been defined as “the sample standard deviation expressed as a percentage of the sample mean” according to the formula

\[
CV = 100 \frac{s}{\bar{x}}
\]

where \( s \) is the sample standard deviation and \( \bar{x} \) is the mean of the sample. We also performed this calculation on the results from previous studies involving healthy subjects and compared these results with those of the hemiparetic subjects of this study.

A parametric block-design two-way analysis of variance (ANOVA) was used to determine significant pressure condition-subject differences. We used Scheffe post hoc pair-wise comparisons to construct confidence intervals for assessing pressure condition differences and to evaluate contrasts between continuous- and intermittent-pressure means and between 5- and 10-kg pressure means. The level of significance for all tests and confidence limits was set at the .05 level.

RESULTS

The linear regression analyses for the four pressure conditions for all eight subjects revealed that all adjusted (\( t = 25 \)) pressure values were negative except for a single subject for the 10-kg continuous-pressure condition (Fig. 2). These negative adjusted pressure values indicated an inhibitory effect attributable to pressure. The magnitudes of this effect, and their time courses, varied widely among subjects. When these midpoint values were pooled, all pressure conditions except the 10-kg continuous-pressure condition were found to be significantly different from zero (Fig. 3, open columns).

The slopes of the linear regression models were the major means of evaluating the time courses of the reflex inhibition in each subject. For the 5-kg continuous-pressure condition, the slopes were positive in six subjects and significantly different from zero in two subjects (one with a positive slope and one with a negative slope). For the 10-kg continuous-pressure condition, all slopes were positive, with only one being significantly different from zero. For the 5-kg intermittent-pressure condition, all slopes except one were negative, with two of the negative slopes being significantly different
from zero. For the 10-kg intermittent-pressure condition, six slopes were negative, with one negative slope being significantly different from zero.

The ANOVA revealed a significant difference among pressure conditions (Tab. 2); however, Scheffe post hoc 95% confidence intervals (Tab. 3) exhibited no significant differences among pair-wise pressure comparisons. Scheffe post hoc contrast comparisons revealed significant differences between intermittent and continuous pressure but no difference between 5 and 10 kg of pressure (Tab. 4).

The t tests comparing postpressure adjusted pressure values to prepressure baseline medians revealed no significant differences between the two conditions, indicating that H-reflex amplitudes returned to prepressure baseline levels after tendon pressure. Paired t tests between M-wave amplitudes before and after experimentation revealed no significant differences, verifying the consistency in stimulating conditions between the beginning and end of the experiment.

**DISCUSSION**

The results of this study revealed that in hemiparetic subjects, the H-reflex was depressed during the application of both continuous and intermittent Achilles tendon pressure. Intermittent pressure was more effective than continuous pressure, but 10 kg of pressure had no greater effect than 5 kg. Because the H-reflex is an indirect measure of motoneuron excitability, these results suggest that tendon pressure may be used to reduce motoneuron excitability in hemiparetic subjects. These findings are in general agreement with previous reports on healthy subjects and a patient with spinal cord injury, which support the clinical impression of reduced muscle tone during tendon pressure.

Comparison of the results of this study with those obtained under similar conditions in previous studies of healthy subjects provides insight into the effectiveness and limitations of tendon pressure when used as a therapeutic modality. Three differences between the protocols of the previous studies of healthy subjects and that used in this study on hemiparetic subjects should be noted. First, the smaller of the two pressure intensities used in this study was 5 kg; in the previous studies, the force was 2 kg. The intensity of pressure used in this study was 5 kg; in the previous studies, the force was 2 kg. Therefore, was slightly less than half of that used in this study (5 kg exerted through a 4.4-cm2 transducer = 6.5 × 10^3 N/m^2, therefore, was slightly less half of that used in this study (5 kg exerted through a 4.4-cm2 transducer = 11.1 × 10^3 N/m^2). Second, the H-reflex sampled at t = 25 in this study was used as the measure of pressure effectiveness in reducing motoneuron excitability. Because no significant differences were found between H-reflexes at 20 or 30 seconds of pressure in the previous studies, the 20-second value was used for comparisons with the t = 25 value in this study. Finally, the previous studies of healthy subjects used a repeated-measures design to evaluate a single type of pressure for a single pressure intensity. For hemiparetic subjects in this study, we evaluated two types of pressure at two different intensities. A repeated-measures design would have created a lengthy experimental session (4–5 hours) that the subjects in this study would be unable to tolerate. We decided, therefore,
to sacrifice statistical power to gain a qualitative appreciation for the effects of type and intensity of pressure on motoneuron excitability.

Despite these differences, results for continuous pressure for both healthy subjects and hemiparetic subjects were found to be supportive of each other. The average reduction in the H-reflex was 7% for healthy subjects and 11% for the hemiparetic subjects in this study. Qualitatively, both groups displayed a similar time course for the pressure-induced H-reflex changes—an initially large decrease in reflex amplitude that gradually returned to baseline levels as the pressure was maintained. For intermittent pressure, healthy subjects displayed a mean 45% decrease in the H-reflex, whereas for the hemiparetic subjects, a 29% decrease was observed. Again, the time course of the effects were similar for each group—an initially large decrease that lasted throughout the stimulus presentation. The slopes of these time courses were not significantly different from zero for the hemiparetic subjects and undoubtedly were due to the large variability in H-reflex measurements. Regardless of the type of tendon pressure used, continuous or intermittent, the effects on the H-reflex lasted only as long as the pressure was present.

A large variability in the H-reflex measurements at rest was found for the hemiparetic subjects in this study, which contrasted with earlier reports on healthy subjects. The occasional occurrence of aberrant H-reflex values within a control group of measurements in this study attested to this increased variability and was the major impetus for using the median as a measure of central tendency. To evaluate an effect attributable to pressure, it is critical that a valid baseline measurement be established before pressure application. The usual approach is to record a number of H-reflexes before pressure application and then calculate a mean value. In this study, it was immediately obvious that one or two H-reflexes in the prepressure tests were generally very different from the others. The mean, therefore, did not adequately represent the central tendency of the H-reflex measurement. The median appeared to be the preferred measure, thereby minimizing the effects of the aberrant values. Rather than exclude these aberrant values from the data analysis, we decided to include all measurements and use the median as the measure of central tendency for the baseline level. By further adjusting the treatment H-reflexes as described previously, intersubject comparisons were possible, and visual inspection of each treatment value facilitated assessment of an excitatory or inhibitory effect.

To facilitate comparisons of the measurement variabilities between the healthy subjects of previous studies and the hemiparetic subjects in this study, CVs were calculated. This technique is a way of normalizing the variability such that relative differences in variability between two groups may be compared. The subjects in this study displayed CVs of 54% and 72% for continuous and intermittent pressures, respectively, whereas the CVs of the healthy subjects were 22% and 38%. We are tempted to postulate that the greater variability in the responses of the subjects in this study, as compared with the previous studies, was caused by their CNS lesions; however, caution is warranted. The differences in variability could as likely be due to sampling differences among the studies. The mean values for the healthy subjects were obtained from 30 and 28 subjects, each evaluated three times, whereas for the hemiparetic subjects in this study, the mean values represent single measurements from each of 8 subjects. The possibility that hemiparetic subjects demonstrate greater variability in response than healthy individuals as a result of their CNS lesions, therefore, must await a more controlled and systematic investigation.

We found no significant difference between 5 and 10 kg of pressure and between 10 kg of continuous pressure and the prepressure baseline values. The lack of a significant difference between 10-kg continuous-pressure and prepressure baseline values may be explained by the large aberrant increase in the H-reflexes observed for a single subject (Fig. 2). This subject's data caused an inflation in the mean and standard deviation for the adjusted (t = 25) H-reflex value for the 10-kg continuous-pressure test. When the subject was excluded from the data analysis (Fig. 3, hatched bars), a statistical difference was found between 10-kg continuous-pressure and prepressure baseline levels. The aberrant results for a single subject most likely affected the lack of statistical significance for the 10-kg continuous-pressure condition. We believe, therefore, that all four types of tendon pressure as used in this study can produce a reduction in motoneuron excitability.

This large deviation of a single subject from the general response of the group emphasizes the importance in considering individual responses to a treatment technique. This subject was cooperative, tolerated testing well, and gave no indication that the response to tendon pressure should differ from the group. The subject's H-reflexes varied over extreme ranges (Fig. 2), however, indicating an excessive sensitivity to the test conditions. Although our results indicate that the most likely response of a patient with stroke to tendon pressure is an inhibition of the motoneuron pool, exceptions therefore may be found. This finding must be recognized in the treatment setting.

Exclusion of the subject with the aberrant result had no effect on the lack of statistical significance for 5 and 10 kg of pressure, suggesting that the intensities of pressure had little effect on alpha motoneuron inhibition. This result is further supported by comparisons of healthy subjects' results with those reported here. The healthy subjects were tested with a pressure slightly less than half of that used on the hemiparetic subjects in this study. For continuous pressure, however, the healthy subjects and the hemiparetic subjects displayed similar H-reflex changes (11% and 7%, respectively), and for intermittent pressure, the healthy subjects displayed a slightly greater decrease than the hemiparetic subjects (45% and 29%, respectively). For the range of pressures used in these studies (6.5 × 10^4 N/m^2 to 22.2 × 10^4 N/m^2), intensity appeared to have little influence on the inhibition of motoneurons. A more effective means of increasing the inhibition would be the application of intermittent rather than continuous pressure.

Over the course of the experiments, a consistent time effect was evident during the pressure application. For continuous pressure, the effect was a large initial depression in the H-reflex followed by a gradual return toward the baseline value. For intermittent pressure, the initial large depression was followed by a continued gradual increase in the depression. An average value taken over the time period of pressure application did not reflect these dynamic changes. Fitting the data to a linear regression model provided the information on the dynamic changes.

In summary, this statistical method greatly facilitated data analysis. Aberrant values obtained in the prepressure measurements would have biased the calculation of a mean baseline value. Use of the median circumvented this potential problem and, we believe, gave a more accurate assessment of
the measure of central tendency. Adjustment of the H-reflexes by normalizing them to the median allowed quick visual inspection of excitability changes attributable to pressure intensity. Finally, the regression analysis provided additional information on the time-dependent changes in the H-reflex, which would have been obscured by a more conventional ANOVA approach.

Because the t = 0 data point was consistently atypical, we excluded it from the regression model and analyzed it separately. The reason for the first data point being atypical was most likely due to the change in tissue resistance encountered by the force transducer on contact with the skin. We have reported that the force delivered to the Achilles tendon was either 5 or 10 kg and was calibrated before each pressure trial. We, therefore, were assured that the force delivered was at least 5 or 10 kg, which were steady-state forces. During the initial application (ie, within the first second), the tendon forces were actually two to three times higher than the calibrated level. After the initial application, the forces immediately plateaued to near-calibrated levels. The reason for this large discrepancy is likely due to an initially large resistance encountered by the transducer when first applied. This resistance could arise from the transducer having to displace subcutaneous tissues at the point of contact. After the tissues are displaced, which appears to occur within the first second of pressure application, the resistance encountered drops dramatically, and the force recorded approximates that of the steady-state calibrated value. The large atypical H-reflex change obtained on initial contact of the transducer, therefore, most likely reflects this initially high resistance encountered.

CONCLUSIONS

The results from this study clearly indicate a reduction in motoneuron excitability during tendon pressure application in adult hemiparetic subjects. This finding suggests that motoneuron excitability was altered in a way that was conducive to reducing muscle tone. Tendon pressure, therefore, should be an effective means for producing a transient reduction of tone in the hypertonic muscles of hemiparetic patients. We must emphasize that we did not measure muscle tone; we inferred what we believe would be probable changes in tone from the changes we measured in motoneuron excitability.

Intermittent pressure, unlike continuous pressure, produced a sustained depression of the H-reflex during the period of stimulus presentation. Clinicians interested in maintaining a period of reduced motoneuron excitability, therefore, might choose an intermittent rather than continuous stimulus. Because the H-reflex remained depressed even with 45 seconds of intermittent pressure application, this type of stimulus may conceivably produce a continuous effect. This possible result might be one reason for the reported effectiveness of inhibitive casting in which Achilles tendon pressure pads are built into the cast.16

Finally, we should also emphasize that we observed the effects of pressure only during stimulus application. No carryover effect was observed. Nonetheless, several therapeutic techniques including stretching of shortened musculotendinous units, strengthening of antagonists, and improved lower extremity wheelchair and bed positioning could benefit from the short-lived decrease in motoneuron excitability.

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