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CLINICAL REPORT

Influences of Cane Length on the Stability of Stroke Patients

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Abstract—The purpose of this study was to investigate the influence of cane length on the standing and walking stability of stroke patients. Ten stroke patients were used as subjects and evaluated by using two different cane lengths based on the measurements of the distance from distal wrist crease to the ground (WC cane), and the distance from greater trochanter to ground (GT cane). Force plates were used to determine the center of pressure (COP). The maximum sways, the total travel distances, and the mean travel speeds of the COP were analyzed for each patient standing and walking with and without canes. It was found that the total travel distance and the mean travel speed of the COP in the medial-lateral (M-L) direction were significantly lower when standing with a cane than when standing without one. It was also found that the values of these parameters and the maximum sways of the COP in both anterior-posterior (A-P) and M-L directions were significantly lower when standing with the WC cane than when standing with the GT cane. No significant difference was found in the maximum M-L sway, the total travel distance, and the mean travel speed of the COP in walking. These results suggest that the standing stability of stroke patients is improved by using canes, especially by using a WC cane, although no significant influence of using canes on the walking stability was detected. Based on the results of this study, the vertical distance from the wrist crease to ground is recommended as the appropriate cane length for stroke patients.

Key words: *cane, posture, stability, stroke.*

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INTRODUCTION

Cerebrovascular accidents (CVAs) or strokes are a common neurological problem in the United States. The prevalence rate of strokes is approximately 5 percent for those aged 65 and older (1), and rises with age. People who have suffered from a stroke frequently have poor coordination, unilateral muscle weakness, decreased standing and walking stability, and impaired sensation (2). One of the common consequences of these problems is falling. It has been reported that the incidence of falls is 14 percent in the acute setting (3), and 54 percent after hospital discharge (4). Poor stability is believed to be the major cause of falls after strokes (5). The standing and walking stability of a stroke patient, either during admission or after discharge from a hospital, is thought to be the most important predictor of ambulation ability (6).

The standing and walking stability of a stroke patient can be improved by using a cane. It has been shown that using a cane can widen the base of support (7), assist hip and spinal extensor muscles (7), assist with accelerating and braking in locomotion (8), reduce the loading on the impaired limb (9,10), and decrease the shift of the center of gravity (COG) during locomotion (1,2,8). In the selection of an appropriate cane for a stroke patient, cane length is an important consideration. Sainsbury and Mulley reported that using a cane with an inappropriate length might be dangerous and have a substantial relationship with falls and other complications. They also reported that 75 percent of the patients

involved in that study had canes with inappropriate lengths (11). However, the appropriate cane length was not defined in their study. It is believed that a cane that is too short forces the patient to lean toward the cane and thereby lessens his or her stability. On the other hand, a cane that is too long may also reduce stability by limiting the triceps' effectiveness (7,12,13). In addition, a cane that is either too short or too long may result in discomfort and increased energy consumption for the patient during walking (7).

Two methods for determining appropriate cane length are commonly used in the clinic: the distance from the greater trochanter to the ground (7,11,12), and the distance from the wrist crease to the ground (1,11). There is a discrepancy in the prescribed cane lengths between these two methods, and a recent review of the literature failed to find convincing support for either of them. Due to the importance of canes for stroke patients, and the lack of studies on the influence of cane length on standing and walking stability, the purpose of this study was to compare the standing and walking stability of stroke patients with canes prescribed using these two methods.

Maximum sway, total travel distance, and mean travel speed of the center of pressure (COP) are commonly used parameters in the literature representing stability (14–19). If cane length has any effect on the stability of stroke patients, there should be a significant difference in at least one of these parameters for these patients. Therefore, the hypothesis to be tested in this study was that there is a significant difference in at least one of the three stability parameters: the maximum sway, the total travel distance, and the mean travel speed of the COP for stroke patients between different supporting conditions (without a cane or with canes of different lengths).

METHODS

Subjects

Ten male stroke patients with hemiplegia due to CVA were recruited as volunteer subjects for the study. Their mean age was 59 years with a standard deviation (SD) of 7 years. The mean follow-up time since the onset of symptoms was 49 months (4 to 126 months). Each subject was using a cane for ambulation in his daily activities. Four patients were using ankle-foot orthoses to assist in foot clearance during walking. Seven patients had experienced falls since their strokes. The general characteristics of these patients are listed in **Table 1.** All subjects were able to stand with or without a cane for more than 30 s and to follow simple instructions. The motor and sensory status and the ambulation ability of each patient was recorded from patient history notes. The tones of these patients were graded using the Ashworth scale (20). Before the experiment, each patient was informed of the purpose and procedure of the test in detail and signed a consent form approved by our institutional Internal Human Subjects Review Board.

Table 1.
General Characteristics of the Subjects.

	Age (years)	Weight (kg)	Height (m)	Onset time (months)	Ashworth tone
Mean	58.9	88.5	1.66	49.2	2.8
S.D.	6.9	10.2	0.06	41.2	0.4
Maximum	66.0	104.5	1.76	126.0	3.0
Minimum	44.0	72.7	1.55	4.0	2.0

Data Collection

A single-point, length-adjustable cane with curved top handle was used in this study. The tip of the cane had a plastic ferrule with a good gripping surface to prevent slips. The surface of the cane stem had scales for changing cane length. The cane was used on the uninvolved side of each patient (2,21,22).

Two cane lengths were tested for each subject: greater trochanter length (GT cane) and wrist crease length (WC cane). The greater trochanter length is defined as the vertical distance from the most prominent part of the greater trochanter to the ground. The wrist crease length is defined as the vertical distance from the distal wrist crease to the ground. The cane lengths were measured while the subject was standing upright with both hands hanging loosely at the sides. The elbow angles of the arm when holding different canes were also measured for each subject in this posture using a goniometer. The measured cane lengths were normalized as the percentages of body height of the subject.

Two Kistler force plates (type 9281B, Kistler Instrumente AG, Winterthur, Switzerland) and one Bertec force plate (type 4060A, Bertec Corporation, Worthington, OH) were used to collect ground reaction force data during standing and walking. The feet and the cane of the patient in standing tests and during at least one double support phase in walking tests were in the actual data collection area of the force plates (**Figures 1a** and **1b**). Each Kistler force plate has eight output signals designated

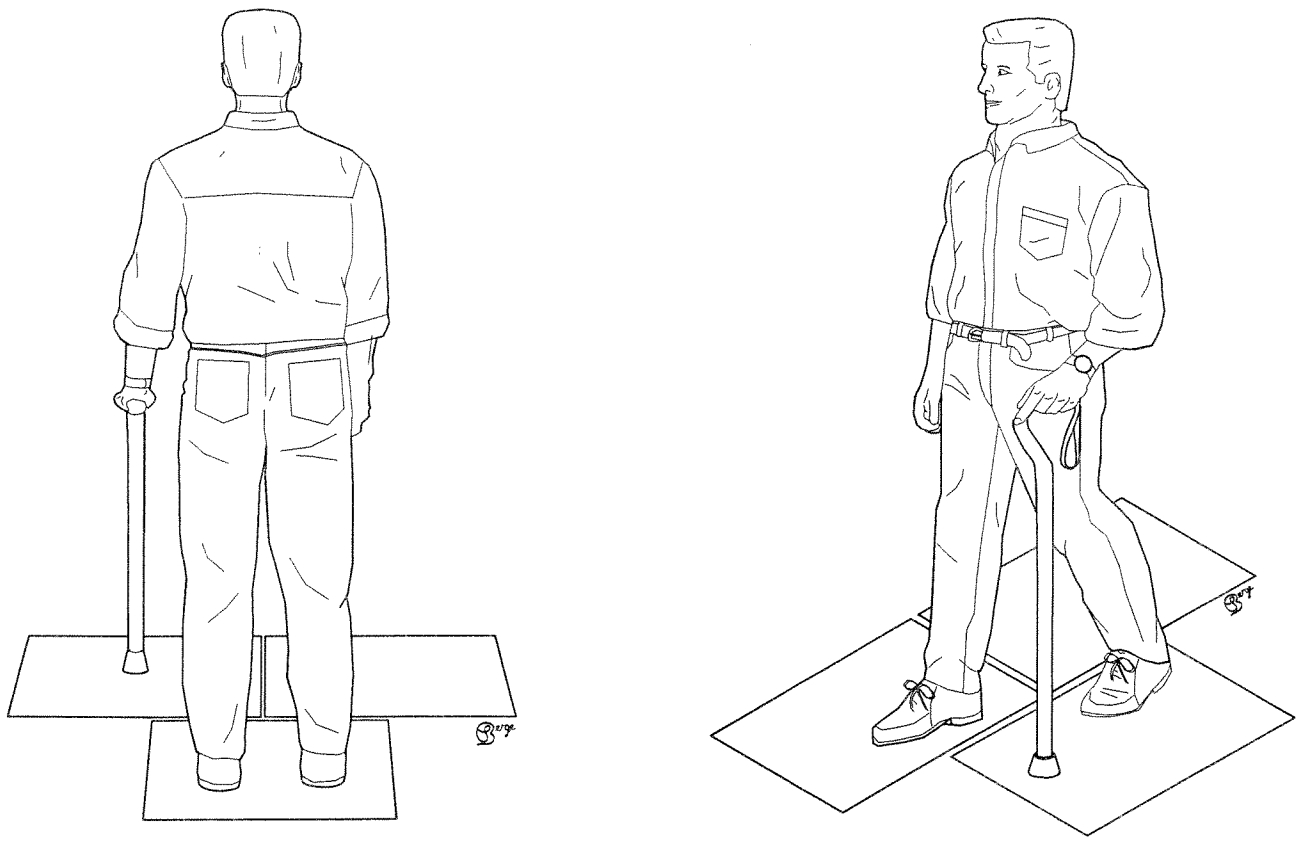

Figure 1.
Placement of the three force plates used to evaluate the stability of stroke patients: *left.* standing test, and *right.* walking test. Walking direction was reversed for patients using canes on the right side.

$F_{x,12}$, $F_{x,34}$, $F_{y,14}$, $F_{y,23}$, $F_{z,1}$, $F_{z,2}$, $F_{z,3}$, and $F_{z,4}$[1]. The Bertec force plate has six output signals named F_x, F_y, F_z, M_x, M_y, and M_z. The output signals of the three force plates were collected by an IBM compatible computer at a sampling frequency of 10 Hz for standing tests and 100 Hz for walking tests.

To combine the measurements of the three force plates, a global reference frame was established, while each force plate had its own local reference frame. The x-axis of the global reference frame was parallel to the medial-lateral (M-L) direction and the y-axis was parallel to the anterior-posterior (A-P) direction in a standing trial (**Figure 2**). In a walking trial, the x-axis of the global reference frame was parallel to the A-P direction and the y-axis was parallel to the M-L direction.

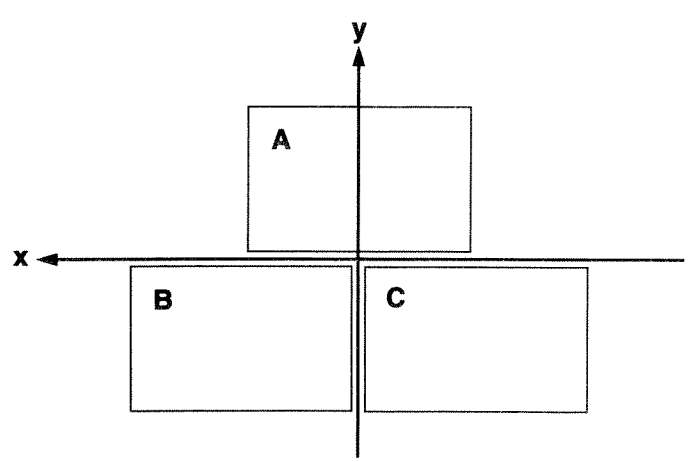

Figure 2.
The top view of the placement of the three force plates (A,B, and C) and the orientation of the global reference frames. The y axis was in the A-P direction and x axis was in the M-L direction in the standing test. The x axis was in the A-P direction and y axis was in the M-L direction in the walking test.

[1]Operating and service instructions, Kistler Instrumente AG, Winterthur, Switzerland.

Preferred foot and cane positions in standing were determined for each subject before the test by asking him to stand on force plates in his own shoes with a toe-out and heel-apart position (17,23) and put his own cane at a position with which he felt most comfortable. The foot and cane positions were then marked on the force plates and considered as the preferred foot and cane positions in standing for the subject. These positions were used in all standing tests for the subject.

To test standing stability, each subject was asked to stand on the force plates with or without a given cane and instructed to look straight forward at a marker on the wall. Ground reaction force data were collected for 20 s for each trial followed by a 1-min rest. A standing trial in which the subject did not move his feet and cane was considered an analyzable trial. The testing order of the three supporting conditions was randomized for each subject, and at least three analyzable standing trials were obtained for each subject and each supporting condition.

To test walking stability, each subject was asked to walk through the surface covered by force plates with or without a cane. A walking trial in which the subject had at least one double support phase and the cane on the force plates was considered an analyzable trial. The testing order of the three supporting conditions for a given patient in the walking test was the same as that used in the standing test for the patient, and at least two analyzable walking trials were obtained for each subject and for each supporting condition. A 2-min rest followed each walking trial.

Data Reduction

The instantaneous magnitudes of the three components of the resultant force on each of the two Kistler force plates were determined using

$$F_x = F_{x,12} + F_{x,34}$$
$$F_y = F_{y,14} + F_{y,23}$$
$$F_z = F_{z,1} + F_{z,2} + F_{z,3} + F_{z,4}$$

where F_x and F_y are two components perpendicular to each other in the horizontal plane; and F_z is the vertical component. The x and y coordinates of the center of pressure (COP) of the resultant force on the surface of each Kistler force plate were determined using

$$x = \frac{zF_x - a\,(-F_{z,1} + F_{z,2} + F_{z,3} - F_{z,4})}{F_z}$$

$$y = \frac{zF_y + b\,(F_{z,1} + F_{z,2} - F_{z,3} - F_{z,4})}{F_z}$$

where x and y are coordinates of the location of the COP in the force plate local reference frame; z is the distance from the surface of the force plate to the origin of the force plate local reference frame; and a and b are the dimensions of the force plate in x and y directions, respectively.

The x and y coordinates of the location of the COP on the surface of the Bertec force plate were determined using

$$x'_t = \frac{z'_t F_x - M_y}{F_z}$$

$$y'_t = \frac{z'_t F_y - M_x}{F_z}$$

The errors in the location of the COP in the force plate local reference frame were corrected (24) and then transformed to the global reference frame.

The location of the resultant COP in the global reference frame was determined using

$$x_t = \frac{\sum_{i=1}^{3} x''_{t,i} F_{z,i}}{\sum_{i=1}^{3} F_{z,i}}$$

$$y_t = \frac{\sum_{i=1}^{3} y''_{t,i} F_{z,i}}{\sum_{i=1}^{3} F_{z,i}}$$

where x_t and y_t are coordinates of the location of the resultant COP in the global reference frame of sample t; $x''_{t,i}$ and $y''_{t,i}$ are coordinates of the location of the COP of force plate i in global reference frame of sample t; and $F_{z,i}$ is the resultant vertical ground reaction force of force plate i.

The maximum sway of the COP in each of the A-P and M-L directions was defined as the difference between the maximum and minimum values of the corresponding coordinates of the COP. The maximum sways in both A-P and M-L directions were determined for each standing trial. Only the maximum sway in M-L direction was determined for each walking trial. The recording of the sway of the COP in each walking trial of a given patient started at the first time when the resultant vertical ground reaction force of the three force plates was greater or

equal to the mean value of this force component obtained in standing trials of the given patient, and ended at the last time when this condition was satisfied. During this time period, both the subject and his cane were in the area of the force plates.

The total travel distance in each of the M-L (x) and A-P (y) directions in a standing trial was determined using

$$d_x = \sqrt{\sum_{t=1}^{T} (x_t - x_{t-1})^2}$$

$$d_y = \sqrt{\sum_{t=1}^{T} (y_t - y_{t-1})^2}$$

where d_x and d_y are total travel distances in x and y directions, respectively; and T is the number of time intervals during the data collection period for a standing trial or during the double support phase for a walking trial. Only the travel distance in M-L (y) direction was determined for each walking trial.

The mean travel speeds in the A-P (y) and M-L (x) directions in a standing trial were determined using

$$\overline{V}_x = \sqrt{\frac{\sum_{t=1}^{T} \left(\frac{x_t - x_{t-1}}{\Delta t}\right)^2}{T}}$$

$$\overline{V}_y = \sqrt{\frac{\sum_{t=1}^{T} \left(\frac{y_t - y_{t-1}}{\Delta t}\right)^2}{T}}$$

where $\overline{v}_x$ and $\overline{v}_y$ are mean sway speeds in x and y directions, respectively; and Δt is the time interval between two consecutive force plate data samples, which is 0.1 s for standing trials and 0.01 s for walking trials. For walking trials, only the mean sway speed in M-L (y) direction was determined.

Data Analysis

An analysis of variance with repeated measures was conducted to test the effect of support condition (no cane, GT cane, and WC cane) on each of the selected stability parameters. In each analysis, the stability parameter was the dependent variable, and the supporting condition was the independent variable. The 0.05 level of confidence was used to indicate statistical significance after considering the consequences of Type I and Type II errors. Follow-up t-tests were conducted to locate the differences if the result of an analysis of variance indicated a significant supporting condition effect. With the given overall level of confidence and the sample size, the power of the statistical tests in this study was no less than 0.9 if the true difference was not less than the true SD.

RESULTS

The mean values for the absolute cane lengths were 88 cm (SD 5 cm) for the GT cane and 86 cm (SD 5 cm) for the WC cane. There was an average absolute difference of 4.6 cm between the GT canes and patients' own canes, and 3.9 cm between the WC canes and patients' own canes. The mean relative cane lengths were 53 percent and 51 percent (SD about 3 percent) of the standing height for the GT cane and WC cane, respectively. The corresponding mean elbow angles were 45° (SD 10°) for the GT cane and 40° (SD 9°) for the WC cane (**Table 2**). The result of a paired t-test showed that there was no significant difference in the elbow angle between the two canes. For the most comfortable cane positions, seven patients put their canes in the anterior-lateral direction, two subjects placed their canes in the lateral direction, and one subject put the cane in the anterior direction.

The location-time history of the COP in a standing trial is shown in **Figure 3.** It was found a) that there was a significant difference in the maximum sway of the COP in both A-P and M-L directions between supporting conditions (**Tables 3** and **4**); b) that the maximum sways of the COP in both A-P and M-L directions were significantly smaller when standing with WC cane than standing with GT cane or without cane (**Figure 4**); and c) that there is no significant difference in the maximum sway of the COP between standing with GT cane and without cane (**Figure 4**).

It was also found a) that there was a significant difference in each of the total travel distances and mean travel speeds of the COP in the M-L direction (**Tables 5** and **6**); b) that the mean values of these two parameters were significantly decreased when using canes (**Figures 5** and **6**); and c) that the values of these two parameters

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Table 2.
Absolute and relative cane lengths and corresponding elbow angles.

	GT cane			WC cane			Patient's cane*		
	Absolute length (cm)	Relative length (%)	Elbow angle (°)	Absolute length (cm)	Relative length (%)	Elbow angle (°)	Absolute length (cm)	Relative length (%)	Elbow angle (°)
Mean	88.1	52.7	45.4	85.6	51.0	39.7	86.3	51.4	42.7
SD	4.7	2.6	10.1	4.9	2.5	9.3	3.5	2.6	6.7
Maximum	95.0	57.2	57.0	93.0	55.4	51.0	91.0	54.3	54.0
Minimum	83.0	51.2	25.0	78.0	48.2	21.0	83.0	47.1	35.0

*The cane a patient used on daily basis.

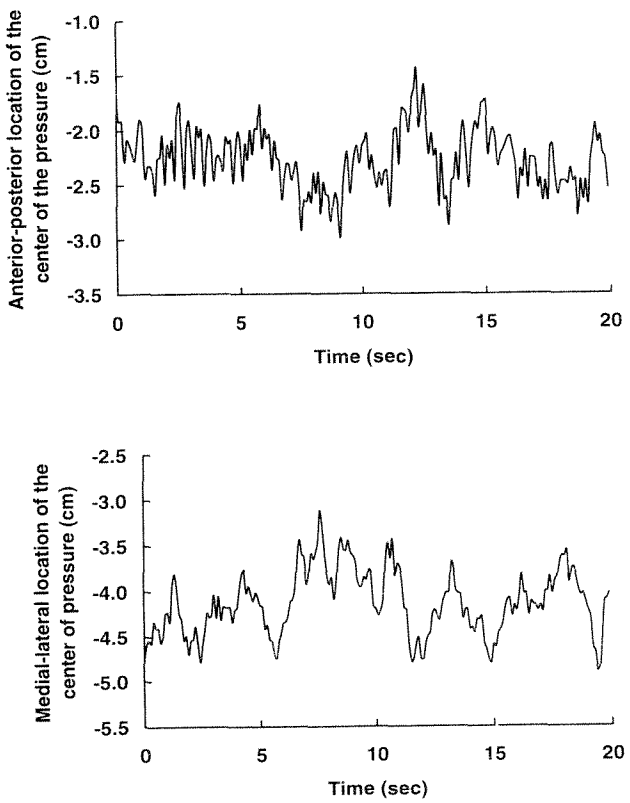

Figure 3.
The location-time history of COP in a standing trial.

Table 3.
Analysis of variance for maximum sway of the COP in the A-P direction for standing under different supporting conditions.

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Cane	2	15.86	7.83	9.31	0.0002
Subject	9	170.08	18.90		
Cane × Subject	15	14.16	0.94		
Within subject	53	47.37	0.89		
Total	79	247.47			

Table 4.
Analysis of variance for maximum sway of the COP in the M-L direction for standing under different supporting conditions.

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Cane	2	14.76	7.38	8.89	0.0004
Subject	9	63.30	7.03		
Cane × Subject	15	12.49	0.83		
Within subject	53	16.92	0.32		
Total	79	107.47			

for WC canes were significantly lower than those for GT canes (**Figures 5** and **6** and **Tables 5** and **6**). No significant difference was found in either the total travel distance or mean travel speed of the COP in the A-P direction between supporting conditions.

No significant difference was found in the maximum sway, the total travel distance, and mean sway speed of the COP in the M-L direction between different supporting conditions in the walking test.

Significant correlations were found between the maximum sways of the COP in standing tests and the elbow angle when the elbow angle was less than 40° (**Figure 7**). The correlation coefficients between the maximum sway of the COP in the A-P direction and the elbow angle and between the maximum sway of the COP in the M-L direction were −0.82 and −0.86 ($p<0.001$), respec-

Table 5.
Analysis of variance for the total travel distance of the COP in the M-L direction for standing under different supporting conditions.

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Cane	2	2597.65	1298.82	3.91	0.04
Subject	9	12755.04	1417.23		
Cane × Subject	15	4979.05	331.94		
Within subject	53	2882.04	58.81		
Total	79	23213.78			

Table 6.
Analysis of variance for mean travel speed of the COP in the M-L direction in standing under different supporting conditions.

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Cane	2	200.62	100.31	3.90	0.04
Subject	9	2459.92	273.32		
Cane × Subject	15	385.81	25.72		
Within subject	53	261.99	4.94		
Total	79	3308.34			

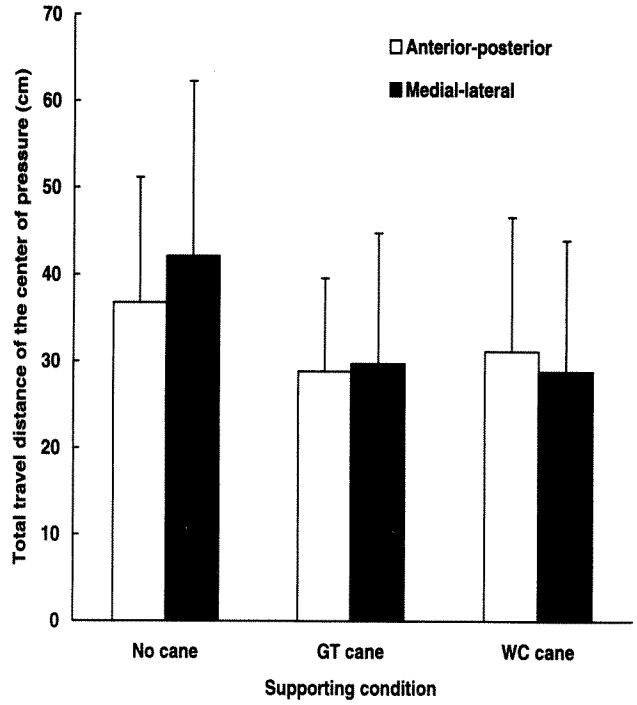

Figure 5.
Total travel distances of COP in A-P and M-L directions for different supporting conditions in standing test. Total travel distance in M-L direction was significantly decreased when standing with canes.

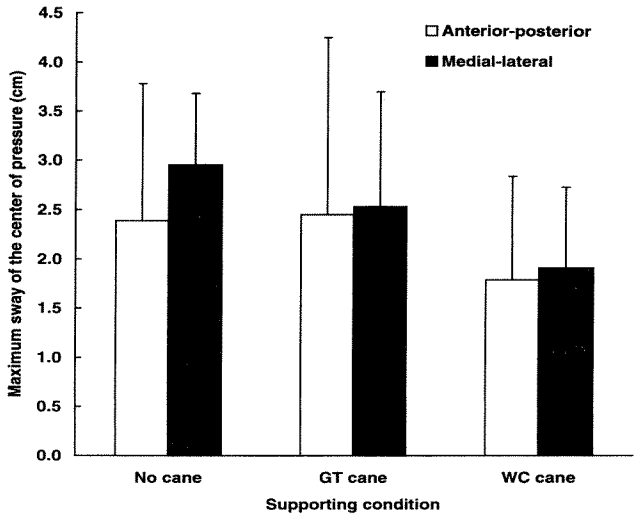

Figure 4.
Maximum sways of COP in A-P and M-L directions for different supporting conditions in standing test. Maximum sway of COP in A-P direction significantly decreased when standing with WC canes. Maximum sway of COP in M-L direction was significantly decreased when standing with canes, and further decreased when standing with WC canes.

tively. Although there were still large variations in both the maximum sways of the COP and the elbow angle, no significant correlation was found between the maximum sways of the COP and the elbow angle when that angle was greater than 40° (**Figure 7**).

No significant correlation was found between the maximum sway in either A-P or M-L direction and the relative cane length.

DISCUSSION

The purpose of this study was to examine the influence of cane length on the standing and walking stability of stroke patients. Maximum sway, total travel distance, and mean travel speed of the COP were used to represent standing and walking stability. These parameters were obtained by combining the data from three force plates. The mean values for the total travel distances of the COP in standing without a cane obtained in this study were

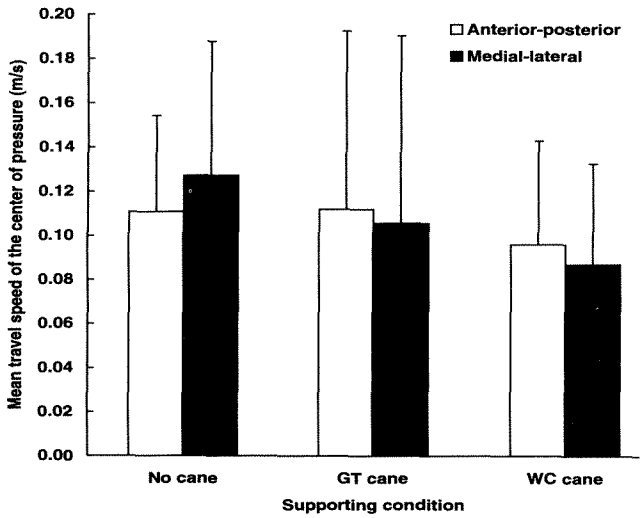

Figure 6.
Mean travel speeds of COP in A-P and M-L directions for different supporting conditions in standing test. Mean travel speed of COP in M-L direction was significantly decreased when standing with WC canes.

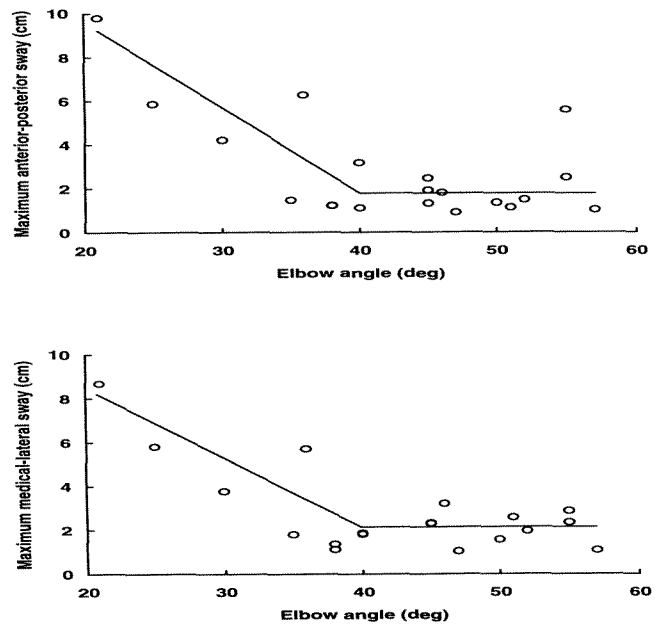

Figure 7.
Relationships between maximum sways of COP and elbow angle of the arm holding a cane. Maximum sways of COP in both A-P and M-L directions were decreased with increase in elbow angle when elbow angle was less than 40° ($r=-0.82$ and $p<0.001$ in A-P direction, and $r=-0.86$ and $p<0.001$ in M-L direction). Elbow angle had no significant influence on maximum sways of COP when >40°.

36.8 cm in M-L direction and 42.1 cm in A-P direction for 20 s. These results were consistent with those obtained in previous studies (18,25,26), and support the validity of the other two parameters obtained in this study.

The effect of cane use on the standing stability of stroke patients has been evaluated in several studies (8,9,21,22). Dettmann et al. found that the shift of the COP in the M-L direction was significantly correlated with the standing stability for stroke patients (27). It has been found that the standing stability of stroke patients can be significantly improved by using a cane, especially the standing stability in M-L direction. These findings are consistent with the results of this study, which showed that the total travel distance in the M-L direction and the mean travel speed in the M-L direction were significantly decreased when standing with canes. These results suggested that using canes did help stroke patients to improve their standing stability, and that this improvement was mainly in M-L direction. These results confirmed the findings of the previous studies and support the hypothesis of this study.

It is believed that different types of canes have different effects on the standing and walking stability of stroke patients. A study by Milczarek et al. showed that the total travel distances of the COP in both A-P and M-L directions were significantly shorter when using a single-point cane than when using a four-footed (quad) cane (18). It is also believed that cane length has some effects on the standing and walking stability of stroke patients (7,12,13). However, no study showing quantitative evidence to support this view was found. The results of this study showed that the maximum sways of the COP in both A-P and M-L directions for the WC cane were significantly smaller than those for the GT cane in standing. The results of this study also showed that the total travel distance and mean travel speed in M-L direction were significantly decreased when using the WC cane. Previous studies have demonstrated that the sway of the COP is an important parameter indicating postural stability and the tendency for falls (5,15). Therefore, the results of this study indicated that using a cane with the adjustment of length to wrist crease can further improve the standing stability of stroke patients and thus reduce the risk of falls for these patients.

The greater trochanter-to-ground distance and the wrist crease-to-ground distance are two parameters most commonly used in selecting appropriate cane lengths for stroke patients (1,7,11,12,18). It was found in this study

that the mean for the length of the WC canes was about 2 cm shorter than that for the length of the GT canes (**Table 2**). However, this does not necessarily mean that the WC canes are always shorter than the GT cane for every individual patient. It was found that the lengths of the WC canes for 2 of the 10 patients were longer than those of the GT canes for them. Like the rest of the patients, the maximum M-L sways of the COP of these two patients in standing with WC canes were significantly decreased. These results suggested that there is no relationship between the standing stability of the stroke patients and the absolute cane length, and thus do not support the view that shorter canes are better than the longer canes (11).

In addition to the distance from the greater trochanter to the ground and the distance from the wrist crease to the ground, another possible parameter for determining the appropriate cane length is the relative cane length to the standing height. The results of this study showed that this parameter had a range of variation of about 6 percent of standing height for both the GT and the WC canes. For the shortest patient in this study, this variation in the relative cane length could result in an error of 9 cm in the absolute cane length. The results of this study further showed that the relative cane length had no significant correlation with the standing stability of the stroke patients. These results suggested that the relative cane length is not a reliable parameter for determining cane length for individual patients.

The elbow angle is another parameter commonly used for selecting appropriate cane length (7,18), although the use of this parameter has not been validated. It has been recommended that a cane length corresponding to an elbow angle between 15° and 30° is optimum (7,18). In a study by Robinson, a load cell was installed on the tip of a cane to record the force on the tip of the cane, and a patient with hip pain was tested. The results of this study showed that the weightbearing on the cane was maximum when the elbow angle was about 30°. Therefore, the cane length corresponding to the elbow angle of 30° was recommended for cane prescriptions for various cane users (28). However, the results of this study showed a) that the maximum sways of the COP in both A-P and M-L directions were negatively correlated to the elbow angle when the elbow angle was less than 40° (**Figure 7**), and b) that the elbow angle had no significant correlation with the maximum sway of the COP in either A-P or M-L direction when the elbow angle was greater than 40°. These results suggested that the standing stability of the stroke patients with canes was sensitive to the elbow angle when the elbow angle was less than 40°, and that the elbow angle for cane prescription should be no less than 40°. However, the maximum sways of the COP in both A-P and M-L directions still had large variations but had no significant correlations with the elbow angle when the elbow angle was greater than 40°. This result suggested that the elbow angle was not a reliable parameter for determining appropriate cane length when it was greater than 40°.

Few studies reported quantitative analysis of the walking stability of stroke patients. In this study, the maximum sway, the total travel distance, and the mean travel speed of the COP in M-L direction in walking under different supporting conditions were compared and no significant difference was found. There are at least three possible explanations for the nonsignificant results obtained in walking tests: a) there is truly no difference in walking stability under different supporting conditions; b) the sample size of this study was too small and thus the power of the test was too low to detect the small difference in the walking stability between different supporting conditions; and c) the movement of the COP associated with the stability was covered by the within-subject variations in gait pattern. Considering the method used in this study and the results obtained for standing stability, it seems that the latter two explanations are most likely to be true. In the future studies, more subjects and more sophisticated stability measures may need to be used.

CONCLUSIONS

The results of this study appear to support the following conclusions:

1. The total travel distance and the mean travel speed of the COP in the M-L direction were significantly decreased for stroke patients when standing with the aid of canes.
2. The maximum sways of the COP in both A-P and M-L directions, the total travel distance of the COP in M-L direction, and mean travel speed of the COP in M-L direction were significantly decreased for stroke patients when standing with the WC canes.
3. The maximum sways of the COP in both A-P and M-L directions when standing with cane were decreased with the increase in the elbow angle of the arm holding the cane until the elbow angle reached 40°.

These results support the hypothesis of this study. Based on these results, it is recommended that the WC canes be used for stroke patients. However, the cane length should be adjusted to have an elbow angle greater than 40° if the elbow angle corresponding to the WC cane for a given patient is less than 40°.

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