J. Phys. Ther. Sci.
19: 117–123, 2007

Electromyography Analysis of Shoulder Joint Muscles in Standing with Three Ambulatory Aids

TOSHIO SOMA, RPT, PhD[1)], HIDEAKI ONISHI, RPT, PhD[1)], MINEO OYAMA, OTR, PhD[2)], YOSHIHIRO EHARA, PhD[1)], YUKIO KUROKAWA, RPT, PhD[1)], KATSUHIKO TACHINO, MD, PhD[3)]

[1)]*Department of Physical Therapy, School of Health Sciences, Niigata University of Health and Welfare: 1398 Shimami-cho, Kita-ku, Niigata, 950-3198, Japan.*
TEL & FAX +81 25-257-4730, E-mail: soma@nuhw.ac.jp
[2)]*Department of Occupational Therapy, School of Health Sciences, Niigata University of Health and Welfare*
[3)]*Department of Impairment Study, Graduate Course of Rehabilitation Science, Division of Health Sciences, Graduate School of Medical Science, Kanazawa University*

Abstract. We investigated the muscle activity of the shoulder joint during single-leg standing three types of ambulatory aid, T-shaped cane (T-cane), Quadripod cane (Q-cane) and Lofstrand crutch (L-crutch) in which were used. The left leg of eight healthy volunteers was assumed to be an affected leg. All participants were asked to keep 20% of the weight-bearing load on the ambulatory aid and the electromyography (EMG) was recorded. Results of the analysis of variance followed by Fisher's PLSD post hoc test reveal that EMG values of the medial and posterior part of the deltoid muscle were significantly related to the three types of ambulatory aid, but the anterior part of the deltoid was not. EMG values of the biceps brachii, triceps brachii, and latissimus dorsi were significantly larger in T-cane and Q-cane users than in L-crutch users, and EMG of the pectoralis major was significantly larger in Q-cane users than in L-crutch users. These results permit us to select an appropriate ambulatory aid for patients.
Key words: Electromyography (EMG), Ambulatory aids, Shoulder joint muscles

(This article was submitted Apr. 28, 2006, and was accepted Dec. 25, 2006)

INTRODUCTION

Several investigations of ambulatory locomotion with cane or crutches have used motion analysis and focused on the lower limbs[1–11]. However, the muscle activity of upper limb as a weight-bearing limb has not been well studied[12–14]. Milczarek J.J. et al. reported that when patients with hemiparesis use a cane to assist standing balance, the postural sway decreases and the average position of the center of pressure shifts forward and towards the cane side[12]. Opila K.A. et al. analyzed post-operative orthopedic subjects using canes and elbow crutches for the loading effect of upper limb moment using a 3-dimensional motion capture system[13]. Reisman M. et al. investigated swing-through axillary crutch gait to determine the effects of gait speed, crutch length and handle position on the forces exerted at the hands and on the moments exerted about the elbow joints. They reported that changing gait speed or crutch length did not affect elbow moment[14]. Additionally, Chiou-tan F.Y. et al. reported that the difference in the wrist joint angle when using a cane has an effect on elbow joint muscles' activity during cane walking[15]. The electromyography (EMG) activity analyzed in this study was that of the biceps brachii, triceps brachii and brachioradialis muscles, as well as the EMG activity of the three parts of the deltoid, pectoralis major and the latissimus dorsi of the shoulder joint during the use of a T-cane, Quadripod cane or Lofstrand crutch in the standing position. The present study was designed to investigate the EMG activity of the shoulder joint muscles during single-leg standing with T-cane, Quadripod cane and Lofstrand crutch, in order to clarify the differences in the upper limb muscle activities when using different supports, to enable therapists to provide the best cane selection for patients.

METHODS

Participants

Eight healthy, male volunteers (ages 19–31 years, mean 21.4 years) participated in this study. Their average height and body weights were 170.6 cm (164.0–177.0, ± 4.0) and 62.8 kg (56.0–74.0, ± 6.1), respectively. Informed consent was obtained from all participants after explanation of the nature and possible consequences of the study.

Ambulatory aids

Three types of ambulatory aid were used in this study. The T-shaped cane (IA-98H, SAKAI Corp., Tokyo) has a T-shaped handgrip and one point of contact on the ground. The Quad cane (IA-86, SAKAI Corp., Tokyo) has four points of contact on the ground, and the Lofstrand crutch (R-23420, SAKAI Corp., Tokyo) has a handgrip and cuff that supports the forearm.

Procedures

In the present study the left lower limb of the participants was assumed to be the affected leg, and the right limb the unaffected leg. In the experiment, the T-cane, Q-cane and L-crutch were held contralateral to the affected leg side. The length of the cane or crutch was determined by positioning the elbow joint at 30 -degrees flexion and the tip of the cane or the crutch at 15 cm anterolateral of the little toe of the unaffected leg.

The EMG activities of the shoulder joint muscles (biceps brachii, triceps brachii, anterior, medial and posterior part of the deltoid, pectoralis major and the latissimus dorsi) were recorded by bipolar surface Ag-AgCl electrodes (Ag-AgCl Blue sensor, GE Marquette Medical Systems Japan, Ltd). The distance between each electrode was 1.0 cm.

Each participant was instructed to stand on the left foot (supposed affected leg) for 5 second with a load of 20% of his body weight (partial weight bearing of 20% or 20%PWB) on the cane or crutch. To monitor a constant load on the cane or the crutch, a lower limb weight-bearing load trainer (MP-100, ANIMA Corp., Tokyo) was attached to the foot of the affected leg. If the weight-bearing surpassed 80% of body weight an audible alarm was set off. The loading was confirmed with force plate (OR6-6-2000, AMTI, MA) measurement data during the data collection. When the required weight-bearing on the affected leg was exceeded, the measurement was considered invalid for data analysis.

The EMG activity at maximum voluntary isometric contraction (MVC) of the upper limb muscles was measured for normalizing the EMG activities in the standing position. The MVC was measured in the supine position with the shoulder abducted at 10 degrees and the elbow flexed at 30 degrees, the same angles as when the subject had 20%PWB in the standing position. The trunk, pelvis and both lower limbs were fixed with belts during the MVC measurement. We conducted two trials with each participant and gave them the 3 minutes rest between the trials of the 5-second MVC test to minimize muscle fatigue. Prior to the experiment, participants were allowed a number of practices to make them proficient at the task.

Data acquisition

Joint angle

Joint angles of the upper limb were measured by using a 3-dimensional motion capture system (VICON512, Oxford Metrics Ltd., Oxford) with 6 charge-coupled device cameras (sampling frequency: 60 Hz). The angle of the shoulder joint was determined from the positions of three infrared ray markers on the elbow (lateral epicondyle of the humerus), the shoulder (acromion) and the hip (the point of the proximal two-third of the line from the greater trochanter to the anterior superior iliac spine). The angle of the elbow joint was determined by three markers on the shoulder, the elbow (olecranon) and the wrist (styloid process of the ulna).

EMG analysis

The EMG signals were recorded at a sampling

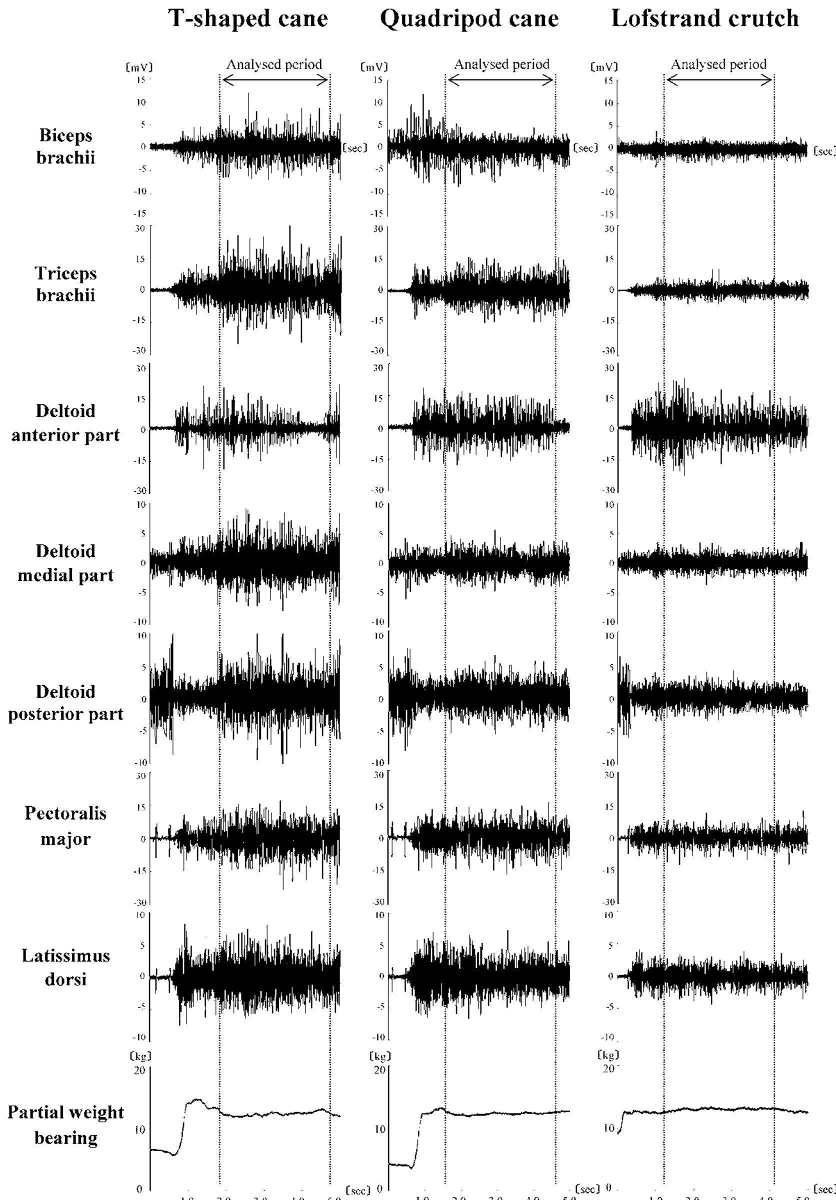

Fig. 1. Electromyography of the shoulder joint muscles in standing with three types of ambulatory aid.

Table 1. Shoulder joint angles of the upper limb in standing with ambulatory aids [°]

	Extention	Abduction
T-cane	3.8 ± 2.1	12.8 ± 6.9
Q-cane	2.9 ± 1.4	13.3 ± 5.8
L-crutch	1.8 ± 1.1	7.9 ± 3.1

n=8, mean ± S.D.

rate of 1 kHz, using a pre-amplifier (DPA-10PB-J16, DIA MEDICAL SYSTEM), EMG amplifier (BIOTOP, NEC SANEI) and a 12 bit A/D converter (ADXM-98FX, Contec, Kobe). The EMG signals were band-pass filtered from 10 Hz to 500 Hz and full-wave rectified. The integrated electromyography (IEMG) was calculated when the PWB was kept consistent for 3 seconds at 20%PWB.

The IEMG values of MVC of each muscle were calculated over 500 msec. The recording was made

Table 2. %IEMG values of the shulder joint muscles in standing with three types of ambulatory aid [%]

	T-cane	Q-cane	L-crutch	
Biceps brachii	2.1 ± 0.5	1.9 ± 0.6	1.4 ± 0.5	4), 5)
Triceps brachii	23.5 ± 15.6	17.7 ± 7.4	8.9 ± 3.6	2), 5)
Deltoid anterior part	2.9 ± 1.5	2.6 ± 1.7	3.7 ± 1.7	
medial part	6.7 ± 2.8	4.9 ± 2.1	3.1 ± 1.2	1), 2), 5)
posterior part	5.1 ± 1.7	3.5 ± 1.5	2.0 ± 0.9	1), 2), 5)
Pectoralis major	15.8 ± 7.1	19.7 ± 8.3	11.7 ± 4.4	4)
Latissimus dorsi	22.8 ± 12.6	27.9 ± 13.8	15.1 ± 4.7	3), 4)

1) T-cane–Qcane $p<0.05$
2) Q-cane–L-crutch $p<0.05$
3) T-cane–L-crutch $p<0.05$
4) Q-cane–L-crutch $p<0.01$
5) T-cane–L-crutch $p<0.01$
ANOVA and Fisher's PLSD post-hoc test were used to test for differences in the values of %IEMG among the T-shaped cane, Quadripod cane and Lofstrand crutch. Error bars indicate standard deviation (S.D.). n=8.

from 250 msec before and after maximum amplitude. The largest EMG amplitude of each muscle out of 2 MVC trials was used in the analysis. The EMG activities in the standing position were normalized (%IEMG) based on the IEMG of MVC.

Data analysis

EMG activity was analyzed by analysis of variance followed by Fisher's PLSD post hoc test. The significance level for all statistical analysis was chosen as $p<0.05$.

RESULTS

Figure 1 shows an example of the EMG activities of the shoulder joint muscles during standing with 20%PWB using the T-cane, Q-cane and L-crutch. A total of 5 seconds of EMG were recorded, and the last 3 seconds were analyzed. The EMG activity results shows that the biceps brachii, triceps brachii, medial and posterior part of the deltoid, pectoralis major and latissimus dorsi were larger with the T-cane and Q-cane than with the L-crutch.

Table 1 shows the average shoulder joint angles of the upper limb with ambulatory aids of all participants. The values of the shoulder joint angles are the averages of the analyzed period of 3 seconds.

Average %IEMG values of each muscle of all the participants are shown in Table 2. The %IEMG values were significantly different among the three types of the ambulatory aid in the deltoid medial and deltoid posterior muscle parts ($p<0.05$), but not in the anterior part of the deltoid muscle. The %IEMG values of the biceps brachii, triceps brachii and the latissimus dorsi were significantly larger in T-cane or Q-cane use than in L-crutch use. For the pectoralis major, %IEMG value was significantly larger in Q-cane use than in L-crutch use ($p<0.05$).

DISCUSSION

The values of %IEMG for the biceps brachii and triceps brachii were significantly larger in T-cane or Q-cane use than in L-crutch use. This result suggests that the biceps brachii and triceps brachii co-contract to keep the stability of the elbow joint when the T-cane or Q-cane are held to stabilize against swaying. The EMG activities have a direct relation to the joint moment[16]. In general, when the weight-bearing load is on the cane, the force of the floor reaction vector to the T-cane is adjusted in such a way that it goes through the long axis of the cane to prevent excessive joint moment at the wrist. Moreover, the distance between the force vector and the elbow joint or the shoulder joint is large, thus, the shoulder and elbow joint moment are large[17]. In a previous study it has been demonstrated that the muscle activity of the shoulder in T-cane use is larger than in L-crutch use during walking with 20%PWB[17]. This result suggests that the distance from the elbow joint to the

T-shaped cane

Fig. 2. Relation between floor reaction force vector and shoulder, elbow and wrist joint in standing with T-shaped cane. F_T: floor reaction force vector on T-cane. S_T: distance between floor reaction force vector and shoulder joint. E_T: distance between floor reaction force vector and elbow joint. W_T: distance between floor reaction force vector and wrist joint.

Quadripod cane

Fig. 3. Relation between floor reaction force vector and shoulder, elbow and wrist joint in standing with Quadripod cane. F_Q: floor reaction force vector on Q-cane. E_Q: distance between floor reaction force vector and shoulder joint. E_Q: distance between floor reaction force vector and elbow joint. W_Q: distance between floor reaction force vector and wrist joint.

line of the force vector might become longer when using the T-cane or Q-cane, since the floor reaction force vector passes through near the wrist joint (Figs. 2 and 3). Therefore, the elbow joint moment and the %IEMG values of the biceps brachii and triceps brachii would be larger. On the other hand, low EMG activities were observed in the biceps brachii and triceps brachii during use of the L-crutch. The L-crutch has a cuff attached around the antebrachial region that stabilizes the wrist joint, and the floor reaction force vector to the crutch is directly applied to the shoulder and the elbow

Lofstrand crutch

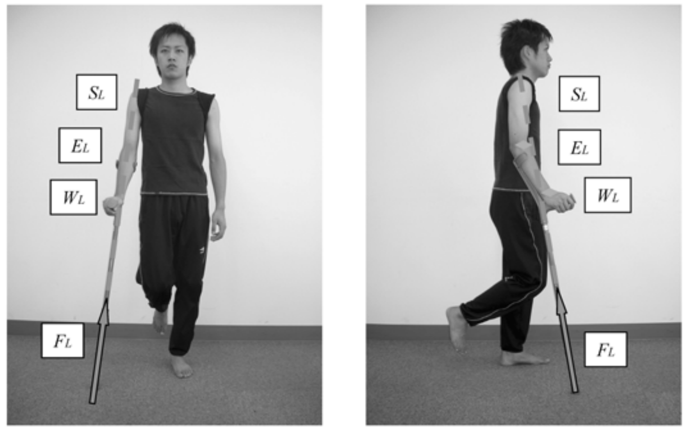

Fig. 4. Relation between floor reaction force vector and shoulder, elbow and wrist joint in standing with Lofstrand crutch. F_L: floor reaction force vector on L-crutch. S_L: distance between floor reaction force vector and shoulder joint. E_L: distance between floor reaction force vector and elbow joint. W_L: distance between floor reaction force vector and wrist joint.

joints[18]. Thus, the L-crutch can support a heavier load than the T-cane or the Q-cane, which are held only by the handgrip[17]. The elbow joint moment seems to be small when using the L-crutch because the force vector passes through near the elbow joint (Fig. 4). Therefore, the %IEMG values of the biceps brachii and triceps brachii are likely smaller in L-crutch use.

The values of %IEMG of the medial and posterior part of the deltoid, pectoralis major and the latissimus dorsi were significantly larger in T-cane and Q-cane use than in L-crutch use. This result suggest that the force vector in T-cane or Q-cane might go though near the wrist and away from the shoulder (Figs. 2 and 3). However, in L-crutch the force vector might go through near the shoulder joint (Fig. 4)[17].

Understanding the different effects of these three types of ambulatory aid would help therapists to choose an appropriate assistive device for patients with different disorders. The use of the L-crutch requires less muscle activity of the shoulder joint and supports a heavier load and would work most effectively for a patient who needs to support a heavy load with minimum upper limb support, such as a patient who had upper and lower limbs injured in a traffic accident. The T-cane or Q-cane might be selected for an elderly or orthopedic patient with an impaired unilateral lower limb, who does not need to support a heavy load, and needs only balancing assistance[19–21].

LIMITATIONS OF STUDY

The data analyzed in this study were obtained with a protocol of only 20% of PWB. Furthermore the participants were all healthy volunteers who didn't use ambulatory aids. Thus, further studies are underway to examine the effect of the Q-cane, T-cane and L-crutch in patients, to confirm if the results seen in this study are appropriate for use in clinical practice.

This research was supported by a Grant-in-Aid for Scientific Research [Scientific Research for Young Investigators B (17700462-6803)], Ministry of Education, Culture, Sports, Science and Technology, and Niigata University of Health and Welfare.

REFERENCES

1) Baxter ML, Allington RO, Koepke GH: Weight-distribution variables in the use of crutches and canes. Phys Ther, 1969, 49: 360–365.
2) Bennett L, Murray MP, Murphy EF, et al.: Locomotion

assistance through cane impulse. Bull Prosthet Res, 1979, 9: 38–47.
3) Edwerds BG: Contrateral and ipsilateral cane usage by patients with total knee or hip replacement. Arch Phys Med Rehabil, 1986, 67: 734–740.
4) Ely DD, Smidt GL: Effects of Cane on variables of gait for patients with hip disorders. Phys Ther, 1977, 57: 777–784.
5) Li S, Armstrong CW, Cipriani D: Three-point gait crutch walking: variability in ground reaction force during weight bearing. Arch Phys Med Rehabil, 2001, 82: 86–92.
6) Mendelson S, Milgrom C, Finestone A, et al.: Effect of cane use on tibial strain and strain rates. Am J Phys Med Rehabil, 1998, 77: 333–338.
7) Neumann DA: An Electromyographic study of the hip abductor muscles as subjects with a hip prosthesis walked with different methods of using a cane and carrying a load. Phys Ther, 1999, 79: 1163–1176.
8) Neumann DA: Hip Abductor muscle activity as subjects with hip prostheses walk with different methods of using a cane. Phys Ther, 1998, 78: 490–501.
9) Opila KA, Nicol AC, Paul JP: Force s and impulses during aided gait. Arch Phys Med Rehabil, 1987, 68: 715–722.
10) Vargo MM, Robinson LR, Nicholas JJ: Contralateral v ipsilateral cane use. Effects on muscles crossing the knee joint. Am J Phys Med Rehabil, 1992, 71: 170–176.
11) Wells RP: The kinematics and energy variations of swing-through crutch gait. J Biomech, 1979, 12: 579–585.
12) Milczarek JJ, Kirby RE, Harrison ER, et al.: Standard and four-footed canes: Their effect on the standing balance of patients with hemiparesis. Arch Phys Med Rehabil, 1993, 74: 281–285.
13) Opila KA, Nicol AC, Paul JP: Upper limb loadings of gait with crutches. J Biomech Eng, 1987, 109: 285–290.
14) Reisman M, Burdett RG, Simon SR, et al.: Elbow moment and forces at the hands during swing-through axillary crutch gait. Phys Ther, 1985, 65: 600–605.
15) Chiou-tan FY, Magee KN, Krouskop TA: Comparison of upper limb muscle activity in four walking canes. A preliminary study. J Rehabil Res Dev, 1999, 36: 94–99.
16) Winter DA: Biomechanics and motor control of human movement. USA: John Wiley & Sons, Inc., 1990.
17) Soma T, Onishi H, Oyama M, et al.: Study of electromyography of the shoulder joint muscles while partial weight bearing gait with a crutch. Bull Jpn Soc Pros Orthop, 2004, 20: 141–147.
18) Soma T, Onishi H, Momose K, et al.: Maximum load on crutch and the load on shoulder and elbow joints while walking with a crutch. Niigata J Health and Welfare, 2003, 3: 69–76.
19) Ashton-Miller JA, Yeh MW, Richardson JK, et al.: A cane reduces loss of balance in patients with peripheral neuropathy: results from a challenging unipedal balance test. Arch Phys Med Rehabil, 1996, 77: 446–452.
20) Jeka JJ: Light touch contact as a balance aid. Phys Ther, 1997, 77: 476–487.
21) Maeda A, Nakamura K, Higuchi S, et al.: Postural sway during cane use by patients with stroke. Am J Phys Med Rehabil, 2001, 80: 903–908.