Assessment of muscle electrical activity in spinal cord injury subjects during quiet standing

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Disturbed motor control due to a spinal cord lesion is generally considered to be the cause of unusual standing utilized by those people suffering from spinal cord injury (SCI). Electromyographic (EMG) leg muscle activity during quiet standing was analyzed in four functional groups of SCI subjects and compared to the data of healthy people. A rating system for visual assessment of the stripchart recording was developed and its adequacy was confirmed by comparison of the rating system with computerized integrated EMG values of some of the recordings. The division of 47 subjects into functional groups was based on their ambulatory capabilities ie a non-support group, crutches, cane and walker user groups. Mean total muscle EMG activity was the highest in the group of subjects standing without support and it was significantly higher when compared to the other groups including the control group. Comparison between more and less active legs within each group showed significant differences in the non-support and crutches groups, whereas cane, walker and control groups showed nearly symmetric EMG patterns during standing. Analysis of the contribution of single muscles to the asymmetry of standing showed significantly higher activity in hamstring and triceps surae muscles than in other muscles in the non-support group. No significant differences in the activity of single muscles compared to their contralateral pair between more and less active leg were obtained in the remaining groups. It is evident, however, that different support devices used by SCI subjects greatly influence EMG patterns of postural muscles. The present findings suggest that disturbed conduction in the spinal cord is related to altered motor strategies employed by SCI subjects in attempts to perform the same volitional act as before the injury.

Keywords: posture; spinal cord injury; electromyography; integrated electromyogram

Introduction

Injury to the spine and spinal cord is one of the most devastating injuries that can distress a human being. The level of independence in a person who sustains a severe spinal injury is altered, at best, independence in walking without support or with supportive devices is preserved but usually the necessity of passing through several levels of functional disability appears to be the rule. Yet, when the highest level of independence is reached, stability of standing in humans after spinal cord injury is uncertain or is disturbed to such a degree that utilization of physical orthoses and assistive devices is required. Gait presents such features as slowness, awkwardness and the subject is usually capable of only a very reduced control of speeds. Quality of standing and walking seems not to depend on the injury level but more likely on the extent of the spinal cord lesion.

Posture is the upright, well-balanced standing of the human subject in a normal position. In this sense, the

electromyography of posture deals with the muscle activity against gravity.¹ During standing and ambulation, the central nervous system presumably controls body segment alignment, ultimately controlling the location of the center of gravity, ie the brain controls posture to maintain balance. Since postural adjustments are constantly, associated with purposeful movements, quantitative measures of posture and postural control are essential to understanding normal and pathological human movement.^{2,3} Experimental animal work has shown that selective destruction of certain descending pathways causes specific functional deficits.^{4,5} In subjects with SCI, the lesions do not selectively interrupt corticospinal, rubrospinal, or propriospinal pathways as can result in experimental SCI but have a much more diffuse character. The work of McKay *et al*⁶ on humans with SCI suggests that the usual strategy used to perform such voluntary motor acts as multijoint hip and knee flexion and extension and single joint ankle dorsi- and plantar flexion is altered but the subjects are still able to employ alternative motor strategies in attempts to perform the same volitional motor acts as

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before the injury. Studies on muscle activity distribution during standing in subjects with SCI have not been performed up to date, consequently stripchart EMG recordings of 47 SCI subjects were reviewed in a retrospective manner. The aim of the present study was to assess the mechanisms utilized by SCI subjects to maintain the upright posture. In order to determine different patterns of muscle activation, the EMG from postural muscles of the lower limbs and from the lower trunk were analyzed. A rating system based on visual assessment of the EMG signal amplitude was developed to evaluate such features of quiet standing as symmetry, level of activation of certain muscle groups, ie anterior, posterior, proximal or distal muscle compartments, or activity of single muscles. Utilization of similar rating systems for evaluation of motor function has been previously reported by Nesmeyanova⁷ in SCI patients and by other authors^{8,9} in healthy subjects. We also analyzed computerized recordings of some of the same subjects calculating the integrated EMG (IEMG) of each recorded muscle to ascertain the validity of the rating system. In the present study, EMG activity in the postural muscles was quantitatively evaluated in four different functional groups of SCI subjects and compared to the control group to find discriminating patterns of muscle activation during standing.

Materials and methods

Subject recruitment

All subjects for this study were taken from the registry generated by the Division of Restorative Neurology and Human Neurobiology. Forty seven subjects (34 men, 13 women age 39 ± 14 years) were screened, with different levels of traumatic spinal cord injury (SCI). The level of spinal cord lesion ranged from C2 to L5. Patients were divided into four functional groups according to assistive devices required for walking: no support (NS), cane (CA), crutch (CR) and walker (WA) group. Further details of the subjects are summarized in Table 1. There were repeated recordings of 13 of the subjects. For a control group (CO) seven healthy subjects (four men, three women, mean age 36 ± 7 years) were examined.

To show the different patterns of muscle activation

during standing, multichannel surface EMG from lower limb muscles was analyzed. EMG was recorded placing bipolar surface electrodes (diameter 10 mm) over the muscle belly of both right and left paraspinal (PS), quadriceps (Q), hamstring (H), tibialis anterior (TA) and triceps surae (TS) muscle groups. The EMG signals were amplified by an Elema-Schonander (Elema-Schonander, Schaumburg, IL) 16-channel electroencephalograph, with a 100, 200, or 300 $\mu\text{V}/\text{cm}$ sensitivity and a 0.5 Hz to 1 kHz bandwidth displayed on ink jet recorder. Prior to each experiment the electroencephalograph was calibrated with the same setting of amplification for all channels. Stripchart recordings were collected in all studies. Additionally some studies were on-line computerized as well as video-recorded. Standardized protocol was used to control standing of all subjects. They stood looking straight forward with eyes open in a comfortable position, fully relaxed before the recording began. Subjects stood their heels 15 cm apart and with toes turned out by approximately 25° . Recording lasted 1 min while subjects had their eyes open. When subjects were not able to stand independently they used the same support and orthopedic devices like orthoses and braces as during normal walking. In detail, subjects from CR group used 12 bilateral elbow crutches, one right arm crutch; subjects from CA group - three one cane and two bilateral canes; and from WA group - seven used a walker. Braces and orthoses were used by two subjects in NS group, by 11 in CR group, by two in CA group and by 6 in WA group.

Methods of analysis

A rating system for the Visual Assessment of the stripchart recordings (VA) was developed. The measurements of each recorded muscle EMG amplitude were taken by a ruler and transferred to the rating system (for further details see Table 2), which resulted in a single number representing EMG in a quantitative fashion. That number showed averaged EMG activity recorded through the whole period of 1 min of quiet standing. In addition, to confirm the visual rating we calculated the correlation coefficient between the VA score and IEMG values which were calculated for each single muscle from computerized data of five individual

Table 1 Functional spinal cord injury subject groups participating in the study; characterization of the healthy subject is included

	<i>Non-support</i>	<i>Cane(s)</i>	<i>Crutch(es)</i>	<i>Walker</i>	<i>Healthy</i>
Number of subjects	22	5	13	7	7
mean age $\pm$ SD	41 ± 16	42 ± 12	36 ± 11	39 ± 13	36 ± 7
Injury level					
cervical SCI	13	1	6	3	—
thoracic SCI	8	2	5	4	—
lumbar SCI	1	2	2	—	—

Table 2 EMG scoring system for different gains of stripchart recordings

Score	100 $\mu V/div$	150 $\mu V/div$	200 $\mu V/div$	300 $\mu V/div$
1	0–6	0–4.5	0–3	0–2
2	6–12	4.5–9	3–6	2–4
3	12–18	9–13.5	6–9	4–6
4	18–24	13.5–18	9–12	6–8
5	24–30	18–22.5	12–15	8–10
6	30–36	22.5–27	15–18	10–12
7	36–40	27–31.5	18–21	12–14
8	40–46	31.5–36	21–24	14–16

Measurements were done in millimeters

subjects. EMG recorded during the first 10 s of quiet standing starting from the moment of complete relaxation of the subject were assessed by calculation of IEMG and once again by VA. The choice of the time period was based on the observation that subjects stood more stable in the early part of the task compared to the later part when disturbances of balance more frequently occurred. VA was indispensable for retrospective evaluation of available stripchart recordings which had not been recorded on computer.

Simple drawings showing the distribution of the EMG activity in each subject were prepared. The total muscle activity (TMA) was calculated for each leg. The side presenting with higher TMA value, regardless of whether it was right or left, was analyzed as one entity for all subjects while the side with smaller activity was analyzed as another. Averaged TMA values ($\pm$ SD) were computed using the above method in all subject groups. Division into more and less active side was not employed in the healthy control group since statistical differences in TMA between legs were not observed.

To analyze the results of VA paired *t*-test was used to detect statistical difference between EMG activity in more and less active legs in each subject group. Each single muscle activity, different muscle compartments activities, ie anterior compartment AC (sum of Q and TA muscles), posterior compartment PC (sum of PS, H and TS or only H and TS muscles), distal compartment DC (sum of TA and TS), proximal compartment PxC (sum of Q and H), and total muscle activity were analyzed. In addition the above mentioned values were calculated as a sum of more and less active legs and later they were compared between NS and all other groups as well as between the control and all other groups.

Results

The analysis of SCI subjects showed varying patterns of leg muscle activation during standing. Total muscle activity presented as a total EMG score in all functional groups is displayed in Figure 1. The highest total mean value of the score (10.41 ± 3.95) was obtained in the NS standing group while the mean

values in the CA group (7.75 ± 1.86), CR group (7.05 ± 2.02), WA group (6.5 ± 2.36) and the CO group (5.42 ± 0.65) were significantly lower when compared to the NS group ($P < 0.001$). The total EMG activity was significantly less in the CO group than in CR or CA groups ($P < 0.003$). No other differences were observed between the groups.

Distribution of EMG activity between more and less active leg within each group is shown in Figure 2. A significant difference was seen between the legs in both NS ($P < 0.01$) and CR ($P < 0.02$) groups. The CA, WA and CO groups showed no differences in EMG output between the two legs.

The question as to which muscle was principally responsible for the increased motor output in the more active leg was also looked into. When comparing anterior,

Figure 1 Total EMG activity displayed as a sum of the scores obtained from 4 muscles of both legs (Q, H, TA, TS) and from the paraspinal muscles in all functional SCI groups and the healthy control group during standing. Means $\pm$ SD calculated for both sides were plotted. The minimum total score was 5 when the EMG activity was absent

Figure 2 Differences between EMG activity in the muscles of more and less active leg expressed as the percentage of the total EMG activity $\pm$ SD recorded from both legs during standing. All functional SCI groups, and the healthy subjects are presented. Note the highest asymmetry in the non-support group

posterior, distal and proximal muscles within subjects in NS group, significant differences were observed between more and less active legs. The result is shown in Table 3. Muscles such as H ($P < 0.02$) and TS ($P < 0.04$) principally contributed to asymmetry whereas TA activity only showed a trend towards significance. No statistical difference was obtained between PS and Q muscles. The remaining SCI groups showed no significant differences in single muscle activity between more and less active legs.

The distribution of EMG activity between AC and PC within each functional group is depicted in Figure 3. Only leg muscles were assessed. Two muscles from anterior (Q+TA) as well as from posterior (H+TS) compartments were used. No differences between analyzed compartments were observed although tendency to higher activity in the PC compared to AC was seen in all SCI groups. Also healthy subjects showed a tendency towards higher activity in PC.

The analysis of the activity of the proximal and distal compartments showed no differences in all SCI groups. Single muscle EMG scores from all corresponding muscles were summed and also the sum of the EMG scores was calculated for AC, PC and for all studied muscles from the more and less active leg. Differences of these values between NS and all other groups as well as between CO and all other groups are shown in Table 4. Each muscle output and the total EMG activity were significantly different when CO and NS groups were compared ($P < 0.001$). Testing of the H, TA, TS, AC and PC muscles between NS and CR as well as between NS and WA groups showed significant differences, whereas significance was not reached in the PS and Q muscles. Comparison between NS and CA groups showed differences only in the H, TA, PC and in the total output. Healthy subjects *versus* CA and CR groups showed differences in PC and the total EMG output. No differences were seen between CO and WA group.

The contribution of individual muscles to the total EMG activity during standing was assessed. The TS muscle presented the highest output in NS, CA, WA

group while in CR group its activity was slightly less compared to the most active PS muscle. The least activity was obtained from TA and H muscles. The control group, as mentioned above, showed very low total activity and the distribution pattern in this group showed the highest activity in the H muscle with slightly less output in the PS and TS muscles and with almost no activity in the Q and TA muscles.

The correspondence of the calculated IEMG values and the VA scores was analyzed in five SCI subjects. The linear correlation between the IEMG values and the score ($r = 0.86$) confirmed the validity of the scale.

Figure 3 Differences between EMG activity in the muscles of anterior (Q, TA) and posterior compartment (H, TS) expressed as the percentage of the total EMG activity $\pm$ SD recorded from both legs during standing. All functional SCI groups, and the healthy subjects are presented. Note the higher activity of the posterior compartment in all SCI subjects and in the healthy subjects

Table 3 Comparison of EMG activity between more and less active leg muscles in non-support SCI group

Group	Q	H	TA	TS	PS	Q+TA	H+TS	PS+H+TS	Q+H	TA+TS
Non-support	ns	P < 0.02*	ns	P < 0.04*	ns	P < 0.05*	P < 0.008**	ns	P < 0.004**	P < 0.01**

Level of significance: * = 0.05, ** = 0.01%, ns = not significant. Abbreviations: Q = quadriceps, H = hamstring, TA = tibialis anterior, TS = triceps surae, PS = paraspinal muscles. No significant differences were observed in any other SCI groups nor in the healthy group

Table 4 EMG output differences between SCI groups using data separately from individual muscles, anterior and posterior compartments, and from all muscles taken together

	PS	Q	H	TA	TS	Q+TA	H+TS	Total
NS	P < 0.05	CO	All	All	CR, WA, CO	CR, WA, CO	All	All
CO	P < 0.05	NS, CR	NS	NS	NS, CA	NS	NS, CA, CR	NS, CR, CA

NS group and CO group were compared to SCI groups. NS = non-support, CA = cane(s), CR = crutch(es), WA = walker, CO = control group. Other abbreviations as in Table 3

Discussion

Electromyographic studies of postural muscles have been performed on healthy subjects by a number of investigators⁽¹⁰⁻¹⁵⁾. These studies have demonstrated basic strategies of muscle activation utilized by healthy people during standing in a relaxed position. Our observation of electromyographic quiescence in TA and Q muscles and low EMG activity level in the TS and H muscles in the CO group are in agreement for instance with the findings of Joseph and Nightingale^{11,12} who showed no EMG activity in the thigh and TA muscles in most of the subjects during standing while there was significant activity in soleus muscle.

The non-support (NS) group provided most important results since their records of EMG activity in postural muscles were not disturbed by additional devices required for standing used in other functional groups. The inclusion of CA, CR and WA groups into the present study gives a possibility to try to understand the mechanisms used for standing by the SCI subjects with more severely impaired ambulation. It should be kept in mind that the recorded EMG activity does not reflect the amount of energy used for standing by subjects of other groups than to some extent by the NS group. Subjects distributed part of their weight on their arms supporting themselves on walking devices. We did not measure the amount of activity distributed by individuals for support on hands and on orthoses or braces. This may partially explain the significantly lower total muscle output in all groups using support compared to the NS group. On the other hand, as shown by Alstermark *et al.*^{4,5} in experiments on cats, the degree and the location of the spinal cord lesion differently influences motor performance so that lower muscle output in support groups may be attributed to subject's inability to create sufficient voluntary activity for standing. High total EMG activity exhibited in the NS group can be explained on the basis of work performed by McKay *et al.*⁶ They showed that there was preservation of afferent input to the spinal cord and a low threshold for segmental reflexes in ambulatory SCI subjects, and suggested that these factors are responsible for exaggerated stretch and cutaneomuscular responses, resulting in high EMG activity.

The finding that the NS group showed asymmetric standing while other groups were standing with more symmetric activation of both legs does not seem to be related to the injury of particular structures of the spinal cord, since it is rather unlikely that NS group was injured more unilaterally while CA, CR and walker group experienced more symmetric lesions. Symmetrical activation pattern of standing may be obtained by using an additional support during standing ie partial unloading of the leg with better functional performance resulting in more symmetric muscle activation. Greatly impaired ability of muscle activation during volitional movements resulting in a

very low EMG output, especially in the WA group, was responsible for a more symmetric pattern of standing. However, appearance of the symmetric pattern in the WA group can be in part related to the applied rating system which does not show differences between totally absent and very low EMG activity.

Analysis of single muscle activity and muscle groups such as anterior, posterior, distal and proximal compartments leads us to assume that TS was the most and TA was the least active muscle and that their roles in supporting the upright posture seems to be similar in the healthy as well as in the SCI subjects. Lack of significant difference in the activity of the PS and Q muscles between functional groups suggests that they were not involved in creating different patterns of muscle activation in most of the subjects.

Low contribution of the H muscle output to the total EMG activity in the SCI subjects compared to healthy subjects is not easy to explain. Different postures may influence hamstring muscle activity. Goff¹⁵ showed, that the H showed activity if the subjects were *standing at ease* with the feet close together, but not when the feet were placed 14" apart, and it may follow that different postures utilized by SCI subjects influence H activity.

Nashner^{2,3} studied the role of various reflexes in postural control. He showed that the first postural adjustment of the subject standing on the platform translated in the antero-posterior direction stabilizing the induced sway occurs in the ankle musculature 100-120 ms following the onset of the sway inducing stimulus. The longer onset latency of that adjustment compared to the onset latency of the classic myostatic stretch reflex suggests that different pathways are involved. Utilization of the moving force plate in studying postural control has elucidated the role of postural reflexes in various neurological diseases such as Parkinson's disease¹⁶ or in spastic paresis.¹⁷ The data on the role of postural reflexes in standing as studied in such controlled conditions is not yet available on SCI subjects.

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