



Electromyographic activity and kinematics of sit-to-stand in individuals with muscle disease

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Received: 28 February 2019 / Accepted: 7 June 2019 / Published online: 19 June 2019
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Abstract

Objective The aim of this study was to compare activation levels of *rectus femoris*, *biceps femoris*, *tibialis anterior*, and *soleus* muscles and biomechanical properties of individuals with muscle disease and healthy individuals during sit-to-stand.

Methods Fifteen patients (11 muscular dystrophy, 4 myopathy) and 15 healthy individuals were included in the study. A Noraxon superficial electromyography device and high-speed cameras were used to evaluate muscle activations and biomechanical properties.

Results There was a difference between the activation levels of bilateral rectus femoris, tibialis anterior, soleus, and right biceps femoris of patients and healthy subjects ($p < 0.05$). When groups were compared in terms of biomechanical properties, there was no difference in the range of motion during sit-to-stand ($p > 0.05$), but there was a difference in phase 1: flexion momentum phase, phase 3: extension phase, phase 4: stabilization phase, and total time of sit-to-stand ($p < 0.05$).

Conclusion We observed that individuals with muscle disease are able to stand up in a similar sit-to-stand pattern to healthy individuals with longer duration and higher muscle activation levels. Prolonged high muscle activation during functional activities may cause fatigue and muscle destruction in patients. For this reason, planning of exercise programs for appropriate muscles and phases will enable the patients to perform the activity of sit-to-stand more easily. Thus, patients will become more functional and independent in their daily lives with less effort.

Keywords Individuals with muscle disease · Sit-to-stand · Electromyography · Muscle activation · Kinematic

Introduction

Muscle diseases (muscular dystrophy, myopathies, etc.) are a group of hereditary or acquired diseases characterized by progressive muscle weakness and functional loss [1]. Due to progressive muscle weakness, individuals with muscle disease often have difficulty in daily life activities such as walking, climbing stairs and downhill, sit-to-stand, overhead activities, and reaching out [2, 3]. Sit-to-stand (STS) is one of the most affected activities in individuals with muscle diseases, which are mainly accompanied by progressive muscle weakness in the early stages of the disease. STS is a prerequisite for upright position and an important functional task for the ability to move in a vertical posture in daily life activities [4]. Studies have

shown that healthy adult individuals typically perform STS activity approximately four times per hour in daily life. The successful completion of this activity is a precursor to a normal gait and is necessary for maintaining independent daily life [5]. Restriction of STS can lead to fatigue and muscle destruction with overloading of muscles due to the fact that most of the patients' current energy potentials are needed to perform this activity. In addition, the difficulty of STS is also considered as an activity limitation that negatively affects the daily living activities of patients and reduces their quality of life [1].

When the literature was examined, it was seen that STS activity is evaluated from different viewpoints in different neurological patient groups such as those affected by stroke, multiple sclerosis, or Parkinson's disease [4, 6, 7]. In a small number of studies dealing with STS activity in individuals with muscle disease, only the compensatory STS patterns or co-activations of the lower extremity muscles were emphasized [2, 8]. The STS activity, on the other hand, is a complex activity that must be evaluated in terms of electromyographic properties by dividing it into different phases in terms of

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kinematics. In terms of treatment success, an objective evaluation of the factors that confound or constrain STS activity, identification of kinematically affected phases and distinction of problems such as underlying muscle activation or range of motion, prioritization of clinical interventions, and selection of appropriate approaches are all important.

The primary aim of the current study was to describe and compare the biomechanical analysis (range of motion, phase times and total time) and muscle activation with electromyography (EMG) of STS activity between individuals with muscle disease and healthy individuals.

Materials and methods

Participants

Fifteen individuals with muscle disease (11 muscular dystrophy, 4 myopathy) and 15 healthy individuals matched with age and sex were included in the study. The inclusion criteria for the patients were between the ages of 18 and 50 and being able to perform the STS activity without hand support independently and painlessly. They were excluded from the study if they had any neurological disorder other than muscle disease and had any orthopedic problem that prevents the STS action (fracture, endoprosthesis, etc.). The healthy individuals were excluded from the study if they had any systemic, orthopedic, and/or neurological problems that would affect STS activity. The flow chart of study is shown in Fig. 1. Written informed consent was obtained from all participants, as approved by the Ethics Committee of Hacettepe University (GO 17/334).

Demographic data such as age, height, weight, sex, and dominant side of all the participants were recorded prior to electromyographic and kinematic measurements. The motor function measure scale was used to determine of disease severity of individuals with muscle disease. In addition, the origin of the complaints and the dates of diagnosis for the patients were also recorded.

Measurements

The motor function measure scale

The motor function measure scale was used to determine of disease severity associated with motor function of individuals with muscle disease. The motor function measure scale consists of 32 instructions related to the patient's motor functions in the supine, seated on the mat, seated on the chair, and standing. For each directive, the patient's performance is observed and scored from 0 to 3. The lowest total score is 0 and the highest total score is 96. A high total score means that the patients have a good motor function [9].

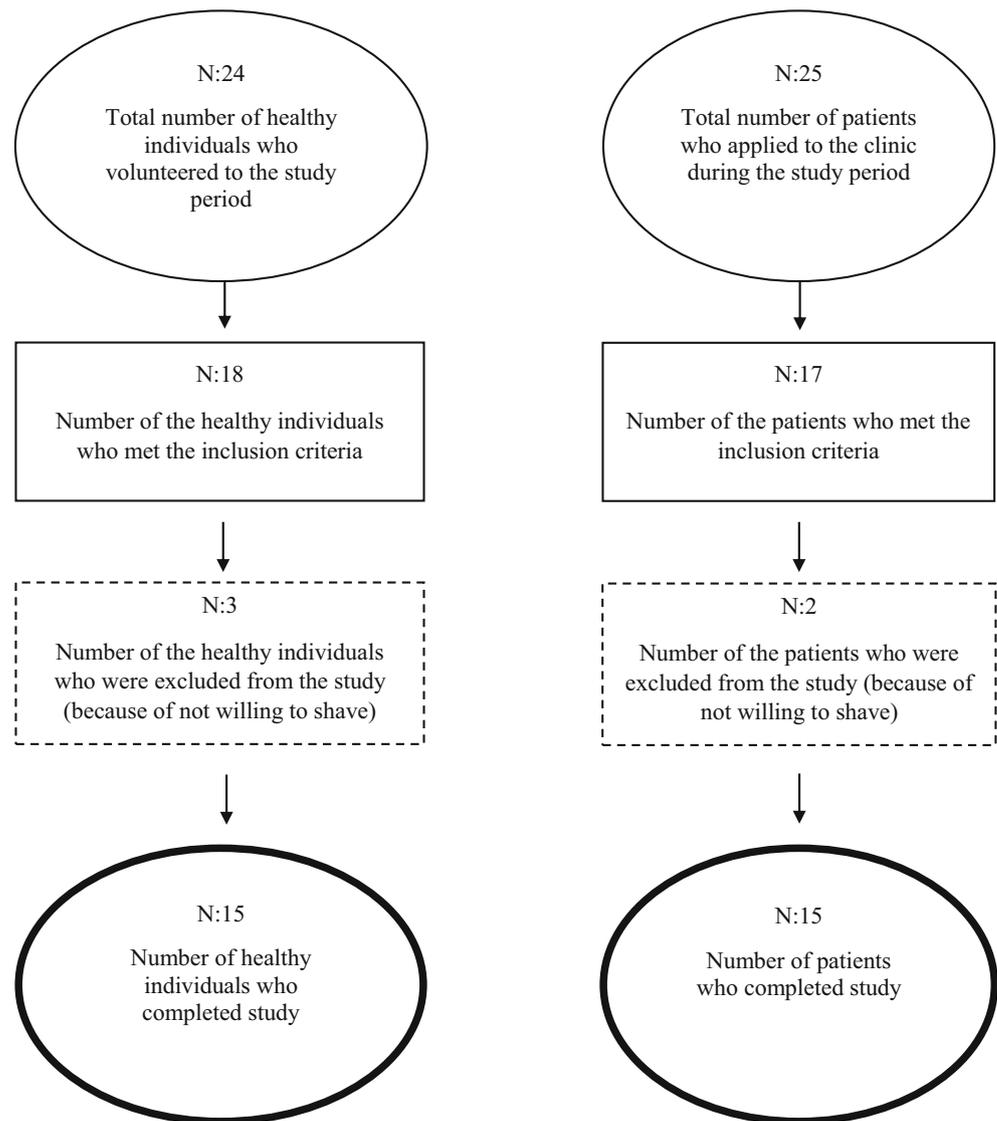
EMG measurements

An 8-channel surface EMG system (Noraxon Telemetry DTS System, Scottsdale, USA) was used for the bilateral rectus femoris, biceps femoris, tibialis anterior, and soleus muscle activation levels during STS. Bipolar Ag/AgCl surface electrodes were placed at an interelectrode distance of 2 cm. The electrode width was 1 cm, the common-mode rejection ratio was greater than 80 dB, and the input impedance was greater than 10 M Ω . The sampling rate for EMG data was 1500 Hz.

Prior to electrode placement, the electrode sites of the body were prepared by shaving any hair on the skin, abrading the skin with fine sandpaper, and cleaning the skin with 70% isopropyl alcohol to minimize the skin impedance. Then, the electrode placements were performed according to SENIAM's (surface EMG for non-invasive assessment of muscles) European Recommendations for Surface Electromyography [10]. For the rectus femoris test, the electrodes were placed on the midpoint of the line between the anterior spina iliaca superior and superior of the patella, parallel to muscle fibers. For the biceps femoris, the electrodes were placed on the midpoint of the line between the ischial tuberosity and the lateral condyle of the tibia, parallel to the muscle fibers. The placement of the electrodes for the tibialis anterior was at 1/3 of the line between the fibula head and medial malleolus, parallel to the muscle fibers. For the soleus, the electrodes were placed on 2/3 of the line between the medial condyle of the femur and medial malleolus, parallel to the muscle fibers. Following the electrode placements, the activation of the muscles at rest was measured for 15 s to see if the electrodes recorded any external noises.

Maximum voluntary isometric contraction

The maximum voluntary isometric contractions (MVICs) were recorded prior to STS task and they were used for the normalization of the muscle activation levels during STS. Individuals were instructed to perform their maximum effort against the applied manual resistance by the investigator for 6 s. During the measurement, the participants were verbally encouraged to exert maximum effort. The MVIC testing was repeated three times for each muscle with a 1-min rest between each trial. To measure rectus femoris MVIC, the participants were seated on a chair in 90° of hip flexion and 90° of knee flexion and secured with straps across the trunk and thigh and above the ankle joint. The manual resistance was applied over the ankle joint. For the biceps femoris, the manual resistance was applied on the ankle in a supine lying position where the amount of flexion was 45°. For the tibialis anterior, the manual resistance was applied dorsally from the foot in a lying position on the back where the heels did not contact the bed. For the soleus, manual resistance was applied from the soles of the feet in the supine lying position where the ankles did not contact the bed [11]. The positions of MVIC are shown in Fig. 2.

Fig. 1 The flow chart of the study

Kinematic measurements

Bassler acA1300-200uc brand high-speed cameras (Basler AG, Ahrensburg, Germany) were used during the kinematic measurements at 100 fps. Two cameras positioned to receive body images on the left and right sides of the individuals were run synchronously on the same protocol as the EMG measurements.

Within the kinematic evaluations, STS's phase and total durations were assessed with neck extension, trunk flexion, hip flexion, and ankle joint dorsiflexion joint movements arising during STS. The activity of STS is examined in four different phases in terms of kinematic characteristics. These phases are:

- *Flexion momentum* ends at the lift-off from seat.
- *Momentum transfer* begins at the lift-off and ends when maximal ankle dorsiflexion is achieved.

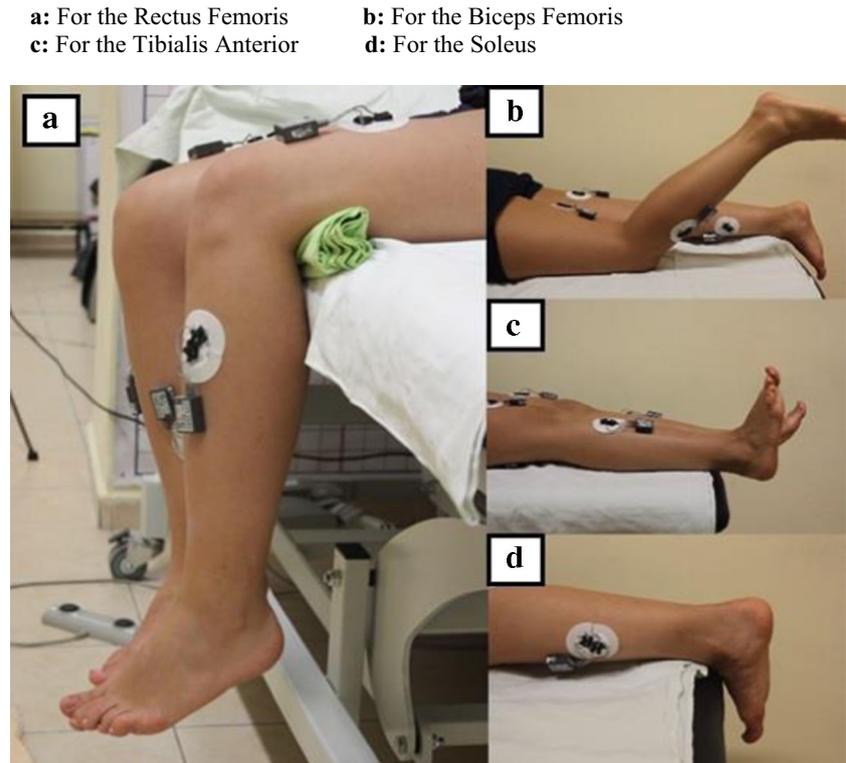
- *Extension* starts just after maximum ankle- dorsiflexion and it ends when the hip cease to extend.
- *Stabilization* starts after hip extension is reached and it ends when stabilization is completed [12].

Test procedure

The sitting heights of the individuals were adjusted to put the individual's ankle in the neutral position and the knee flexion angles to be 90° with a height-adjustable chair without back support or armrests [13].

Individuals are asked to cross their hands on their breasts. When the individuals who started STS with “1-2-3 Start” command came to the upright and stable position, they finished STS with “1-2-3 End” command. Electromyographic and kinematic measurements were performed simultaneously when the individuals performed STS.

Fig. 2 The positions of MVIC. **a** For the rectus femoris. **b** For the biceps femoris. **c** For the tibialis anterior. **d** For the soleus



a: For the Rectus Femoris
c: For the Tibialis Anterior

b: For the Biceps Femoris
d: For the Soleus

Data processing

Electromyographic data processing was accomplished using Noraxon MyoResearch XP Master Edition software (Noraxon USA, Inc). The EMG signals obtained from the muscles of individuals with the surface electrodes were rectified and filtered. The EMG signals were band-pass filtered (20–500 Hz) and smoothed using a root-mean-square moving-window function with a time constant of 100 ms. The average of the EMG signal amplitude recorded during the STS activity was calculated with the program and converted to numerical data. For each of the MVIC trials, the maximum value obtained over the 6-s maximum effort was recorded, and the average of 3 MVIC trials was used for normalization of the EMG data obtained during the STS. In the normalization process, the average of the EMG signal amplitude of STS activity was divided by the MVIC value for each muscle of interest. The muscle activation levels, expressed as a percentage of MVIC (MVIC%), was used for statistical analysis.

Images obtained via the right and left sides of the patient during kinematic measurements were analyzed using the Dartfish ProSuit 8 program (Dartfish HQ, Friborg, Switzerland). During the STS activity of individuals, the range of motions in the joints of the neck, trunk, hip, and ankle was measured and recorded in degrees and biomechanically evaluated. The kinematic measurements of the four phases of STS activity, including the flexion momentum, momentum transfer, extension, and stabilization phases, and the total STS time were

analyzed and recorded in seconds using images taken with a video camera recording synchronized with EMG measurements.

Statistical analyses

The data obtained in this study were evaluated using the IBM SPSS 21.0 package program. The Mann-Whitney *U* test, a non-parametric test, was used to determine whether there were significant differences between the groups included in the study because the number of individuals included in the study was small and the data were not normally distributed. As a result of the power analysis of the difference between the patients and the control group in terms of tibialis anterior muscle activation, the effect size was $d=2$ and the power of the study ($1 - \beta$) was 99%.

Results

The average age of the 15 patients was 30.47 ± 10.37 years, and the average age of the 15 healthy individuals was 29.60 ± 7.46 years. The average of the motor function measure scale score of individuals with muscle disease is 82.53 ± 8.45 . According to the motor function measure scale score, the disease severity of the individuals with muscle disease has a mild effect. In addition, the type of myopathy patients is proximal myopathy. The descriptive characteristics of the individuals are shown in Table 1.

Table 1 The descriptives of the individuals

	Muscle disease group $X \pm SD$ ($n = 15$)	Control group $X \pm SD$ ($n = 15$)	Z	p
Age (year)	30.47 \pm 10.37	29.60 \pm 7.46	-0.291	0.771
Height (cm)	171.67 \pm 12.05	171.33 \pm 8.66	-0.062	0.950
Weight (kg)	64.73 \pm 14.26	70.93 \pm 13.84	-0.747	0.455
BMI (kg/m ²)	21.89 \pm 4.06	23.68 \pm 2.78	-0.809	0.419
Gender (male/female)	9/6	9/6	0.000	1.000
Dominant side (right/left)	14/1	13/2	-0.598	0.550
The duration of the disease (month)	84 \pm 62.31			
Motor function measure scale score Min–max (0–96)	82.53 \pm 8.45			

$p < 0.05$, Mann-Whitney U test

BMI body mass index

Surface EMG

When comparing muscle activation levels that occur during STS activities of patients and healthy subjects, patients showed increased levels of activation of right ($p = 0.018$) and left ($p = 0.012$) rectus femoris, right biceps femoris ($p = 0.018$), right and left tibialis anterior muscles ($p = 0.000$), and soleus muscles ($p = 0.004$) compared with healthy individuals (Table 2).

Kinematics

Range of motion

When comparing the range of motion that occurs during STS activities of patients and healthy subjects, neck extension, trunk flexion, hip flexion, and ankle dorsiflexion movements were similar between the groups ($p > 0.05$) (Table 3).

Phase times and total time

When comparing phase times and total time of STS activities of patients and healthy subjects, patients showed increased

time of phase 1: flexion momentum phase ($p = 0.023$), phase 3: extension phase ($p = 0.021$), phase 4: stabilization phase ($p = 0.000$), and total duration of STS ($p = 0.000$) compared with healthy individuals (Table 4).

Discussion

As a result of this study, the factors affecting the activity of STS in individuals with muscle disease were investigated and identified. It was found that patients have higher muscle activation levels and required longer time compared with the healthy individuals with similar range of motion. These results suggest that patients completed their movements in longer time with more muscle activation in the normal STS pattern. A common view in previous studies comparing muscle activation levels that occur during STS in neurological patient groups to healthy individuals was that patients had higher muscle activation levels than healthy individuals. Lu and colleagues, investigating stroke patients, compared the activation levels of *quadriceps femoris*, *biceps femoris*, *tibialis anterior*, and *gastrocnemius* muscles during STS with their healthy age group. The levels

Table 2 Muscle activations during sit-to-stand (MVIC%)

Muscles	Side	Muscle disease group $X \pm SD$ ($n = 15$)	Control group $X \pm SD$ ($n = 15$)	Z	p
Rectus femoris	Right	23.24 \pm 16.50	10.5 \pm 5.64	-2.365	0.018*
	Left	21.56 \pm 14.66	8.67 \pm 4.50	-2.509	0.012*
Biceps femoris	Right	24.22 \pm 20.07	8.62 \pm 6.47	-2.372	0.018*
	Left	21.49 \pm 21.68	11.33 \pm 9.03	-1.854	0.064
Tibialis anterior	Right	29.56 \pm 13.81	9.22 \pm 4.23	-4.086	0.000*
	Left	30.30 \pm 12.95	10.72 \pm 5.43	-4.086	0.000*
Soleus	Right	21.70 \pm 13.62	8.16 \pm 5.86	-2.880	0.004*
	Left	25.56 \pm 18.31	9.76 \pm 5.26	-2.841	0.004*

* $p < 0.05$, Mann-Whitney U test

MVIC maximum voluntary isometric contraction

Table 3 Range of motion during sit-to-stand

Motion	Side	Muscle disease group $X \pm SD$ ($n = 15$)	Control group $X \pm SD$ ($n = 15$)	Z	p
Neck extension		26.18 \pm 12.93	27.60 \pm 12.24	-0.456	0.648
Trunk flexion		46.53 \pm 12.89	43.02 \pm 7.75	-0.519	0.604
Hip flexion	Right	31.76 \pm 8.18	35.92 \pm 7.60	-1.390	0.164
	Left	32.98 \pm 9.91	35.18 \pm 7.04	-0.975	0.330
Ankle dorsiflexion	Right	15.30 \pm 7.61	14.90 \pm 3.26	-0.145	0.884
	Left	17.28 \pm 6.10	18.12 \pm 3.54	-0.685	0.494

$p < 0.05$, Mann-Whitney U test

of muscle activation in the affected and unaffected sides of stroke patients were increased relative to the healthy group [14]. According to Lu et al., individuals with loss of muscle strength after stroke have to stand up with higher muscle activation compared with healthy individuals by spending more energy in relation to “constant effort” hypothesis. In addition, according to the authors, high muscle activation during STS might be a compensation strategy developed due to loss of muscle strength. In our study, it was also observed that individuals with muscle disease had an increase in activation levels of *rectus femoris*, *biceps femoris*, *tibialis anterior*, and *soleus* muscles during STS in comparison with healthy individuals. According to these results, it is thought that individuals with muscle disease has produced muscle activation to perform the STS by using more motor units. Thus, it is seen that individuals with muscle disease have higher muscle activation levels than their healthy peers with higher effort and contractile mass during STS. This result supports the results of the study examining muscle activation levels during STS of stroke patients. Individuals with muscle disease compensate for loss of muscle strength by demonstrating high muscle activation levels with excessive effort to stand up.

High muscle activation (MVIC%), which occurs in the lower extremity muscles of individuals with muscle disease during STS compared with the maximal muscle forces present, causes patients to use most of their current capacity during STS. High muscle activations that force patients’ existing potentials cause muscle fatigue and excessive muscle strain in individuals with muscle disease. In the literature, it is

suggested that high-resistance exercises with high muscle activity cause muscle damage and injury in individuals with muscle disease [15]. Therefore, the STS activity performed four times per hour may cause the patients to load in their muscles and thus may cause muscle destruction. From this point of view, the results of this study, in which the STS activity was evaluated with EMG, are noteworthy for clinicians both in the disease progression and in the treatment planning stages. Individuals with muscle disease who do not allow the current muscle strength STS to be performed in a normal pattern tend to show increased lumbar lordosis, one of the major problems in the disease, by developing compensatory STS patterns, such as lifting with taking the body overflexion. Thus, in patients group who cannot stand in normal patterns, permanent orthopedic deformities such as lumbar lordosis may occur, in addition to neuromuscular problems. When these reasons are considered together, the increase in muscle activity in diseases such as stroke and Parkinson’s causes only a symptom of fatigue, whereas it is a factor that can increase the severity of the disease by muscle destruction in individuals with muscle disease. From this point of view, it is important to investigate STS in detail and to compare the results of related muscle activations with those of the healthy group, providing important clinical and academic information.

Inkster and colleagues have shown that off-period Parkinson’s patients have an increase in the duration of STS activity due to the decrease of speed compared with on-period Parkinson’s patients and healthy subjects [7]. In a study by

Table 4 Phase periods and total duration of sit-to-stand

Phase	Muscle disease group $X \pm SD$ ($n = 15$)	Control group $X \pm SD$ ($n = 15$)	Z	p
Phase 1: Flexion momentum	0.94 \pm 0.37	0.67 \pm 0.15	-2.266	0.023*
Phase 2: Momentum transfer	0.27 \pm 0.35	0.25 \pm 0.09	-1.708	0.088
Phase 3: Extension	1.15 \pm 0.53	0.80 \pm 0.19	-2.304	0.021*
Phase 4: Stabilization	1.02 \pm 0.66	0.20 \pm 0.12	-4.261	0.000*
Total	3.38 \pm 1.16	1.94 \pm 0.14	-4.012	0.000*

* $p < 0.05$, Mann-Whitney U test

Cattaneo et al. who examined STS duration of multiple sclerosis patients, another neurological patient group, they reported that multiple sclerosis patients had an average of 1.5 times longer period compared with healthy subjects while providing postural control to ensure a more stable and secure posture in the stabilization phase of STS [16]. When the results of our study were evaluated considering kinematic terms, phase 1: flexion momentum phase, phase 3: extension phase, phase 4: stabilization phase, and total duration of STS of individuals with muscle disease were longer than those of healthy individuals. These results support the results of studies comparing STS durations of other neurological patient groups and healthy individuals in the literature [7, 16]. However, since previous studies concentrate on total STS duration and do not compare durations at different phases of STS, our study provides more detailed results than other studies. According to these results, individuals with muscle disease were able to perform phase 2: momentum transfer phase in which the momentum of body flexion was transferred to the lower extremities as fast as the healthy individuals. This indicates that individuals with muscle disease develop a compensatory strategy for reducing the extensor muscle strength of the lower extremities by shortening the duration of the momentum transfer phase where lower extremity extensor muscle strength is required at a high level.

Study limitation

It is known that the trunk muscles, together with the lower extremity muscles, play an important role in STS. In our study, it is an important limitation that the activation levels of the trunk muscles were not examined because of the inadequate number of EMG device channels available.

Conclusions

This study demonstrated that individuals with muscle disease performed the flexion moment by shifting the trunk in a longer period compared with healthy individuals. Also, patients' knee, hip, and trunk extension durations that started with the patient's thighs' interruption of contact with the chair and ended with hip extension and are required for the transition to the standing position (which is less stable) are extended. Similarly, the periods of stabilization required to stand with good stability are extended. Both the increase in muscle activation level and the prolongation of muscle activation times increase the risk of fatigue, falling, and muscle destruction. The data obtained at the end of the study is thought to be a guide to issues about daily activities of patients, planning of exercise programs, adding energy conservation techniques to the program, and training the appropriate muscles in the correct phases.

Acknowledgments We acknowledge all the participants with muscle disease and healthy volunteers.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Abbreviations BMI, Body mass index; EMG, Electromyography; MVIC, Maximum voluntary isometric contraction; SENIAM, Surface EMG for non-invasive assessment of muscles; STS, Sit-to-stand

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