Gamma Loop Dysfunction of the Quadriceps Femoris of Elderly Patients Hospitalized after Fall Injury

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ABSTRACT

Background and Purpose: Gamma loop dysfunction may increase the risk of falls. Therefore, we evaluated gamma loop function in subjects hospitalized after fall injury and examined whether aging affects the gamma loop. **Methods**: Maximal voluntary contraction (strength) of knee extension and integrated electromyography (I-EMG) of the quadriceps femoris were examined to evaluate the activities of alpha motoneurons before and after 20-min vibration applied to the quadriceps femoris. Mean percentage changes were calculated as: (previbration value−postvibration value)/previbration value×100). As strength and I-EMG of both uninjured (UG) and injured limbs (IG) of patients with a history of falls resulting in hospitalization were examined in each group, the mean percentage changes of the 4 groups were compared with those of controls [young control group (YCG) and elderly control group (ECG)]. **Results**: Mean percentage changes in strength of UG and IG were significantly different from YCG but not the ECG. Mean percentage changes in I-EMG for VL (vastus lateralis) and VM (vastus medialis)in IG were significantly different from YCG. However, I-EMG of RF of IG were not significantly different from YCG. Although mean percentage changes in I-EMG of UG were not significantly different from ECG, those for VL and VM of IG were different from ECG. **Conclusions**: As the gamma loop dysfunction exited in the uninjured limbs of subjects with a history of falls resulting in hospitalization, a dysfunctional gamma loop could be a risk factor for falling. Further studies are needed to identify the effects of aging on gamma loop function.

Key Words: vibration stimulation, falls, aging, muscle strength, electromyography

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INTRODUCTION

Falls in the elderly population are an important clinical and social problem. To prevent falls in the elderly, it is essential to determine the mechanism responsible for such falls. Although various factors may be associated with falls in the elderly, such as lack of strength, coordination, and functional performance,[1-4] it is difficult to clearly identify the cause of falls in elderly people. Proprioceptive sense is an important contributor to the maintenance of posture. Thus, deterioration of proprioceptive sense in the elderly population may be a factor increasing the risk of falls.[5,6] Indeed, many previous studies have demonstrated age-related declines in proprioceptive sense in the human knee joint.[5,7-9] To assess proprioceptive sense, many investigators have had subjects reproduce an angle of the joint passively.[5,7-9] The muscle spindle contributes to proprioception as it detects changes in muscle length, and induces the stretch reflex. Furthermore, gamma motor neurons innervate the muscle spindle and form a loop known as the gamma loop.[10] This loop is important for maintaining resting tension of muscle, which is a manifestation of the normal stretch reflex.[11] Since sustained resting tension of muscle facilitates rapid muscle movement, such as postural adjustment,[11] gamma loop dysfunction may increase the risk of falls. However, the measurement of joint position sense does not primarily reflect the function of the muscle spindle, especially in the middle of joint motion, because the amount of mechanical stimulation to the muscle spindle is reduced during passive joint motion. Therefore, it is important to examine the function of the gamma loop in elderly patients with major injuries relevant to falls to determine the mechanism of falls in the elderly. To our knowledge, the relationship between falls and gamma loop function has not been documented. The presence of gamma loop dysfunction in elderly subjects with injuries following a fall would suggest a relationship between falls and gamma loop dysfunction. Thus, the purpose of the present study was to evaluate gamma loop function in subjects with a history of falls resulting in hospitalization. In addition, the relationship between gamma loop function and aging has not yet been determined in detail.[5] Therefore, the secondary purpose of the present study was to determine whether aging affects the integrity of gamma loop function.

METHODS

Subjects

Nine subjects (2 men, 7 women) who were hospitalized after a fall injury (age, 78.7 ± 5.8 years, height, 156.2 ± 9.0 cm, weight, 49.6 ± 13.8 Kg, mean ± SD), 10 healthy elderly subjects

(6 men, 4 women; age, 76.0 ± 6.1 years, height, 159.9 ± 10.4, weight, 55.6 ± 15.0, mean ± SD), and 10 healthy younger subjects (5 men, 5 women; age, 28.9 ± 4.8 years, height: 166.3 ± 5.8 cm, weight, 64.4 ± 15.3 Kg, mean ± SD) participated in the present study. There were 4 groups in the present study. Ten younger healthy subjects were assigned to the young control group and the 9 healthy elderly subjects were assigned to the elderly control group. For subjects with a history of falls resulting in hospitalization, the injured side was assigned to the injured side group and the uninjured side was assigned to the uninjured side group. Based on the opinion of their medical doctor and physical therapist, we confirmed that all subjects with fall injury in present study were independent in their activities of daily living. Subjects with mental deterioration were excluded from the present study. All injuries were fractures of the femoral neck. In addition, none of the subjects had any other injuries or a history of knee injuries. Treatment procedure, age, months after fall, and duration of hospitalization are listed in Table 1. All procedures were performed in accordance with the ethical standards of the Committee in Human Experimentation at the Saitama Jikei hospital. Informed written consent was obtained from each subject prior to participation in the study.

Vibration Procedure

The modified method of vibration described by Kouzaki et al[12] was used in the present study. Briefly, subjects sat on the isometric exercise machine (Isoforce OG Giken Ltd., Okayama City, Japan) (Figure 1) with their legs hanging down from the seat. They were asked to relax their thighs as much as possible during the application of vibration. Vibration stimulation was applied manually using a Hit Masser (Kinesio Co., Tokyo, Japan) (Figure 2) to the mid-portion of the infrapatellar tendon to induce attenuation of the Ia afferent through the tonic vibration reflex of the quadriceps muscle. The frequency, amplitude, force of application, and duration of vibration stimulation were modified in this study. Theoretically, induction of Ia discharge is necessary to induce effective attenuation of the Ia afferent. However, the vibration protocol of Kouzaki et al[12] is less effective in inducing Ia discharge than those used in previous

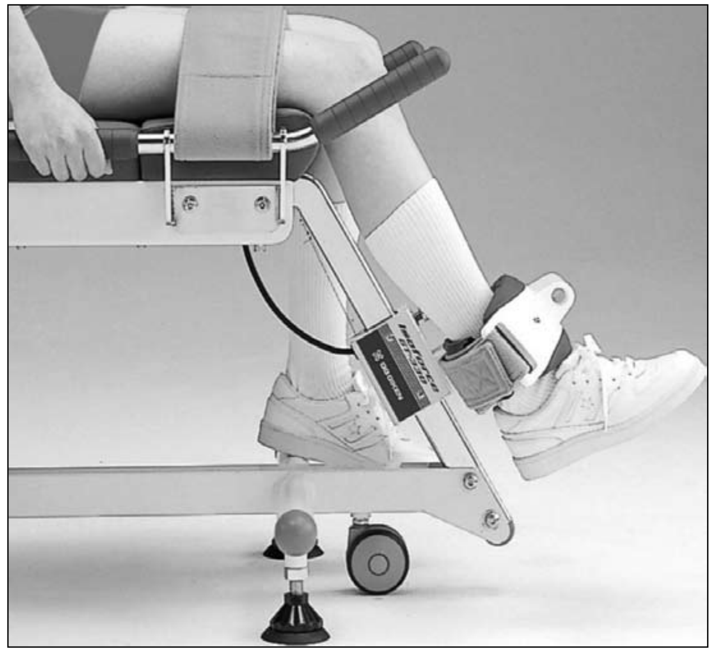

Figure 1. Position of the lower extremity during measurement.

Table 1. Characteristics of Subjects with a History of Hospitalization after a Fall Injury

Subject	Age	Sex	Months since injury	Hospitalization (weeks)	Treatment
1	72	F	24	6	Conservative *
2	88	M	19	5	Conservative *
3	81	F	19	11	Osteosynthesis (Compression Hip Screw)
4	71	F	170	Unknown	Osteosynthesis (Compression Hip Screw)
5	72	F	34	8	Total hip arthroplasty
6	81	M	14	5	Total hip arthroplasty
7	79	F	6	10	Osteosynthesis (γ nail)
8	82	F	17	7	Total hip arthroplasty
9	82	F	14	4	Osteosynthesis (Multiple pining)

* No surgical procedure was performed

Figure 2. Equipment for providing the vibration stimulation.

studies.[13-18] Therefore, we conducted a pilot study to design a protocol that resulted in reduction of the maximal voluntary contraction (strength) and integrated electromyography (EMG). These studies indicated that the most suitable vibration frequency was 50 Hz, which resulted in displacement of 1.5 mm. The force and duration of application were $\leq$ 30 N and 20 min, respectively.

Electromyograph Procedure

Electromyography was performed on the vastus medialis, vastus lateralis, and the rectus femoris during strength measurement at a sampling rate of 1 kHz. The EMG was recorded using bipolar surface disposable electrodes (Blue Sensor, Medicotest) placed on the belly of the vastus medialis, vastus lateralis, and rectus femoris. The inter-electrode distance was 30 mm. The electrodes were connected to an EMG measurement unit (ME3000, Nihon Medix). The EMG data were transferred into PowerLab (ADInstruments) *via* an A/D conversion unit. Simultaneous recordings of force and EMG signals during maximal voluntary isometric contraction were performed. To obtain the integrated EMG signal, the EMG signals during over a 1-s period of steady force output were full-wave-rectified and integrated.

Experimental Protocol

Subjects learned to perform maximal voluntary contraction (MVC) in a practice session before measurements were conducted. All subjects were asked to perform MVC of knee extension 3 times at the 70° knee-flexion position before application of vibration. The measurements were performed with the subject in the sitting position, with the upper body and thigh kept tightly secured to the seat of the isometric exercise machine by belts. The I-EMGs of all muscles were measured simultaneously during strength measurement. After finishing strength and I-EMG measurements, vibration stimulation was applied for 20 minutes. Immediately after completion of vibration stimulation, the strength of knee extension and I-EMG were measured again using the same method as used prior to vibration. For several reasons, the quadriceps femoris was chosen as the object in the present study. First, the quadriceps is the largest muscle in the lower limb and important to maintain posture. Second, a previous study demonstrated that the knee extensors are one of the affected muscle groups in people with a history of falls.[19] Third, as the quadriceps has already been examined in many previous studies,[20-22] the protocol was established as a valid method.

Statistical Analysis

All data are expressed as means ± SD. In this study, comparisons of changes in strength and I-EMG were performed between the following 4 groups: (1) young control group, (2) elderly control group, (3) injured side group, and (4) uninjured side group to evaluate the effect of prolonged vibration on the alpha motoneuron activities. One-factor ANOVA was used to determine the differences of the mean percentage changes in strength and I-EMG among the 4 groups. The mean percentage changes in strength and I-EMG after vibration stimulation were calculated as: [(previbration value – postvibration value)/previbration value × 100]. $p < 0.05$ was taken to indicate statistical significance. Scheffe's F test was used as a *post hoc* test. Also, one-factor ANOVA was used to determine the significance of differences in baseline strength value (previbration value) among the 4 groups and Scheffe's F test was used as a *post hoc* test.

RESULTS

The mean values of knee extension strength before and after 20 min of vibration stimulation in all groups are listed in Table 2. One-factor ANOVA detected significant differences in strength among the 4 groups. In addition, Scheffe's test revealed that the mean percentage changes in strength of the uninjured (3.09 ± 14.7%) and injured sides (7.49 ± 11.9%) were significantly different from that of the young control group (–13.2 ± 9.57%) but not from that of the elderly control group (–4.60 ± 8.03%). Also, one-factor ANOVA detected significant differences in baseline strength value among the 4 groups. Scheffe's test revealed that the mean strength of elder control group (333.8 ± 91.0 N), the uninjured (258.2 ± 79.4 N), and injured groups (215.4 ± 112.4 N) were significantly different from that of the young control group (569.5 ± 200.7N).

The mean values of I-EMG (vastus lateralis, vastus medialis, rectus femoris) before and after 20 minutes of vibration stimulation in all groups are listed in Table 3. One-factor ANOVA revealed significant differences in I-EMG of and vastus medialis, but not in the rectus femoris, among groups. Scheffe's test revealed that the mean percentage changes in I-EMG values for vastus lateralis and vastus medialis in the injured group (vastus lateralis, 17.5 ± 34. 6%; vastus medialis, 19.0 ± 24. 5%) and the uninjured group (vastus lateralis, 8.4 ± 11.7%; vastus medialis, 4.9 ± 12.9%) were significantly different from those of the young control group (vastus lateralis, –19.8 ± 16.5%;

Table 2. Knee Extension Strength (N) Measured Before and After Vibration and Percentage Change after 20-min Vibration Stimulation in all 4 Groups

Group	Previbration Mean ± SD	Postvibration Mean ± SD	Change (%) Mean ± SD
Young Control	569.5 ± 200.7	496.8 ± 191.7	−13.2 ± 9.6
Elerly Control	333.8 ± 91.0**	317.1 ± 85.1	−4.60 ± 8.0
Injured Side	215.4 ± 112.4**	223.4 ± 102.6	7.49 ± 11.9††
Uninjured Side	268.2 ± 79.4**	271.5 ± 72.0	3.09 ± 14.7††

** $p<0.01$, Significant difference compared with the young control group
†† $p<0.01$, Significant difference compared with the young control group

Table 3. Integrated Electromyography Values (mV) in Each Superficial Quadriceps Femoris Muscle Measured before and after 20-min Vibration and Percentage Change after Vibration in All Study Groups

Muscle	Group	Previbration Mean ± SD	Postvibration Mean ± SD	Change (%) Mean ± SD
Rectus Femoris	Young Control	0.057 ± 0.024	0.048 ± 0.021	−13.6 ± 15.1
	Elerly Control	0.044 ± 0.021	0.036 ± 0.01	−15.2 ± 20.4
	Injured Side	0.033 ± 0.017	0.036 ± 0.023	10.1 ± 35.9
	Uninjured Side	0.040 ± 0.01	0.041 ± 0.02	2.7 ± 20.6
Vastus medialis	Young Control	0.067 ± 0.024	0.054 ± 0.018	−18.2 ± 10.5
	Elerly Control	0.058 ± 0.037	0.050 ± 0.027	−8.8 ± 11.4
	Injured Side	0.038 ± 0.023	0.044 ± 0.026	19.0 ± 24.5†† *
	Uninjured Side	0.049 ± 0.03	0.050 ± 0.03	4.9 ± 12.9†
Vastus lateralis	Young Control	0.086 ± 0.052	0.065 ± 0.032	−19.8 ± 16.5
	Elerly Control	0.060 ± 0.020	0.052 ± 0.015	−11.7 ± 10.8
	Injured Side	0.043 ± 0.028	0.047 ± 0.029	17.5 ± 34.6†† *
	Uninjured Side	0.049 ± 0.02	0.054 ± 0.026	8.4 ± 11.7†

* $p < 0.05$, Significant difference between injured side group and elderly control group
†† $p < 0.01$, Significant difference compared with the young control group
† $p < 0.05$, Significant difference compared with the young control group

vastus medialis, −18.2 ± 10.5%) (Table 3). However, I-EMG of rectus femoris (10.1 ± 35.9%) of the injured group was not significantly different from that of the young control group (−13.6 ± 15.1%). In addition, even though the mean percentage changes in I-EMG value of the uninjured group (vastus lateralis, 8.4 ± 11.7%; vastus medialis, 4.9 ± 12.9%) were not significantly different from those of the elderly control group (vastus lateralis, −11.7 ± 10.8%; vastus medialis, −8.8 ± 11.4%), the mean percentage changes in I-EMG value for vastus lateralis and vastus medialis of the injured group (vastus lateralis, 17.5 ± 34. 6%; vastus medialis, 19.02 ± 24. 5%) were not significantly different from those of the elderly control group (vastus lateralis, −11.7 ± 10.8%; vastus medialis, −8.8 ± 11.4%).

DISCUSSION

The strength and I-EMG were reduced after prolonged vibration stimulation in the young healthy subjects. The decreases in strength and I-EMG in subjects of the young control group represent normal responses to prolonged vibration stimulation.[12,20-22] However, the mean percentage changes of strength and I-EMG of vastus lateralis and vastus medialis of the injured group following prolonged vibration stimulation were significantly different from those of healthy young subjects. These abnormal changes in alpha motor neurons in response to prolonged vibration stimulation indicated gamma loop dysfunction in the injured limbs of these elderly subjects. However, these results could not eliminate the possibility that the injury sustained by these subjects may have affected these abnormal responses. Therefore, the present study was designed to compare the changes in alpha motor neurons in response to prolonged vibration stimulation between the uninjured side of elderly subjects with a history of falls resulting in hospitalization and healthy young subjects. The mean percentage changes of strength and I-EMG of vastus lateralis and vastus medialis of the uninjured group following prolonged vibration stimulation were significantly different from those of healthy young subjects. Taken together, these observations indicate that the gamma loop in the quadriceps femoris was dysfunctional not only in the injured limbs of these elderly subjects but also in their uninjured limbs. As the gamma loop dysfunction existed even in the uninjured limb of the patients and there were no significant differences in alpha motor neuron activity in response to prolonged vibration stimulation between the injured and uninjured sides, the gamma loop dysfunction found in these subjects was not induced by their old injury. Thus, we inferred that the gamma loop dysfunction was a pre-existing condition before the injury.

However, the effect of aging on gamma loop function cannot be ignored as previous studies indicated that proprioceptors could degenerate with aging,[5] and these receptors play an important role in modulating the gamma loop function.[23-27] Therefore, the gamma loop function of elderly subjects who have had no history of falls resulting in hospitalization was also examined in the present study to determine the influence of aging. However, the results of the present study could indicate that gamma loop dysfunction did not exist in the quadriceps of healthy elderly subjects because the mean percentage changes in strength and I-EMG in the young control group were not significantly different from those of healthy elderly subjects, and the strength and I-EMG in response to prolonged vibration stimulation in elderly control group tended to be reduced, which could be considered normal response. Therefore, we insisted that aging may not be a factor involved in the induction of gamma loop dysfunction. However, the statistical analysis in present study could not detect differences in the mean percentage of strength and I-EMG between elderly subjects with no history of falls resulting in hospitalization and the uninjured side of subjects who had such a history of falls. If the gamma loop of subjects in the elderly control group functions as normal as in young normal subjects, significant differences in the mean percentage changes of strength and I-EMG would have been detected in elderly control group and the uninjured side in elderly subjects with a history of falls resulting in hospitalization. Indeed, the mean percentage changes of strength and I-EMG in 3 of 10 subjects with no history of falls resulting in hospitalization tended to increase or showed almost no change, which is not considered a normal response; subjects with gamma loop dysfunction as a risk factor of falls may have been included in the elderly control group. Therefore, we speculated that this discrepancy within the elderly control group may explain why no differences in mean percentage changes of strength and I-EMG were detected between elderly subjects with no history of falls and the uninjured side of subjects with a history of falls. Indeed, in contrast to the results of the present study, a recent study concluded that aging results in gamma loop dysfunction even though only a small number of subjects (4 subjects) were included in the study.[28] Further studies are needed to identify the effects of aging on gamma loop function.

CONCLUSIONS

In conclusion, as the gamma loop did not function normally in both the injured and uninjured sides of subjects with a history of hospitalized injury, the existence of gamma loop dysfunction could be a risk factor associated with falls. However, gamma loop dysfunction was not detected in healthy elderly subjects. There is a discrepancy within the group of healthy elderly subjects regarding gamma loop dysfunction. These elderly subjects who may have gamma loop dysfunction might have a higher risk of falls. Furthermore, the results of the present study demonstrated that all elderly subjects do not have a dysfunctional gamma loop. Therefore, aging is not the only factor involved in increasing the risk of falls, but other factors must also play a role. The detection of gamma loop dysfunction may be useful for screening to identify elderly subjects at risk of fall injury. Additionally, further research that investigates how neurological disease and aging could interact to reduce gamma loop function in elderly population will need to be performed.

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