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Original

Difference in erector spinae fatigability between hemodialysis patients and age- and sex-matched healthy controls

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Abstract

Muscle weakness and wasting have been observed in patients with chronic kidney disease and those on hemodialysis (HD). Although many reports on muscle fiber composition in HD patients are available, the status of muscle fatigability in these patients remains unclear. This study aimed to determine erector spinae strength and fatigability in HD patients using surface electromyography (EMG) power spectrum analysis.

We enrolled 23 patients in the HD group, and 27 healthy participants in the control group. In all participants, grip and isometric trunk extension strength was measured, and an unsupported trunk holding test was performed, during which surface EMG signals were recorded from the erector spinae at the L1 level. The slope of median frequency (MF) was calculated from recorded electromyography and compared between the two groups. The MF slope in female HD patients was significantly greater than that in healthy females ($p = 0.007$). There was no significant difference between male HD patients and healthy males ($p > 0.05$).

The results demonstrated that the fatigue resistance of the erector spinae in female HD patients was lower than that in healthy female participants. Interventions to prevent fatigability and loss of muscle strength in HD patients are recommended.

Key words : *chronic kidney disease, hemodialysis, surface electromyography power spectral analysis, fatigability, the erector spinaele myeloma*

I. Introduction

The number of patients with chronic kidney disease (CKD) and undergoing hemodialysis (HD) is increasing worldwide due to an increase in the older population and the prevalence of diabetes mellitus [1, 2]. Complications such as anemia, muscle weakness, osteoporosis, and cardiovascular disease are common in CKD and HD patients and contribute greatly to

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mortality by reducing daily activity and quality of life [3-6]. Lower back pain is often seen in CKD and HD patients [7]. The erector spinae muscle, rich in type I muscle fibers, has been the focus of research for lower back pain [7-9]. Type I muscle fibers are mitochondria-rich and remain efficient over long durations under aerobic conditions [10], whereas type II muscle fibers contribute to muscle strength at high-speed contraction or maximal isometric muscle strength [11]. Their proportion determines the fatigability and strength of muscles. Previously, in a review article [12], Sawant et al. described 16 studies that have reported atrophy of type II muscle fibers as a common finding in patients on HD for end-stage renal disease; however, some studies have also reported atrophy of type I muscle fibers [13-17]. Thus, there is uncertainty about the type of fibers that undergo atrophy in HD patients, and no universal agreement exists on appropriate muscle strength training in such patients.

Biering-Sørensen demonstrated unsupported trunk holding time in the supine horizontal position as a factor predictive of the first episode of lower back pain; the Biering-Sørensen test has often been adapted by researchers to evaluate back muscle endurance [18]. By contrast, the median frequency (MF), calculated by power spectral analysis of surface electromyography (EMG) recording, shifts toward lower values with fatigue [19-24]. Moreover, the MF slope is associated with a higher proportion of type I muscle fibers [8, 19-24]. Previous studies that used this method have also reported lower endurance of the erector spinae in healthy female adults than in healthy male adults [19-23]. To our best knowledge, no study has reported the fatigue resistance in both female and male HD patients using this method.

Based on the above background, we hypothesized that the fatigue resistance of the erector spinae was lower in both female and male HD patients than in age- and sex-matched healthy individuals. This study aimed to evaluate the fatigue resistance of the erector spinae in male and female HD patients by performing a surface EMG power spectral analysis; subsequently, we compared the results with those obtained in age- and sex-matched healthy individuals.

II. Materials and Methods

1. Participants

We enrolled 23 HD patients and 27 age-matched healthy volunteers and divided them into two groups of HD patients and healthy control participants. The HD group underwent hemodialysis 3 days a week. This group included 10 female [age 40–59 years, median (first quartile – third quartile) 52 (47.8–55.8)] and 13 male [42–57 years, 49 (47-50)] patients, and the control group included 13 healthy female [41–59 years, 49 (46-57)] and 14 healthy male [41–59 years, 50 (42.3-54)] patients. The physical characteristics of each group and the duration of HD and CKD in the HD group are shown in Table 1. Age, weight, BMI, and grip strength were similar among the participants of both groups. Individuals with lower back pain, spinal disease, respiratory and circulatory diseases, or history of neurological disease were excluded.

This study was approved by the Human Ethics Committees of Iwate Medical University School of Medicine, Morioka Municipal Hospital, and

Table 1. Anthropometric characteristics of each group, with no significant difference observed in either males or females

	Females		Males	
	HD group (n =10)	Control group (n = 13)	HD group (n = 13)	Control group (n = 14)
Age (years)	52 (47.8 - 55.8)	49 (46 - 57)	49 (47 - 50)	50 (42.3 – 54)
Height (cm)	161.5 (157.5 - 162)	156 (153 - 159)	173 (172 – 176)	167 (163.3 – 174.5)
Body weight (kg)	49 (47.1 - 60.3)	52.3 (47.4 – 55.7)	69.4 (60 - 79.9)	68 (65.9 - 80)
Body mass index (kg/m^2)	20.1 (18.8 – 23.2)	22.5 (19.6 – 22.6)	22.7 (22 – 26.7)	24.8 (23.4 – 27.1)
Grip strength (kg)	23.9 (22.8 – 26.1)	25.1 (21.9 – 28.1)	32.5 (29 – 39.9)	42.3 (38.3 - 45)
Duration of HD (years)	11 (4.25 – 20.5)	N/A	4 (2 – 8)	N/A
Duration of CKD (years)	21 (13.3 – 25.8)	N/A	8 (6 – 33)	N/A

Data are median (first quartile – third quartile).
CKD, chronic kidney disease; HD, hemodialysis; N/A, not applicable.

Seitetsu Memorial Hospital in Iwate prefecture (Iwate Medical University: MH2109-188, Morioka Municipal Hospital: RH-14, Seitetsu Memorial Hospital: 014). Written informed consent was obtained from all participants. The test protocol was the same as that published previously by the authors [25, 26]. The methods employed to collect data for analysis are detailed below.

2. Isometric trunk extension maximum voluntary contraction (MVC) force

The strength of trunk extensor muscles was measured with a handheld dynamometer (μTas F-1, ANIMA, Tokyo, Japan), as described elsewhere [25, 26]. The participants were placed face down on two beds that moved up and down. They were positioned such that their superior anterior iliac spines were at the edge of the bed on which their lower body was strapped at the hip, knee, and ankle joints; their upper body rested on the other bed. The sensor attachment was positioned at the midpoint between the lower edges of the right and left scapulae. Dynamometer sensors were positioned in the middle of the back between the bilateral shoulder blades at the height of the subscapularis angle.

To measure MVC, the participants were asked to raise their upper body as high as they could for 5 s with their hands touching their head and their elbows abducted. The test was performed three times, with an interval of 30 s, and the maximum value was recorded. Torque values, expressed in Newton-meters (Nm), were calculated relative to the body weight (Nm/kg).

3. Trunk holding test (modified Biering-Sorensen test)

Following a 15-min rest, the participants were positioned in the same pronated position as earlier. The upper bed was moved down, and the participants were asked to hold their upper body horizontal, as described in a previous study [25, 26]. In this study, considering the risk of blood pressure elevation in HD patients, the test duration was set at 60 s. The horizontal position during the test was maintained through feedback from the participant. Despite the participants' willingness to continue, the test was finished when the participant could no longer hold the upper body in the horizontal plane as described in a previous study ("defined as > 2-cm reduction in height for 2 s")[25, 26].

4. EMG signal recording and analysis

During the trunk holding test, the EMG activity was recorded using the Trigno EMG system (Delsys Inc., USA), as described elsewhere[27]. The skin of the lumbar region was cleaned with an alcohol swab, and electrodes were attached. Active electrodes were placed unilaterally (3 cm outside the midline; level L1) over the erector spinae. EMG signals were recorded using a DELSYS wireless dynamic EMG tester (TrignoTM Wireless Systems, Delsys Inc., USA), with a sampling frequency of 2000 Hz and a bandwidth of 20–450 Hz. Wireless EMG signals were transmitted to the EMG acquisition software through electrodes placed on the muscle surfaces; the signals were processed and analyzed using EMGworks Analysis (Delsys Inc., USA). Linear regression analysis was applied to the MF time series (MF as a function of time) to calculate the MF slope values. In this study, the MF values derived from the left erector spinae was evaluated as described in earlier studies[25, 26].

5. Statistical analysis

Data of each group are presented as median (first quartile – third quartile). The Shapiro-Wilk test was used to assess normality. Because of the non-normality of one group, differences of MVC between groups were analyzed using Wilcoxon signed – rank test, a non-parametric test. Correlations were evaluated using Spearman's rank correlation coefficient. A p-value of < 0.05 was considered significant. Statistical analysis was performed using SPSS software (version 26.0; SPSS Inc., Chicago, IL).

Post-hoc power analysis was performed using G*Power software (version 3.1, Heinrich-Heine-University Software); the mean difference between the HD and control female groups was 0.22. The type 1 error was set at 0.05, and the study power was calculated as 0.952 according to the main results[28, 29].

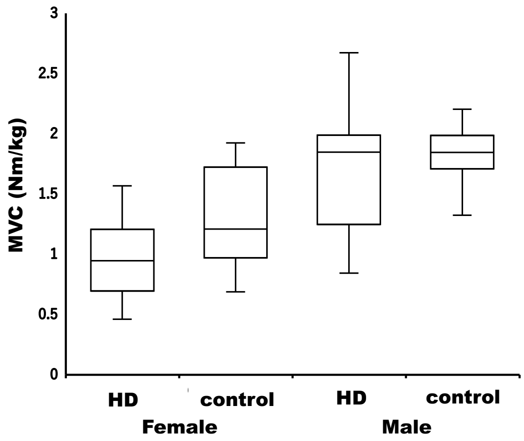

Fig. 1. Maximum voluntary contraction (MVC) in the hemodialysis (HD) and control groups.

III. Results

1. MVCs

Among female participants, the median MVCs of the HD and control groups were 0.95 (0.70 – 1.21) and 1.21 (0.97 – 1.72) Nm/kg, respectively, and those among males were 1.85 (1.25 – 1.99) and 1.84 (1.708 – 1.99) Nm/kg, respectively (Fig. 1). The MVC was no significant difference was observed between male and female participants of the HD and control groups.

2. Median frequency slope during the trunk holding test

All healthy participants completed the trunk holding test (60 s). However, one female HD patient (1/10) and four male HD patients (4/13) could not complete the test. The MF

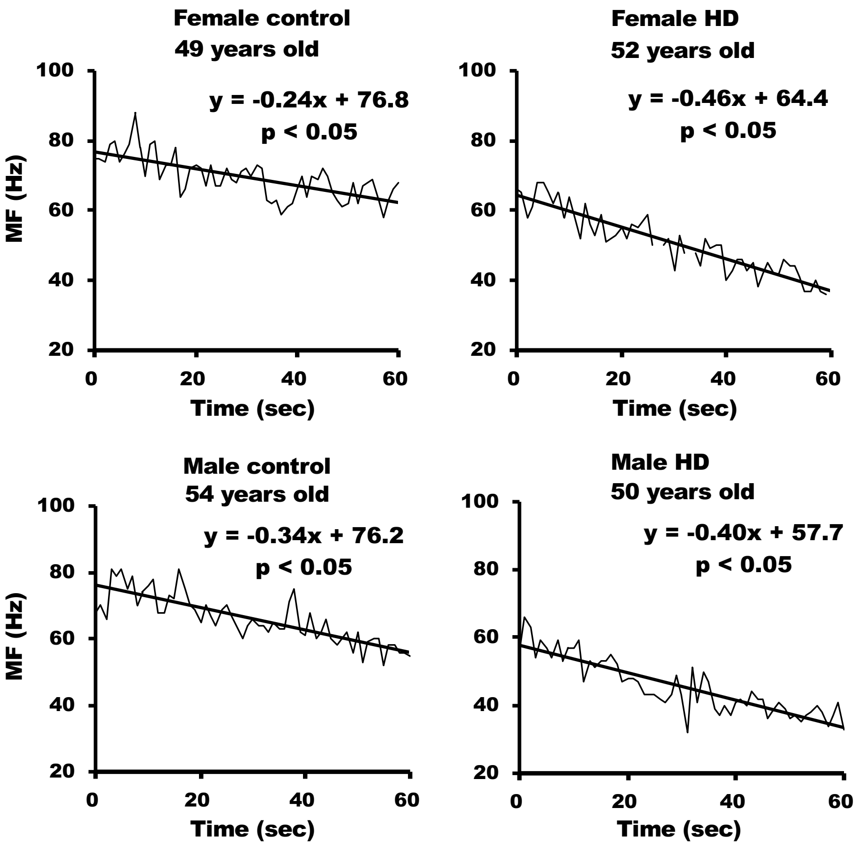

Fig. 2. Changes in median frequency (MF) of the individuals in the hemodialysis (HD) and control groups.

decreased linearly with time in all participants. Fig. 2 shows the MF changes of the individuals in each group. The MF values in the HD male group were not normally distributed (p = 0.026). Among female participants, the median MF slope values in the HD and control groups were −0.44(−0.61 – −0.31) and −0.24 (−0.33 – −0.23) Hz/s, respectively, whereas those among male participants were 0.34 (−0.55 – −0.31) and –0.29 (−0.34 – −0.227) Hz/s, respectively (Fig. 3). The MF slope among female participants was significantly greater in the HD group than in the control group (p = 0.007). By contrast, no significant difference was found in the MF slope values between the male participants of the two groups (p > 0.05). No correlation was found between MF slope values and duration

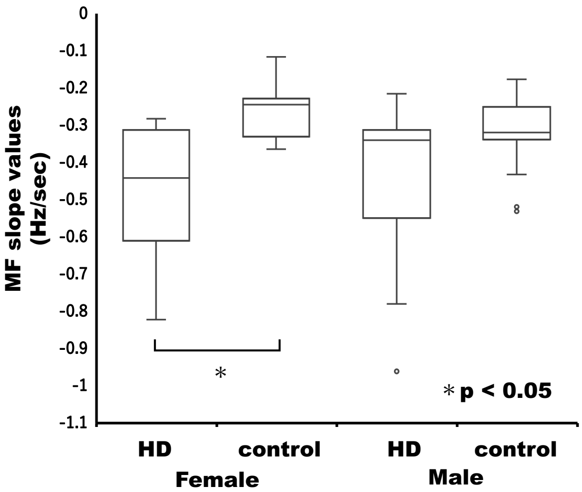

Fig. 3. Slope values of median frequency (MF) in the hemodialysis (HD) and control groups.

of HD (p > 0.05).

IV. Discussion

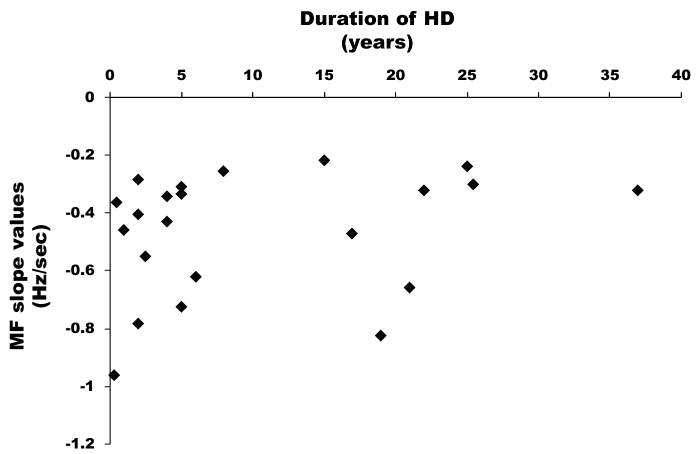

Fig. 4. Scatter plot of slope values of median frequency (MF) and duration of hemodialysis (HD).

In this study, despite showing similar MVC, the fatigue resistance of the erector spinae in female HD patients was lower than that in their age- and sex-matched controls. By contrast, no difference in the erector spinae fatigability was observed between the male participants of both groups.

The erector spinae has a high proportion of type I muscle fibers; however, the proportion of type II muscle fibers in this muscle is higher in male than in female individuals. As type II muscle fibers show selective atrophy with aging and disuse, it is important to eliminate their influence as much as possible while evaluating the properties of the erector spinae in HD patients [30, 31]. Therefore, in this study, we only included individuals aged < 60 years who had no lower back pain or obvious gait disturbances, such as walking with the use of an assistive device.

Grip strength can be used as a screening tool for the measurement of upper body strength and overall strength. In our study, grip strength and MVC of isometric trunk extension were comparable between HD patients and age- and sex-matched healthy individuals. Our finding that HD patients do not necessarily lose muscle strength is in agreement with those of previous reports [6, 32]. By combining the trunk holding test and EMG power spectral analysis, we could noninvasively measure the fatigability of the erector spinae. The principal finding of this study was that a lower fatigue resistance of the erector spinae was noted in female HD patients, in comparison with age- and sex-matched individuals.

Muscle fatigability has been associated with a shift in the MF toward lower values [24]. Additionally, the MF changes have been associated with the proportion of type I muscle fibers in the erector spinae [8]. Molsted et al. examined muscle biopsies from the vastus lateralis of HD patients and reported a decrease in type I muscle fibers [33]; their results are consistent with our findings. Since type I muscle fibers are rich in mitochondria, mitochondrial dysfunction due to oxidative stress, reported in CKD and HD patients, may be one of the factors that influence the resistance of the erector spinae to fatigue in these patients. Additionally, several previous studies have reported a decrease in mitochondrial density and mitochondrial DNA copy number within muscles in HD patients, thereby supporting our results [34]. Therefore, based on our results, a possible reason for the increased erector spinae fatigability in female HD patients is the relative proportion of type I muscle fibers in them; such HD-related changes were not observed in male patients.

A previous study conducted in young adults reported that erector spinae fatigability was lower in female adults than in male adults, and this difference was believed to be due to the difference in muscle fiber composition [23]. Tsuboi et al. compared the erector spinae fatigability, measured with the trunk holding test, between older individuals and young adults; although they found higher fatigability in older male individuals, no significant difference in muscle fatigability was observed between female adults of both groups [21]. Muscle loss begins around age 25 years [31], and the relative area of the type II muscle fibers selectively decreases with age [30, 31]. Therefore, selective atrophy of type II muscle fibers with age is more significant in male individuals. To our best knowledge, no previous studies have reported the muscle fiber composition in middle-aged male individuals; moreover, middle-aged male individuals may be affected by both aging and HD, but that aspect was not explored in this study.

This study has some limitations. First, the number of participants in the HD group was relatively small. Second, we could not evaluate whether the differences observed in the erector spinae fatigability between the two groups in this study were due to mitochondrial damage owing to oxidative stress, changes in the myofiber composition, or whether other influencing factors were present. However, despite these limitations, this study confirmed that differences exist in the erector spinae fatigability between female HD patients and age- and sex-matched healthy individuals.

Previous studies have reported the benefits of exercise therapy such as resistance training and aerobic exercise, in CKD and HD patients [35-37]. We suggest that HD and pre-dialysis CKD patients should be given exercise regimes as early as possible to prevent reduction in the muscle volume and the development of fatigability. Further studies are required to design safe and effective exercises to maintain and improve muscle strength in CKD and HD patients.

In comparison with age- and sex-matched healthy individuals, a lower fatigue resistance of the erector spinae was observed in HD patients aged 40–60 years; however, no significant difference was observed in the erector spinae fatigability between male participants of the two groups of similar age. These findings emphasize the importance of regular exercise for CKD and HD patients to prevent fatigability and loss of muscle strength. Moreover, we believe that understanding the differences in muscle fatigability between HD patients and healthy individuals may allow for specific muscle strength training to be designed for HD patients.

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血液透析患者と健常者における 腰部筋疲労特性の検討

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要旨

高齢者人口の増加や糖尿病の有病率の上昇により，慢性腎臓病（CKD）や血液透析（HD）の患者数は世界的に増加している．CKD 患者や HD 患者は筋力低下を伴っていることが多く，日常生活の活動性や生活の質の低下に大きく寄与している．先行研究では末期腎疾患で HD 治療を受けている患者においてⅠ型筋線維，Ⅱ型筋線維それぞれの筋萎縮について報告されており，統一された見解が得られていない．このように，HD 患者で萎縮を起こす筋線維の種類については不確実性があり，そのような患者における適切な筋力トレーニングについては普遍的な合意は存在しない．今回，我々の研究の目的は筋電図周波数パワースペクトル解析を用いて HD 患者の腰背部の筋繊維の割合と筋疲労について評価した．その結果，女性の HD 患者において健常者に比べて腰背部の筋疲労性が高く，持久力の低下が示唆された．女性の HD 患者には早期からのリハビリテーションの介入の必要であると考えられた．