

# EFFECT OF RENAL DIALYSIS DURATION ON PATIENT PHYSICAL PERFORMANCE AND BLOOD METABOLITES

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**Abstract.** Maintenance hemodialysis (MHD) is a common method for preventing complications of end-stage renal disease (ESRD) and physical performance serves as an important indicator of patient health. In this cross-sectional study, we aimed to determine what the effects of extended hemodialysis (HD) sessions and long-term MHD had on subject physical performance and laboratory testing in order to determine what was the best length of a HD session that could optimize subject physical performance and laboratory tests and identify possible problems associated with the length of HD sessions. Study subjects were chosen randomly from 7 HD centers in Shanghai, People's Republic of China during July 2020-March 2023. The minimum number of subjects determined to be needed for the study was 350. Inclusion criteria for study subjects were being aged  $\geq 40$  years, undergoing maintenance hemodialysis for  $\geq 3$  months and giving consent to be included in the study. Exclusion criteria for study subjects were being unwilling to participate in the study, not completing the required questionnaire, physical performance assessment or laboratory testing or having a serious health condition that could interfere with the physical performance assessment or blood tests. Subjects were categorized based on duration of each dialysis session into a conventional group (duration of each HD session of  $\leq 4$  hours or having  $\leq 3$  HD sessions per week) and extended group (duration of each HD session of  $> 4$  hours or having  $> 3$  HD sessions per week). Subjects were also classified by total length of time they had been undergoing MHD into a short-term group (total duration of  $\leq 12$  months) and a long-term group (total duration of  $> 12$  months). Each subject completed a questionnaire asking their age, gender, education level, alcohol consumption level and smoking status. The following physical performance tests were performed in each subject: grip strength categorized into low (males  $< 28$  kg and

females <18 kg) and normal (males  $\geq$ 28 kg and females  $\geq$ 18 kg), a 4-meter walk test categorized into slow speed (<1.0 m/s) and normal speed ( $\geq$ 1.0 m/s), a knee-extension strength test categorized into weak (males <0.5 $\times$ their body weight and females <0.4 $\times$ their body weight) and normal (male  $\geq$ 0.5 $\times$ their body weight, female  $\geq$ 0.4 $\times$ their body weight). Subject heights and weights were checked and the body mass index (BMI) of each subject was calculated as weight in kilograms divided by height in meters squared (kg/m<sup>2</sup>). The following laboratory tests were performed on each subject: total cholesterol (TC) (normal:  $\leq$ 5.2 g), triglycerides (TG) (normal:  $\leq$ 1.7 mmol/l), high-density lipoprotein-cholesterol (HDL-C) (normal: <1.04 mmol/l), low-density lipoprotein-cholesterol (LDL-C) (normal: <3.12 mmol/l), hemoglobin (HGB) (normal: 120-160 g/l for males and 110-150 g/l for females), serum albumin (ALB) (normal: 35-55 g/l) and  $\beta_2$ -microglobulin ( $\beta_2$ -MG) (normal: 1.28-1.95 mg/l). Statistical analyses were performed using non-parametric tests and subgroup comparisons were made. A total of 875 subjects were included in the study, 586 (67%) males. The mean ( $\pm$ standard deviation) age of subjects was 59 ( $\pm$ 13) (range: 40-80) years. Of these, 512 (58.5%) were in the conventional group for duration of each dialysis session and 363 (41.5%) were in the extended group for duration of each dialysis session. Subjects in the extended group compared to the conventional group had significantly lower ( $p$ -value <0.010) (both males and females) mean grip strength (24.3 kg *vs* 19.4 kg), significantly lower ( $p$ -value = 0.010) overall knee extension strength (21.5 kg *vs* 17.0 kg), significantly lower ( $p$ -value <0.010) overall 4-meter walk speeds (1.0 m/s *vs* 0.7 m/s), significantly lower ( $p$ -value = 0.014) overall TG levels (2.4 mmol/l *vs* 1.7 mmol/l) and significantly lower ( $p$ -value <0.010) overall  $\beta_2$ -MG levels (35.1 mg/l *vs* 20.5 mg/l), respectively. Subjects in the long-term treatment group compared to subjects in the short-term group had a significantly lower ( $p$ -value <0.010) overall mean grip strength (25.0 kg *vs* 23.8 kg), a significantly lower ( $p$ -value = 0.004) overall mean knee extension strength (21.4 kg *vs* 21.3 kg), a significantly lower ( $p$ -value <0.010) overall mean BMI (23.9 *vs* 20.2) and a significantly lower ( $p$ -value <0.05) overall mean  $\beta_2$ -MG level (35.8 mg/l *vs* 28.1 mg/l). In summary, in our study population, subjects with extended HD sessions and long-term MHD both had significantly lower grip strength, knee extension strength, 4-meter walk speeds and TG and  $\beta_2$ -MG levels and subjects with long-term MHD had significantly lower BMIs. We conclude having extended HD sessions and long term MHD resulted in poorer performance and malnutrition

showing conventional HD sessions are preferred over extended HD sessions. Subjects having extended HD and with long term MHD need to have strength and nutritional assessments and possibly counseling to prevent or manage problems in these areas. Further studies are needed to determine what methods should be employed to improve and prevent deterioration in physical performance and nutrition.

**Keywords:** hemodialysis, physical performance, blood biochemical indicators

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## INTRODUCTION

End-stage renal disease (ESRD) is a global public health problem affecting millions of people and imposing a substantial burden on healthcare systems worldwide (Hassanein *et al*, 2022). Maintenance hemodialysis (MHD) helps prevent hyperkalemia and uremia, common complications of ESRD (Kadatane *et al*, 2023). However, the 5-year survival rate of patients with ESRD increased from 45% at the end of the 20th century to >65% at present (Kramer *et al*, 2021).

A conventional hemodialysis (HD) session lasts 4 hours, occurs 2-3 times per week and removes <30% of toxins, such as  $\beta_2$ -microglobulin and other medium-sized protein waste products (Assimon *et al*, 2016). Incomplete toxin clearance and fluid fluctuations between HD sessions, may contribute to cardiac hypertrophy, vascular stiffness and other metabolic disturbances that can compromise cardiovascular health (Assimon *et al*, 2016).

Some studies have recommended longer (extended) HD sessions

(>4 hours) in hopes of improving toxin clearance and hemodynamics (Chertow *et al*, 2016). Previous studies have evaluated the efficacy of MHD and survival outcomes without evaluating physical performance. Physical performance may be evaluated by measuring grip strength, conducting a 4-meter walk test (measuring the speed in which the patient is able to walk 4 meters) and measuring knee-extension strength. It is unclear what the effect of extended HD sessions and long-term MHD has on physical performance.

In this study, we aimed to determine what the effects of extended HD sessions and long-term MHD had on subject physical performance and laboratory tests in order to determine what the best length of a HD session is to optimize physical performance and blood test results and identify problems associated with the length of HD sessions and with long term MHD.

## MATERIALS AND METHODS

### Study subjects

We conducted this cross-sectional study (clinical trial study number: UMIN000056404) during July 2020-March 2023. Subjects were recruited from patients undergoing MHD at 7 HD centers in Shanghai, PR China. Inclusion criteria for study subjects were: 1) being aged  $\geq 40$  years, 2) undergoing MHD for at least 3 months and 3) being willing to participate in this study. Exclusion criteria for study subjects were: 1) being unwilling to participate in the study, 2) being unable to complete the required questionnaire, physical performance assessment or blood test or 3) having a serious health condition that could interfere with the physical performance assessment or blood test. Sample size was calculated using G\*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany) with  $\alpha = 0.05$  and power = 0.90. This accounts for a 20% attrition rate. As a result, the minimum number of subjects

calculated to be needed for this study was 350.

### **Subject interviews**

Each subject was asked to complete a standardized questionnaire *via* a face-to-face interview. Subjects were asked their age, gender, education level, marital status, whether they smoked and whether they drank alcohol.

### **Assessment of physical performance**

In each study subject we measured their heart rate in beats per minute, body weight and height and calculating body mass index (BMI) in  $\text{kg}/\text{m}^2$ , measured grip strength in the dominant hand in kilogram (kg) using a handheld dynamometer (GRIP-D; Takei Engineering Co Ltd, Niigata, Japan), performed a 4-meter walk test by determining the time it took the subject to walk 4 meters and conducted a knee-extension strength test, which measured the maximum weight a subject was able to raise by extending his or her knees. The measured

values for grip strength, 4-meter walk test, and knee-extension strength were subsequently categorized based on the following criteria: grip strength was categorized into low (males  $<28$  kg and females  $<18$  kg) and normal (males  $\geq 28$  kg and females  $\geq 18$  kg); the 4-meter walk test categorized subjects into walking with a slow speed ( $<1.0$  m/s) or a normal speed ( $\geq 1.0$  m/s); and the knee-extension strength test categorized subjects into being weak (males  $<0.5 \times$  their body weight and females  $<0.4 \times$  their body weight) or normal (male  $\geq 0.5 \times$  their body weight, female  $\geq 0.4 \times$  their body weight). This was used to assess subject physical performance (McInnes *et al*, 2005) (Fig 1). All assessments were conducted by the same person.

### **Laboratory testing**

In each subject we checked the following blood tests: total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C),

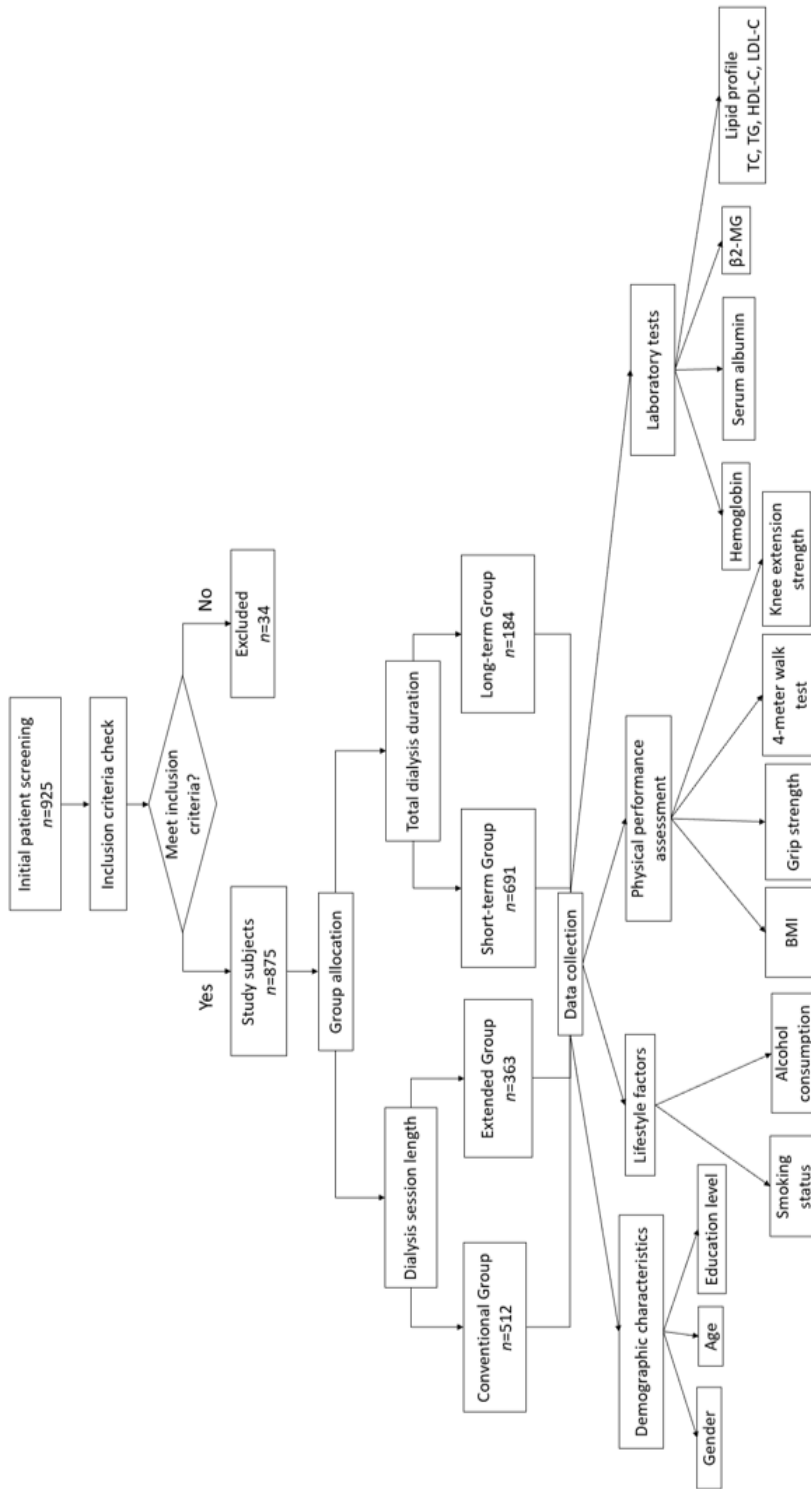


Fig 1 - Study flow chart

BMI: body mass index; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol; TC: total cholesterol; TG: triglycerides; β<sub>2</sub>-MG: beta 2-microglobulin

$\beta_2$ -microglobulin ( $\beta_2$ -MG), hemoglobin (HGB), albumin (ALB) and plasma albumin (Table 1). The  $\beta_2$ -MG level was measured to evaluate renal function where an elevated  $\beta_2$ -MG level greater uremia due to poorer clearance via HD. The following laboratory tests were performed on each subject: TC (normal:  $\leq 5.2$  g), TG (normal:  $\leq 1.7$  mmol/l), HDL-C (normal:  $< 1.04$  mmol/l), LDL-C (normal:  $< 3.12$  mmol/l), HGB (normal: 120-160 g/l for males and 110-150 g/l for females), ALB (normal: 35-55 g/l),  $\beta_2$ -MG (normal: 1.28-1.95 mg/l).

### Hemodialysis duration

Our study had 2 parts. In the first part, study subjects were divided into 2 groups: 1) those undergoing conventional MHD (Conventional Group) where they had HD  $\leq 3$  times per week lasting  $\leq 4$  hours and 2) those undergoing extended MHD (Extended Group) where subjects had HD  $> 3$  times per week and/or each session lasted  $> 4$  hours. In the second part of our study, subjects

were divided into 2 groups: 1) those undergoing long-term MHD (Long-term Group) where the total length of time subjects had been having MHD was  $> 12$  months and 2) those undergoing short-term MHD (Short-term Group) where the total length of time subjects had been having MHD was  $\leq 12$  months.

These 4 overall categories, were used to assess the effect of different durations of HD and MHD on subject physical performance and laboratory values, which indirectly assessed the health of study subjects.

### Statistical analysis

Associations between physical performance, laboratory tests and MHD and HD duration were assessed using the Kruskal-Wallis test. A  $p$ -value  $< 0.05$  was considered statistically significant. All statistical analyses were performed using the Statistical Package for Social Sciences, version 26.0 (International Business Machines Corporation, Armonk, NY).

Table 1  
Reference ranges and cutoff values for measured variables

Variables	Reference range or cutoff
Grip strength	Low grip strength: <28 kg for men, <18 kg for women
Knee extension strength	Knee extension weakness: (males <0.5×weight and females <0.4×weight); normal knee extension strength (male ≥0.5×weight, female ≥0.4×weight).
Walking speed	Slow gait: <1.0 m/s (frailty threshold)
Total cholesterol	Normal: ≤5.2 mmol/l
Triglycerides	Normal: ≤1.70 mmol/l
β <sub>2</sub> -Microglobulin	Target value <25 mg/l (no universally agreed upon threshold; lower is better). A single reading > 35 mg/l or persistently elevated levels indicate high mortality risk, necessitating enhanced cardiovascular and nutritional management.
Albumin	Normal: 35-50 g/l; malnutrition if <35 g/l
Hemoglobin	Males: 120-160 g/l; females: 110-150 g/l
High-density lipoprotein cholesterol	Normal: >1.04 mmol/l
Low-density lipoprotein cholesterol	Normal: <3.12 mmol/l

Note: Cutoff values used in this Table are those published previously (Chen *et al*, 2020).

g/l: grams per liter; kg: kilogram; mg/l: milligrams per liter, mmol/l: millimoles per liter; m/s: meters per second

### Ethical approval

This study was approved by the Ethics Committee of Shanghai Health University (Approval

No. 2019-A4-2621-19-201001-03-12010419771113601X) and conducted in accordance with the principles of the Declaration

of Helsinki. All subjects gave informed consent prior to being included in the study.

## RESULTS

### Subject characteristics

A total of 875 subjects were included in this study, 586 (67%) males. The mean ( $\pm$ standard deviation) age of study subjects was 59 ( $\pm$ 13) (range: 40-80) years. 43.7% of subjects had an education level  $>9$  years, 35.2% had a level of 7-9 years, 17.3% had a level of 1-6 years and 3.8% had no formal education. 82.5% of subjects were married, 8.9% were single, 4.6% were widowed and 4.0% were divorced. 20.6% of subjects were smokers and 11.9% of subjects drank alcohol (Table 2).

In Part 1 of the study, 512 subjects (58.5%) were in the Conventional length of each HD session group and 363 patients (41.5%) were in the Extended Group while in Part 2, 691 subjects (79.0%) were in the Long-term MHD Group

and 184 subjects (21.0%) were in the Short-term MHD group.

### Extended Group and physical performance

Compared to subjects in the Conventional Group, subjects in the Extended Group had a significantly lower ( $p$ -value $<0.010$ ) (both males and females) mean grip strength (24.3 kg *vs* 19.4 kg), a significantly lower ( $p$ -value = 0.010) mean knee extension strength (21.5 kg *vs* 17.0 kg), a significantly lower ( $p$ -value  $<0.010$ ) mean 4-meter walk speed (1.0 m/s *vs* 0.7 m/s), a significantly lower ( $p$ -value = 0.014) mean TG level (2.4 mmol/l *vs* 1.7 mmol/l) and a significantly lower ( $p$ -value  $<0.010$ ) mean  $\beta_2$ -MG level (35.1 mg/l *vs* 20.5 mg/l) (Table 3, Fig 2).

### Long-term Group and physical performance

Compared to subjects in the Short-term Group, subjects in the Long-term Group had a significantly lower ( $p$ -value  $<0.010$ ) mean grip strength (25.0 kg *vs* 23.8 kg), a significantly lower ( $p$ -value = 0.004)

mean knee extension strength (21.4 kg *vs* 21.3 kg), a significantly lower ( $p$ -value  $<0.010$ ) mean BMI (23.9 kg/m<sup>2</sup> *vs* 20.2 kg/m<sup>2</sup>) and a significantly lower ( $p$ -value  $<0.05$ ) mean  $\beta_2$ -MG level (35.8 mg/l *vs* 28.1 mg/l) (Table 4, Fig 2).

## DISCUSSION

In our study, subjects in the Extended Group had lower grip strength than subjects in the Conventional Group, similar to the findings of a previous study (Dilloway *et al*, 2023) that reported

Table 2  
Subject baseline characteristics (N = 875)

Variables	Results	$p$ -value
Mean ( $\pm$ SD) age in years	59 ( $\pm$ 13)	0.029
Education level in years, $n$ (%)		0.004
None	34 (3.9)	
1-6	151 (17.2)	
7-9	308 (35.2)	
>9	382 (43.7)	
Alcohol use, $n$ (%)		0.162
Yes	406 (46.4)	
No	469 (53.6)	
Tobacco use, $n$ (%)		$<0.001$
Yes	444 (50.7)	
No	431 (49.3)	
Gender, $n$ (%)		0.230
Male	586 (67.0)	
Female	289 (33.0)	

SD: standard deviation

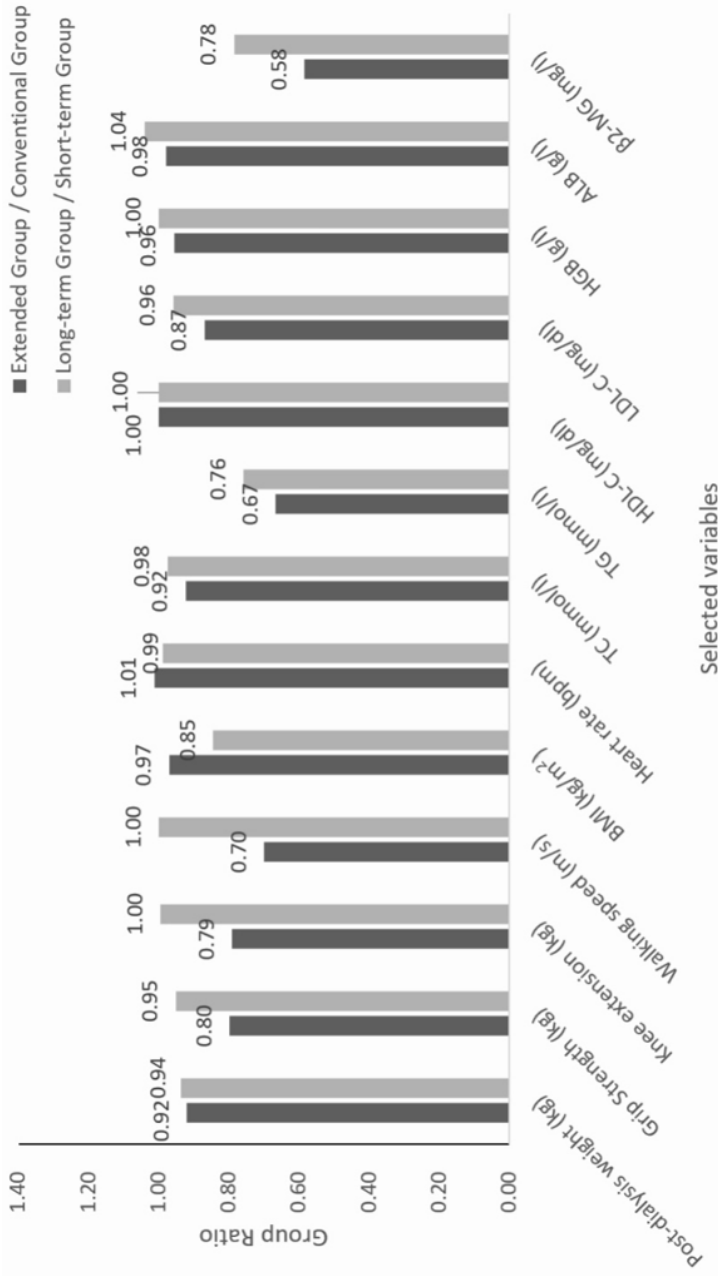


Fig 2 - Comparison of ratios of selected factors between Extended and Conventional Groups and between Long-term and Short duration groups

Extended Group: Subjects had HD >3 times per week and/or each session lasted >4 hours; Conventional Group: Subjects had HD ≤3 times per week lasting ≤4 hours; Long-term Group: Subjects who had undergone MHD for >12 months; Short-term Group: Subjects who had undergone MHD for ≤12 months.

ALB: serum albumin; BMI: body mass index; g/l: grams per liter; bpm: beats per minute; HD: hemodialysis; HDL-C: high-density lipoprotein cholesterol; HGB: hemoglobin; kg: kilograms; kg/m<sup>2</sup>: kilogram per square meter; LDL-C: low-density lipoprotein cholesterol; m/s: meters per second; MHD: maintenance hemodialysis; mg/dl: milligrams per deciliter; mg/l: milligrams per liter; mmol/l: millimoles per liter; TC: total cholesterol; TG: triglycerides; β<sub>2</sub>-MG: beta2-microglobulin

Table 3  
Comparison of selected variables by study subject group

Averaged variables	Conventional Group ( <i>n</i> = 512)	Extended Group ( <i>n</i> = 363)	<i>p</i> -value
Post-dialysis weight in kilograms	62.7	57.7	0.018
Grip Strength in kilograms	24.3	19.4	<0.010
Knee extension in kilograms	21.5	17.0	0.001
Walking speed in meters per second	1.0	0.7	<0.010
BMI in kg/m <sup>2</sup>	23.4	22.7	0.292
Heart rate in beats per minute	80	81	0.501
TC in mmol/l	3.9	3.6	0.084
TG in mmol/l	2.4	1.6	0.014
HDL-C in mg/dl	1.0	1.0	0.501
LDL-C in mg/dl	2.3	2.0	0.118
HGB in g/l	111.0	106.1	0.442
ALB in g/l	40.3	39.5	0.705
β <sub>2</sub> -MG in mg/l	35.1	20.5	<0.010

Conventional Group: Subjects had HD ≤3 times per week lasting ≤4 hours; Extended Group: Subjects had HD >3 times per week and/or each session lasted >4 hours.

ALB: serum albumin; BMI: body mass index; g/l: grams per liter; HD: hemodialysis; HDL-C: high-density lipoprotein cholesterol; HGB: hemoglobin, kg/m<sup>2</sup>: kilogram per square meter; LDL-C: low-density lipoprotein cholesterol; mg/dl: milligrams per deciliter; mg/l: milligrams per liter; mmol/l: millimoles per liter; TC: total cholesterol; TG: triglycerides; β<sub>2</sub>-MG: beta2-microglobulin

Table 4  
Comparison of clinical characteristics by subject group

Averaged variables	Short-term Group ( <i>n</i> = 691)	Long-term Group ( <i>n</i> = 184)	<i>p</i> -value
Post-dialysis weight in kilograms	65.8	61.6	<0.010
Grip Strength in kilograms	25.0	23.8	<0.010
Knee extension in kilograms	21.4	21.3	0.004
Walking speed in meters per second	1.0	1.0	0.523
BMI in kg/m <sup>2</sup>	23.9	20.2	<0.010
Heart rate in beats per minute	82	81	0.666
TC in mmol/l	4.0	3.9	0.972
TG in mmol/l	2.9	2.2	0.256
HDL-C in mg/dl	1.0	1.0	0.213
LDL-C in mg/dl	2.4	2.3	0.999
HGB in g/l	110.9	110.9	0.050
ALB in g/l	39.0	40.6	0.782
β <sub>2</sub> -MG in mg/l	35.8	28.1	<0.010

Short-term Group: Subjects who had undergone MHD for ≤12 months; Long-term Group: Subjects who had undergone MHD for >12 months.

ALB: serum albumin; BMI: body mass index; g/l: grams per liter; HDL-C: high-density lipoprotein cholesterol; HGB: hemoglobin; kg/m<sup>2</sup>: kilogram per square meter; LDL-C: low-density lipoprotein cholesterol; mg/dl: milligrams per deciliter; mg/l: milligrams per liter; MHD: maintenance hemodialysis; mmol/l: millimoles per liter; TC: total cholesterol; TG: triglycerides; β<sub>2</sub>-MG: beta2-microglobulin

finding lower grip strength among those with extended HD. HD induces a catabolic environment. The causes muscle protein breakdown (Deger *et al*, 2017) and the inverse relationship between the extended HD session and muscle health, including both muscle mass and strength (Song *et al*, 2022). This pathophysiological mechanism explains the findings of our study.

Subjects in the Extended Group had lower knee extension strength than subjects in the Conventional Group. We have already mentioned the mechanism described regarding decreased grip strength above. This may also be due to chronic muscle inflammation, uremia and metabolic disorders (Wang and Mitch, 2014). Persistently elevated proinflammatory cytokines activate proteolytic pathways such as the ubiquitin-proteasome system, directly promoting degradation of skeletal muscle myofibrillar proteins and resulting in reduced muscle strength (Späte and Schulze, 2004). This results in the

decreased strength found among our subjects with extended HD sessions. In our study, subjects in the Extended Group had a lower 4-meter walk speed than subjects in the Conventional Group. A previous study (Manfredini *et al*, 2017) reported a decrease of 8.7 meters distance during a 6-minute walk for every additional hour of HD. This could be due to nutrient removal by HD and post-HD fatigue. Polyneuropathy has also been reported during extended HD sessions (Bhuta *et al*, 2022), which also could explain our study findings.

In our study, subjects in the Extended Group had lower mean triglyceride levels than subjects in the Conventional Group. A previous study (Hobson *et al*, 2022) reported uremia disrupts the catabolism of chylomicrons and low-density lipoproteins by inhibiting lipoprotein lipase activity, resulting in delayed triglyceride clearance. Since subjects in the Extended Group had better clearance of

uremia then they were likely to have lower triglyceride levels. These lower triglyceride levels may also be due to malnutrition with extended duration HD. However, there is no evidence to show that among subjects with mild to moderate elevation of TG levels that lowering these levels results in lower morbidity or mortality among study subjects.

In our study, subjects in the Extended Group had lower mean  $\beta_2$ -MG levels than subjects in the Conventional Group.  $\beta_2$ -MG is a middle-molecular-weight uremic toxin (Zhao *et al*, 2024). Reduced  $\beta_2$ -MG levels typically indicate favorable dialysis efficacy (Wani *et al*, 2025). The longer each HD session is, the greater the amount of  $\beta_2$ -MG will be cleared from the blood (Kalim *et al*, 2018). In spite of this lower uremia and lower  $\beta_2$ -MG levels, the more deleterious effects the subjects in our study occurred. This suggests  $\beta_2$ -MG levels do not reflect subject health or physical performance.

In our study, subjects in the Long-term Group had significantly lower mean grip strength than subjects in the Short-term Group. A previous study (Liu *et al*, 2018) reported long-term exposure to uremia and repeated fluid removal accelerate skeletal muscle loss: patients with >20 years MHD have significantly lower grip strength than those with <10 years MHD. A similar study (Shirai *et al*, 2021) reported for each additional year of MHD subjects had a 1.8% decline in isometric knee extension strength due to chronic muscle inflammation and persistent protein catabolism.

In our study, subjects in the Long-term Group had significantly lower knee extension strength than subjects in the Short-term Group. The studies reported in the previous paragraph also apply to this finding. Subjects undergoing long-term MHD also have metabolic acidosis and vitamin D deficiency, worsening muscle protein breakdown and contractile function, resulting in measurable strength loss (Lim *et al*, 2005). Muscle resistance training

has been found to be effective in combating muscle wasting (Cheema *et al*, 2007).

In our study, we found that subjects in the Long-term Group had significantly lower BMI than subjects in the Short-term group. A previous study (Han *et al*, 2024) reported that long-term dialysis induced protein-energy wasting (PEW), which depleted protein and energy reserves, leading to weight loss and reduced fat mass. Nutritional deficiencies can exacerbate muscle wasting and functional decline (Carrero *et al*, 2008). Thus, the lower TG levels and BMI reduction observed in this study may have been associated with muscle weakness and frailty. We recommend routine physical assessments and nutritional counseling for patients undergoing long-term MHD.

In our study, we found that subjects in the Long-term Group had significantly lower  $\beta_2$ -MG levels than subjects in the Short-term Group. A previous study (Francis

*et al*, 2024) proposed that long-term dialysis periods would be associated with gradual deterioration of renal function, as observed in IgA nephropathy and diabetes mellitus. However, in long-term MHD patients, peripheral  $\beta_2$ -MG collects in the joints and soft tissues, forming amyloid fibers that lead to “pseudonormalization” or even decreased serum concentrations of  $\beta_2$ -MG (Tagami *et al*, 2020) when in reality the total amount of  $\beta_2$ -MG in the body is higher than among short-term MHD patients.

Our study had several limitations. First, it was a cross-sectional study, so causal relationships could not be identified. Second, the subjects were Chinese patients attending specific dialysis centers in Shanghai, so our results cannot be applied to other populations. Third, we did not record dietary patterns so we may have missed specific dietary factors among our study subjects that could affect our results.

In summary, in our study population, subjects with extended

HD sessions and long-term MHD both had significantly lower grip strength, knee extension strength, 4-meter walk speeds and TG and  $\beta_2$ -MG levels and subjects with long-term MHD had significantly lower BMIs. We conclude having extended HD sessions and long term MHD resulted in poorer performance and malnutrition showing conventional HD sessions are preferred over extended HD sessions. Subjects having extended HD and with long term MHD need to have strength and nutritional assessments and possibly counseling to prevent or manage problems in these areas. Further studies are needed to determine what methods should be employed to improve and prevent deterioration in physical performance and nutrition.

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#### CONFLICT OF INTEREST DISCLOSURE

The authors declare no conflicts of interest in this work.

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