European Spine Journal (2020) 29:2198–2204
https://doi.org/10.1007/s00586-020-06525-1

ORIGINAL ARTICLE

Handgrip strength correlates with walking in lumbar spinal stenosis

Hirokazu Inoue[1] · Hideaki Watanabe[2] · Hitoshi Okami[3] · Yasuyuki Shiraishi[1] · Atsushi Kimura[1] · Katsushi Takeshita[1]

Received: 20 January 2020 / Revised: 15 June 2020 / Accepted: 1 July 2020 / Published online: 10 July 2020

Abstract

Purpose To examine the relationship between handgrip strength and leg extension power, walking speed, and intermittent claudication for lumbar spinal stenosis (LSS) using computed tomography.

Methods We examined patients who underwent laminectomy for LSS from June 2015 through March 2018. Before spine surgery, we evaluated walking distance, handgrip strength, leg extension power (LEP), 10-m walk test (time and steps), psoas muscle index (PMI), and the area of both total and multifidus muscle using plain computed tomography imaging at the third lumbar level. Handgrip strength was compared with comorbidities including anemia, diabetes, hypertension, marital status, etc.

Results There were 183 patients (55 female, 128 male) with a mean age of 70.5 years. Handgrip strength significantly correlated with LEP ($P<0.001$, $r=0.723$), walking speed ($P<0.001$, $r=-0.269$), 10-m walking test (steps) ($P<0.001$, $r=-0.352$), area of skeletal muscle at L3 level ($P<0.001$, $r=0.469$), area of psoas muscle ($P<0.001$, $r=0.380$), PMI ($P<0.001$, $r=0.253$), and intermittent claudication. Age, height, and weight were correlated with handgrip strength, but BMI was not correlated. Handgrip strength was significantly reduced by anemia, hypertension, and single marital status.

Conclusions The more handgrip strength patients with LSS have, the more LEP, the faster walking speed, the greater area of psoas and skeletal muscle, the fewer steps for a 10-m walk they have, and the longer walking distance. Age, height, and weight were associated with handgrip strength, but BMI has no association. Low handgrip strength was related to comorbidities including anemia, hypertension, and marital status.

Keywords Handgrip strength · Lumbar spinal stenosis · Psoas muscle mass index · Sarcopenia · Walking speed

Introduction

Muscle strength and muscle mass decrease due to age. People annually incur approximately a 1% reduction of muscle mass after age 40 [1]. Sarcopenia is age-related, secondary loss of muscle mass and has recently begun attracting attention in various medical fields. The worldwide number of patients with sarcopenia will increase from 50 million in 2009 to 2 billion in 2050 [2]. The European Working Group on Sarcopenia in Older People developed the consensual definition of sarcopenia, which associates muscle mass loss and weak handgrip strength [2].

Handgrip strength is related to body musculature. A handgrip dynamometer is simple and useful, so it has been used in many studies. Muscle strength physiologically decreases with age [3] and is known as dynapenia [4], which is known to predict the risk of mortality from all causes when it is measured in healthy middle-aged males [3]. In oncology, weak handgrip strength is affected by cancer-related fatigue [5], poor quality of life [6], postoperative complications [7], and high mortality risk [7]. Therefore, handgrip strength is related to prognosis in cancer patients and is used to predict sarcopenia. Moreover, lumbar spinal stenosis (LSS) patients with high handgrip strength (> 26 kg for men and > 18 kg for women) demonstrated better Oswestry Disability Index scores in terms of disability and health status six months after spine surgery [8].

✉ Hirokazu Inoue
hi-kazu@jichi.ac.jp

[1] Department of Orthopaedic Surgery, Jichi Medical University, 3311-1 Yakushiji, Shimotsuke, Japan

[2] Department of Pediatric Orthopaedic Surgery, Jichi Children's Medical Center, Shimotsuke, Tochigi, Japan

[3] Department of Orthopaedic Surgery, Shinkaminokawa Hospital, Kaminokawa, Japan

Symptoms of LSS involve lower back pain, lower extremity pain, lower extremity numbness, lower muscle weakness, and gait disturbance. Moreover, the patients with degenerative lumbar flat back demonstrated paraspinal muscular atrophy and fatty degeneration due to muscle denervation or disuse [9]. Sarcopenia was more prevalent in patients with LSS than matched controls [10, 11]. However, few papers have demonstrated the relationship between handgrip strength and lower leg extension power (LEP). Furthermore, the relationship among handgrip strength, LEP, psoas muscle, walking speed, and walking distance is still largely unknown in LSS patients.

However, one report showed that handgrip strength is not strongly influenced by compromised nerves in the lower extremity for patients with LSS [10]. But using handgrip strength to predict sarcopenia is controversial. The purpose of the present study is to investigate the relationship among grip strength, leg extension power, walking speed, and intermittent claudication for LSS.

Methods

Patients

We retrospectively enrolled patients who received spine surgery at a single hospital between June 2015 and March 2018. Ethics approval was obtained from the Ethics Review Board of Shinkaminokawa Hospital. The present study was performed in accordance with the World Medical Association Declaration of Helsinki principles. The diagnosis of LSS was confirmed through neurologic examination and imaging studies showing spinal canal stenosis. Inclusion criteria included neurogenic claudication, radicular leg pain with LSS as detected on magnetic resonance images (MRI), and failure of conservative treatment for at least three months. Exclusion criteria consisted of non-ambulatory patients, myelopathy, hemodialysis, no available lumbar computed tomography (CT), and no measures of fitness before the operation.

In total, 259 patients underwent lumbar spine surgery. We excluded 50 patients with absent preoperative measures of fitness and 26 non-ambulatory patients. One hundred eighty-three patients (55 female, 128 male) were included in this study. Their mean age was 70.5 years (range, 36–88 years). All patients preoperatively received CT for operative planning.

Measures of fitness

Handgrip strengths of both upper limbs were examined with a handheld dynamometer. The patients gripped the dynamometer as hard as possible for three seconds without pressing the instrument against the body or bending at the elbow with the arm straight by the side in the standing position. Two tests were performed on both right and left hands with a brief rest between the trials. The best performance was used for the analysis [10]. LEP was measured with the isokinetic leg power system (μTas F-1, Anima, Tokyo, Japan) in the sitting position. Likewise, two examinations were received on both right and left legs and the best performance was used.

The measurements of gait speed, time, and steps were acquired from the timed 10-m walk test. The patients walked barefoot along a 10-m walkway at their top speed. Time was measured using a digital stopwatch over the intermediate six of the ten meters to allow for acceleration and deceleration. An investigator standing at the start point said that "I will say ready, set, go. When I say go, walk as fast as you safely can until I say stop." Time starts when the toes of the leading foot cross the 2-m mark and stops when the toes of the leading foot cross the 8-m mark. All patients performed the test twice [12].

Walking distance was measured before surgery by walking up to 300 m side by side with a physical therapist without rest. If the patients can walk more than 300 m, the measurement of walking distance is 300 m.

Muscle mass evaluation and definition of sarcopenia

We analyzed the area of the psoas muscle and skeletal muscle using preoperative CT images. We manually measured the cross-sectional area of the bilateral psoas muscle and skeletal muscle at the caudal end of the third lumbar vertebra (Fig. 1) [13]. The psoas muscle mass index (PMI) was calculated by normalizing the cross-sectional areas for height (cm^2/m^2). According to the guidelines set by the Asian Working Group for Sarcopenia (AWGS) [14], low handgrip strength (< 26 kg for male and < 18 kg for female) and walking speed < 0.8 m/s were used to define sarcopenia in this study. Sarcopenia among the men and the women was defined as a PMI value of < 6.36 cm^2/m^2 and < 3.92 cm^2/m^2, respectively, based on normalized data for sarcopenia in Japanese men and women [13].

Comorbidity

Comorbidities were defined based on laboratory test results of blood samples: anemia (hemoglobin ≤ 13 mg/dL in males, o $r \leq 12$ mg/dL in females); diabetes (glycemia ≥ 126 mg/dL); hypercholesterolemia (total cholesterol ≥ 190 mg/dL); altered high-density lipoprotein (HDL)-cholesterol (< 40 mg/dL in males, o $r < 50$ mg/dL in females), and hypertriglyceridemia (triglycerides ≥ 150 mg/dL) [15]. The use of medication for each disease was also considered.

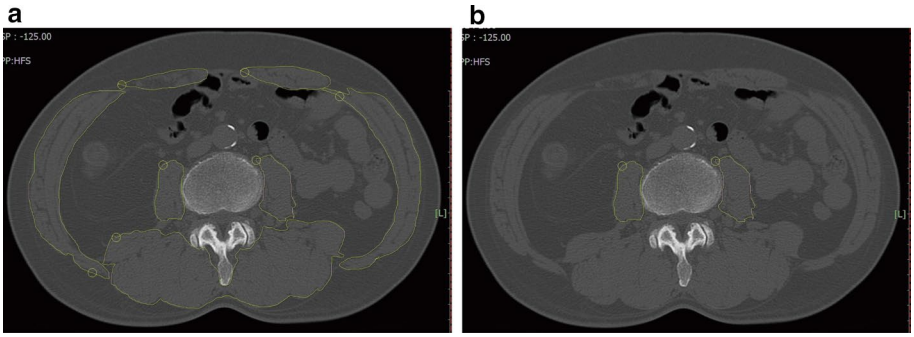

Fig. 1 Cross-sectional computed tomography images at the caudal end of the third lumbar vertebra. The area of the skeletal muscle (**a**) or bilateral psoas muscle (**b**) was measured by manual tracing

Dyslipidemia was identified according to the lipid fraction that was altered, triglycerides ≥ 150 mg/dL, LDL-cholesterol ≥ 160 mg/dL, HDL-cholesterol < 40 mg/dL in males, o r < 50 mg/dL in females.

Hypertension was defined based on the mean of the second and third blood pressure measurements (systolic blood pressure ≥ 140 mmHg and/or diastolic ≥ 90 mmHg) or based on the use of hypotensive medication.

Body mass index (BMI) was calculated (BMI = weight [kg]/ (height [m])^2). Specific cutoff points for BMI were: BMI < 22 for low weight.

Statistical analysis

Continuous data are presented as mean ± standard deviation. Correlation between the continuous variables was assessed using Pearson correlation coefficients and linear regression. Using the Mann–Whitney U test, handgrip strength was compared between yes and no about anemia, diabetes, hypertension, hypercholesterolemia, altered HDL cholesterol, hypertriglyceridemia, dyslipidemia, low weight BMI, and marital status. A P value of < 0.05 was considered significant. All statistical analyses were performed using SPSS for Windows version 17.0 (SPSS, Chicago, IL, USA).

Results

Demographic data

We compared all parameters to the handgrip strength (Table 1). There are significant differences in gender ($r = -0.489$, $P < 0.001$). Males had stronger handgrip strength than females. Sarcopenia was found in 2.2% of the study cohort (four males).

The relationship between body size parameters and handgrip strength

The handgrip strength was significantly correlated with age ($r = -0.372$, $P < 0.001$), height ($r = 0.489$, $P < 0.001$), and weight ($r = 0.360$, $P < 0.001$), but not significantly correlated with BMI ($P = 0.560$) (Fig. 2).

Table 1 Characteristics of subjects and differences from handgrip strength

	Mean (SD)	*P* value	*r* value
Gender (male:female)	128:55	< 0.001	− 0.489
Age (years)	70.5 ± 8.6	< 0.001	− 0.372
Height (cm)	159.8 ± 8.9	< 0.001	0.489
Weight (kg)	63.1 ± 10.5	< 0.001	0.360
BMI	24.7 ± 3.3	0.560	0.043
Handgrip strength (kg)	30.2 ± 9.1	–	–
Leg extension power (kg)	31.1 ± 13.4	< 0.001	0.723
Area of skeletal muscle at *L3* level (cm^2)	138.5 ± 29.5	< 0.001	0.469
Area of psoas muscle at *L3* level (cm^2)	18.3 ± 5.4	< 0.001	0.380
PMI (cm^2/m^2)	7.1 ± 1.8	0.001	0.253
10 m walk test (second)	11.8 ± 5.4	< 0.001	− 0.269
10 m walk test (step)	21.0 ± 5.9	< 0.001	− 0.352
Intermittent claudication (m)	187.8 ± 114.8	0.008	0.201

BMI body mass index, *PMI* psoas muscle mass index

The relationship between each limb strength parameter and handgrip strength

Figure 3 shows the relationship between the handgrip strength and LEP. The right-handgrip strength was strongly correlated with left-handgrip strength ($r = 0.907$, $P < 0.001$). The handgrip strength also correlated with LEP ($r = 0.723$, $P < 0.001$).

The relationship between the area of muscle parameters and handgrip strength

Figure 4 shows the relationship between the area of muscle parameter at the L3 level and handgrip strength. The handgrip strength was significantly correlated with the area of

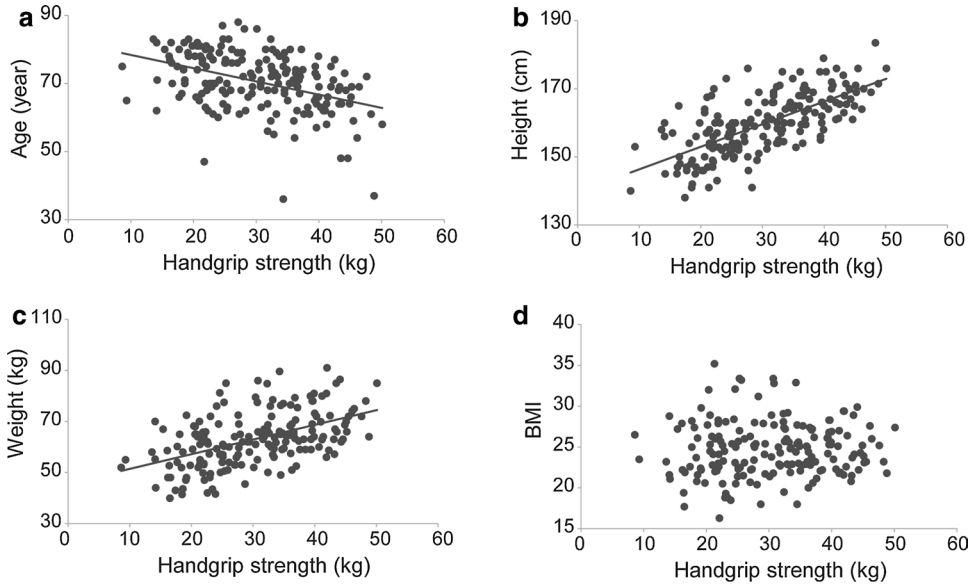

Fig. 2 Relationship between each body size parameter and handgrip strength. A significantly negative relationship was found between age and handgrip strength ($r = -0.372$, $P < 0.001$) (**a**). Height (**b**) and weight (**c**) were significantly correlated with handgrip strength ($r = 0.489$, $r = 0.360$, $P < 0.001$). BMI was not significantly correlated ($P = 0.560$) (**d**). *BMI* body mass index

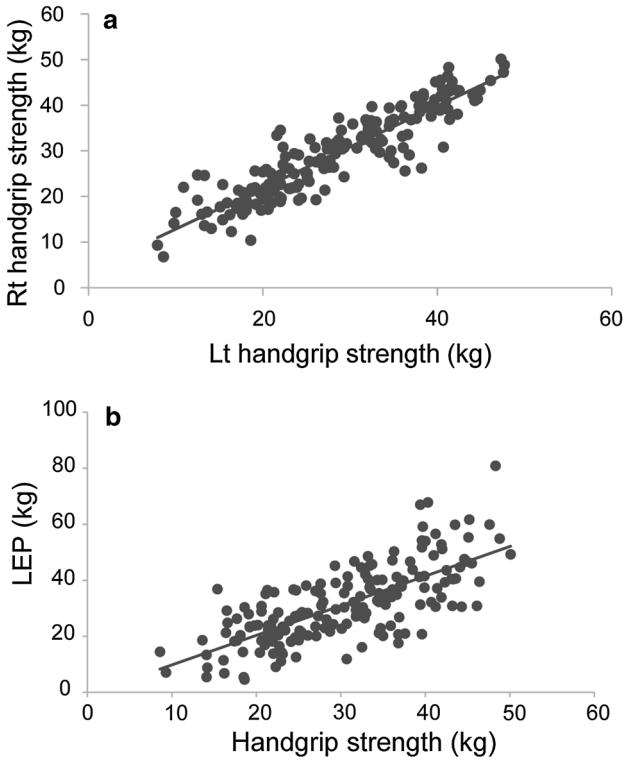

Fig. 3 Relationship between each limb strength parameter and handgrip strength. There was a strong and significant difference between right- and left-handgrip strength ($r = 0.907$, $P < 0.001$) (**a**). LEP was significantly correlated with handgrip strength ($r = 0.723$, $P < 0.001$) (**b**). LEP, leg extension power

skeletal muscle at the L3 level ($r = 0.469$, $P < 0.001$) and area of psoas muscle at L3 level ($r = 0.380$, $P < 0.001$). However, the correlation between handgrip strength and PMI was weak ($r = 0.253$, $P < 0.001$).

The relationship between walking ability and handgrip strength

Figure 5 shows the relationship between walking ability and handgrip strength. The handgrip strength showed a significant weakly negative correlation with 10-m walk test (time) ($r = -0.269$, $P < 0.001$) and 10-m walk test (steps) ($r = -0.352$, $P < 0.001$). There was a significant weakly positive correlation with intermittent claudication ($r = 0.201$, $P = 0.008$).

Comorbidities

Handgrip strength was significantly higher in the no-anemia group [interquartile range, (IQR) 31.6 (22.9–38.4)] vs. anemia group [IQR 27.0 (21.0–32.9)], no-hypertension group [IQR 33.7 (24.3–39.0)] vs. hypertension group [IQR 27.7 (21.9–34.9)], with partner [IQR 32.4 (24.1–38.7)] vs. without partner [IQR 22.0 (18.6–28.7)] (Table 2). There were no significant differences in diabetes, hypercholesterolemia, altered HDL cholesterol, hypertriglyceridemia, dyslipidemia, and low weight BMI.

Discussion

In this study, handgrip strength correlated with many factors: gender, age, height, weight, opposite side of handgrip strength, both sides of LEP, area of skeletal muscle at L3, area of the psoas muscle, PMI, walking speed, walking steps, and intermittent claudication.

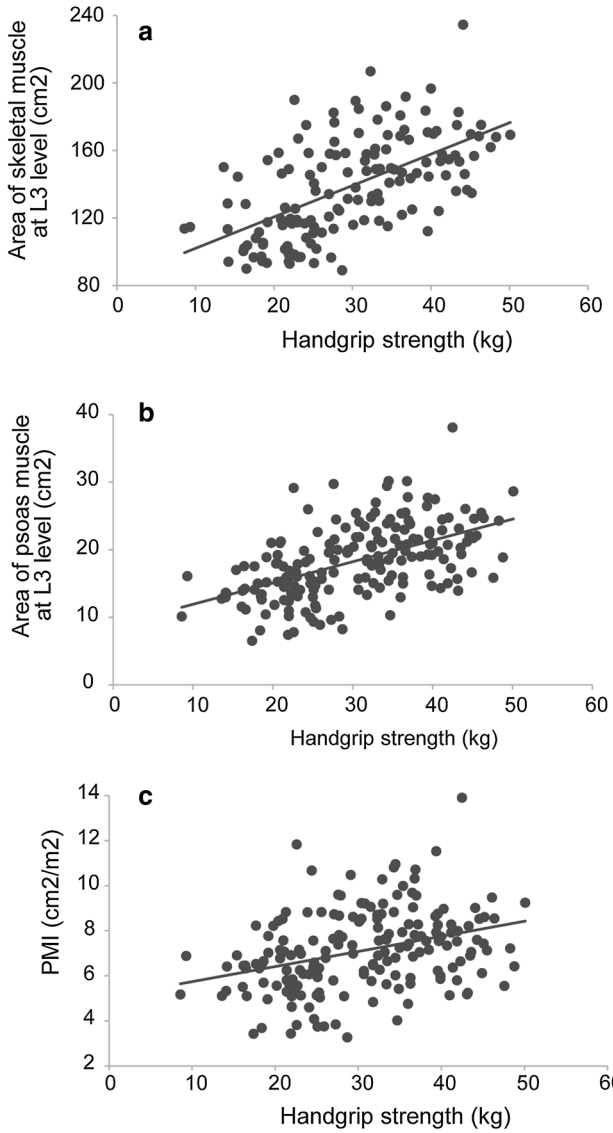

Fig. 4 Relationship between each measured muscle parameter and handgrip strength. Area of skeletal muscle (**a**) and psoas muscle (**b**) was significantly correlated with handgrip strength ($r=0.469$, $r=0.380$, $P<0.001$). A significantly weak relationship was found between PMI and handgrip strength ($r=0.253$, $P=0.001$) (**c**). PMI, psoas muscle index

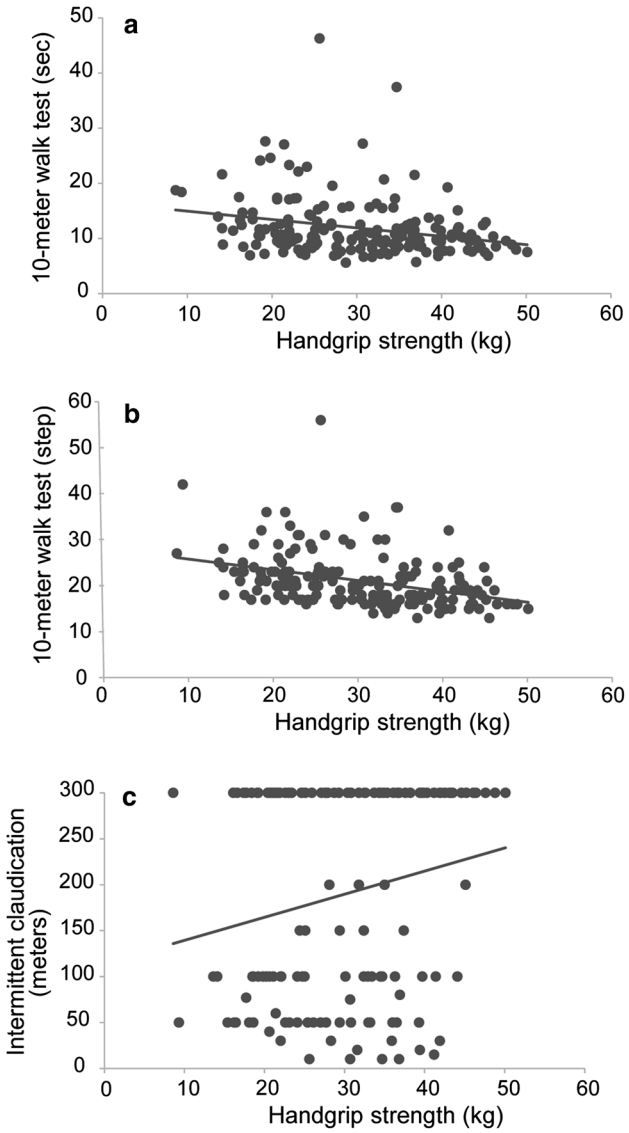

Fig. 5 Relationship between walking perimeter and handgrip strength. 10-m walk test (second) (**a**) and step (**b**) were significant weak negative correlated with handgrip strength ($r=-0.269$, $r=-0.352$, $P<0.001$). Intermittent claudication showed a significant weak positive correlation ($r=0.201$, $P=0.008$) (**c**)

Other studies had shown handgrip strength positively correlating with LEP [16], height [17, 18], weight [18], and BMI [17]. Lauretani et al. showed that handgrip strength declines considerably with aging [19]. Furthermore, they demonstrated that independent of age and in both genders, low muscle strength and power are strongly associated with two complementary definitions of poor mobility. They also showed that handgrip strength was related to age, height, weight, but not BMI. Fragala et al. measuring 6766 older men and women found that the correlation between handgrip strength and LEP was $r=0.57$ ($P<0.001$) in men and $r=0.51$ ($P<0.001$) in women [16]. We also found correlations between handgrip strength and LEP to be $r=0.723$.

Psoas and paraspinal muscle areas are important to grade the vitality of the patient. Low psoas muscle area was correlated with lower handgrip strength and short physical performance battery scores indicative of physical frailty [20]. Low psoas muscle area was also associated with increased length of stay in older patients with cardiac surgeries. Reeve et al. showed that the total psoas area was lower in patients with frailty based on grip strength than in patients without such frailty [21].

Table 2 Characteristics of comorbidities according to median handgrip strength

Comorbidities	*n*	Handgrip strength (kg) Median (interquartile range)	*P* value
Anemia			
Yes	35	27.0 (21.0–32.9)	0.038
No	148	31.6 (22.9–38.4)	
Diabetes			
Yes	47	30.7 (24.1–36.0)	0.868
No	136	30.6 (22.2–37.6)	
Hypertension			
Yes	110	27.7 (21.9–34.9)	0.020
No	73	33.7 (24.3–39.0)	
Hypercholesterolemia			
Yes	123	29.4 (22.1–37,0)	0.640
No	60	32.6 (24.0–36.8)	
Altered HDL cholesterol			
Yes	56	26.9 (21.4–37.0)	0.339
No	127	31.5 (23.1–36.8)	
Hypertriglyceridemia			
Yes	89	30.4 (23.0–37.0)	0.941
No	94	31.7 (22.0–36.9)	
Dyslipidemia			
Yes	98	29.9 (22.5–36.9)	0.734
No	85	31.8 (22.4–36.9)	
Low weight BMI			
Yes	35	27.0 (22.1–36.3)	0.186
No	148	31.7 (22.6–37.1)	
Marital status			
With partner	146	32.4 (24.1–38.7)	< 0.001
No partner	37	22.0 (18.6–28.7)	

BMI body mass index, *HDL* high-density lipoprotein

In the present study, handgrip strength in patients with LSS showed a significant weakly negative correlation with the 10-m walk test (time) and 10-m walk test (step) but was not correlated with intermittent claudication. In older people, muscle weakness of both LEP and handgrip strength is associated with slow gait speed but only LEP predicted slow gait speed [16]. In patients with LSS, functional status such as the Oswestry Disability Index and Quebec Back Pain Disability Scale was inversely correlated with real walking perimeter and walking speed [22]. Back muscle strength is significantly correlated with trunk muscle mass, handgrip strength, and gait speed in patients with spinal disorders [23].

Factors independently related to low handgrip strength in men and women, respectively, were low weight in BMI [(Odds ratio (OR)=2.80; 95% confidence intervals (CI): 1.19, 6.61) and (OR=2.61; 95% CI: 1.46, 4.66)], anemia [(OR=4.15; 95% CI: 2.09, 8.21) and (OR=1.80; 95% CI: 1.06, 3.06)], diabetes in men (OR=1.95; 95% CI: 1.00, 3.81), and marital status in men (OR 2.44; 95% CI: 1.46, 4.66) [15]. In this study, low handgrip strength in the patients with LSS was associated with anemia, hypertension, and marital status.

Sarcopenia is common in the elderly and is diagnosed as an age-associated loss of skeletal muscle mass based on measurements of gait speed, handgrip strength, and muscle mass [2]. The prevalence of sarcopenia was reported at 5–13% in people 60–70 years old [24]. Eguchi et al. reported a sarcopenia prevalence of 26.5% in patients with LSS [11]. Park et al. demonstrated a higher prevalence (24%) of sarcopenia in patients with LSS than the control group (12%) [10]. However, the present study noted only a 2.2% incidence because we excluded non-ambulatory patients who would likely have had sarcopenia..

The term "sarcopenia" was used in its original context to describe the age-related loss of muscle mass, whereas the term "dynapenia" was coined to describe the age-related loss of muscle strength and power [4, 25]. An algorithm for defining dynapenia uses age, presence or absence of risk factors, grip strength screening, and if warranted a test for knee extensor power. A definition for a single risk factor such as dynapenia will provide information in making a risk history for the complex etiology of physical disability. As such, this approach mimics the development of risk profiles for cardiovascular disease that include factors such as hypercholesterolemia, hypertension, hyperglycemia, etc. Future research will provide a specific understanding of the role that dynapenia plays in the loss of physical function and increased risk for disability among older adults.

We note some limitations of our study. First, we exclude patients with severe symptoms, such as walking disability and severe paralysis. If the study population included patients with severe symptoms, the ratio of sarcopenia would be higher. Second, the definition of sarcopenia using PMI was decided based on adult donors for living-donor liver transplantation. Patients with LSS were not analyzed for correlation between PMI and skeletal muscle mass index; however, in the future, we will do so. Third, we supposed that the intermittent claudication in the patients with LSS would be short, so we measured the walking distance until 300 m. However, many patients could walk farther. If we change the metrics for walking distance, the results might change.

In conclusion, the more handgrip strength patients with LSS have, the more LEP, the faster walking speed, the greater area of psoas muscle, the fewer steps for a 10-m walk, and the longer intermittent claudication they have. For lumbar spinal stenosis patients, handgrip strength indicates not only a parameter of whole body muscle strength but also walking ability. Age, height, and weight were related to handgrip strength, but BMI was not. Low handgrip strength

was associated with comorbidities including anemia, hypertension, and marital status.

Acknowledgements The authors acknowledge Mr. Nishikawa and many physical therapists in Shinkaminokawa hospital for providing support in carrying out this study.

Compliance with ethical standards

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

References

1. Janssen I, Heymsfield SB, Wang ZM, Ross R (2000) Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. J Appl Physiol 89:81–88. https://doi.org/10.1152/jappl.2000.89.1.81
2. Cruz-Jentoft AJ, Baeyens JP, Bauer JM et al (2010) Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in older people. Age Ageing 39:412–423. https://doi.org/10.1093/ageing/afq034
3. Rantanen T, Harris T, Leveille SG et al (2000) Muscle strength and body mass index as long-term predictors of mortality in initially healthy men. J Gerontol A Biol Sci Med Sci 55:M168–173. https://doi.org/10.1093/gerona/55.3.m168
4. Manini TM, Clark BC (2012) Dynapenia and aging: an update. J Gerontol A Biol Sci Med Sci 67:28–40. https://doi.org/10.1093/gerona/glr010
5. Kilgour RD, Vigano A, Trutschnigg B et al (2010) Cancer-related fatigue: the impact of skeletal muscle mass and strength in patients with advanced cancer. J Cachexia Sarcopenia Muscle 1:177–185. https://doi.org/10.1007/s13539-010-0016-0
6. Norman K, Stobaus N, Smoliner C et al (2010) Determinants of hand grip strength, knee extension strength and functional status in cancer patients. Clin Nutr 29:586–591. https://doi.org/10.1016/j.clnu.2010.02.007
7. Chen CH, Ho C, Huang YZ, Hung TT (2011) Hand-grip strength is a simple and effective outcome predictor in esophageal cancer following esophagectomy with reconstruction: a prospective study. J Cardiothorac Surg 6:98. https://doi.org/10.1186/1749-8090-6-98
8. Shen F, Kim HJ, Lee NK et al (2018) The influence of hand grip strength on surgical outcomes after surgery for degenerative lumbar spinal stenosis: a preliminary result. Spine J 18:2018–2024. https://doi.org/10.1016/j.spinee.2018.04.009
9. Lee JC, Cha JG, Kim Y, Kim YI, Shin BJ (2008) Quantitative analysis of back muscle degeneration in the patients with the degenerative lumbar flat back using a digital image analysis: comparison with the normal controls. Spine (Phila Pa 1976) 33:318–325. https://doi.org/10.1097/BRS.0b013e318162458f
10. Park S, Kim HJ, Ko BG et al (2016) The prevalence and impact of sarcopenia on degenerative lumbar spinal stenosis. Bone Jt J 98-B:1093–1098. https://doi.org/10.1302/0301-620X.98B8.37623
11. Eguchi Y, Suzuki M, Yamanaka H et al (2018) Influence of skeletal muscle mass and spinal alignment on surgical outcomes for lumbar spinal stenosis. Asian Spine J 12:556–562. https://doi.org/10.4184/asj.2018.12.3.556
12. Wannaprom N, Treleaven J, Jull G, Uthaikhup S (2018) Neck muscle vibration produces diverse responses in balance and gait speed between individuals with and without neck pain. Musculoskelet Sci Pract 35:25–29. https://doi.org/10.1016/j.msksp.2018.02.001
13. Hamaguchi Y, Kaido T, Okumura S et al (2016) Proposal for new diagnostic criteria for low skeletal muscle mass based on computed tomography imaging in Asian adults. Nutrition 32:1200–1205. https://doi.org/10.1016/j.nut.2016.04.003
14. Chen LK, Liu LK, Woo J et al (2014) Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 15:95–101. https://doi.org/10.1016/j.jamda.2013.11.025
15. de Araujo AC, Amaral TLM, Monteiro GTR, de Vasconcellos MTL, Portela MC (2020) Factors associated with low handgrip strength in older people: data of the Study of Chronic Diseases (Edoc-I). BMC Public Health 20:395. https://doi.org/10.1186/s12889-020-08504-z
16. Fragala MS, Alley DE, Shardell MD et al (2016) Comparison of handgrip and leg extension strength in predicting slow gait speed in older adults. J Am Geriatr Soc 64:144–150. https://doi.org/10.1111/jgs.13871
17. Pizzigalli L, Micheletti Cremasco M, La Antonio T, Rainoldi A, Roberto B (2017) Hand grip strength and anthropometric characteristics in Italian female national basketball teams. J Sports Med Phys Fitness 57:521–528. https://doi.org/10.23736/S0022-4707.16.06272-1
18. Wong SL (2016) Grip strength reference values for Canadians aged 6 to 79: Canadian Health Measures Survey, 2007 to 2013. Health Rep 27:3–10
19. Lauretani F, Russo CR, Bandinelli S et al (2003) Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. J Appl Physiol 95:1851–1860. https://doi.org/10.1152/japplphysiol.00246.2003
20. Zuckerman J, Ades M, Mullie L et al (2017) Psoas muscle area and length of stay in older adults undergoing cardiac operations. Ann Thorac Surg 103:1498–1504. https://doi.org/10.1016/j.athoracsur.2016.09.005
21. Reeve TET, Ur R, Craven TE et al (2018) Grip strength measurement for frailty assessment in patients with vascular disease and associations with comorbidity, cardiac risk, and sarcopenia. J Vasc Surg 67:1512–1520. https://doi.org/10.1016/j.jvs.2017.08.078
22. Grelat M, Gouteron A, Casillas JM et al (2019) Walking speed as an alternative measure of functional status in patients with lumbar spinal stenosis. World Neurosurg 122:e591–e597. https://doi.org/10.1016/j.wneu.2018.10.109
23. Toyoda H, Hoshino M, Ohyama S et al (2019) The association of back muscle strength and sarcopenia-related parameters in the patients with spinal disorders. Eur Spine J 28:241–249. https://doi.org/10.1007/s00586-018-5858-8
24. Morley JE (2008) Sarcopenia: diagnosis and treatment. J Nutr Health Aging 12:452–456
25. Clark BC (2019) Neuromuscular changes with aging and sarcopenia. J Frailty Aging 8:7–9. https://doi.org/10.14283/jfa.2018.35