International Journal of Gerontology 17 (2023) 269–274
https://doi.org/10.6890/IJGE.202310_17(4).0011

International Journal of Gerontology

journal homepage: http://www.sgecm.org.tw/ijge/

Original Article

Measurement Error for Hand-Held Dynamometer in Knee Osteoarthritis: Minimal Detectable Change to Monitor Time-Dependent Changes in Knee Strength in Older Individuals

Tetsuya Amano *, Nobuhide Agata, Nobuharu Suzuki

Department of Physical Therapy, Faculty of Health and Medical Sciences, Tokoha University, 1230 Miyakoda, Kita-ku, Hamamatsu, Shizuoka 431-2102, Japan

ARTICLE INFO

Accepted 1 February 2023

Keywords:
knee,
muscle strength,
osteoarthritis,
observer variation,
resistance training

SUMMARY

Background: Accurate measurement of quadriceps muscle strength is important for patients with knee osteoarthritis (OA) to evaluate intervention outcomes. As the prevalence of OA increases, due to aging of the population, understanding the time-dependent effects of aging-related decreases in muscle strength becomes necessary. This study evaluated the errors in measurement of knee flexion and extension strength using hand-held dynamometer (HHD) in individuals with knee joint OA, and to determine the minimal detectable change (MDC) over a 3-month follow-up.
Methods: This was a longitudinal, observational study of 52 individuals with knee OA treated on an outpatient basis, for whom the HHD measurements were obtained at baseline, and at the end of a 3-month follow-up. The time-dependent changes in muscle strength measurements were evaluated using a paired *t*-test for changes in strength between the two time points. A Bland-Altman analysis was used to identify systematic bias on strength measures. We calculated the intra-rater reliability using the intraclass correlation coefficient (ICC), and the MDC_{95}.
Results: There were no differences in HHD measurements for knee extensors and flexors between the two time points. There was no evidence of fixed or proportional bias. The intra-rater reliability was high, with an ICC (1,1) $\geq$ 0.85. The MDC_{95} was 0.23 Nm/kg for knee extension and 0.17 Nm/kg for knee flexion.
Conclusion: HHD measurements can have good reliability for standardized strength testing methods, used in clinical practice. The MDC_{95} values can be used to monitor change in knee strength over time and the efficacy of interventions.

1. Introduction

Knee osteoarthritis (OA) is a gradually progressive degenerative joint disease.[1] Conservative treatment is recommended in the early stages of knee OA, with evidences of increase in quadriceps strength and decrease in knee joint pain through combined resistance training, stretching, and low-load aerobic exercise, which can slow the progression of OA.[2,3] Therefore, accurate measurement of quadriceps strength is necessary to tailor exercise prescription, and to evaluate the effectiveness of an intervention in a patient-specific way. This is important for healthcare professionals involved in the delivery of non-pharmacological interventions.

As the majority of patients with knee OA are older individuals, aging-related sarcopenia is an important clinical issue to consider when evaluating outcomes of an exercise regimen designed to improve muscle strength. A muscle mass loss of 1–2% per year has been reported in those > 50 years, increasing to approximately 3% per year after the age of 60 years.[4,5] This age-related decline in skeletal muscle mass and strength is accelerated in the absence of regular exercise. Therefore, accurate assessment of the change in quadriceps muscle strength in older individuals must take into account these time-dependent effects on muscle strength, as they can lead to systematic errors in measurements of muscle strength, and negatively influence decision-making of clinical interventions.[6,7] However, previous reports on the measurement errors in muscle strength tests have been based on two measurements obtained on the same day.[8,9] As such, the measurement errors calculated from these same-day measurements do not include time-dependent effects. This could lead to a misinterpretation of outcomes of strength training programs in older individuals.

A recent systematic review on the clinical usefulness of resistance training exercises in individuals with knee OA identified the positive effects of increased knee muscle strength in improving physical function and reducing OA-related knee joint pain.[10] Generally, programs regimens of quadriceps strengthening for OA consisting 30–60 min/session, 2 to 3 sets of 8 to 12 repetitions, for an average of 2 or 3 months, have reported positive strength outcomes.[10] Accordingly, in our view, minimal detectable change (MDC) values should be calculated over this time period, rather than from same-day data. Therefore, this study aimed to evaluate the measurement error of muscle strength tests of knee flexion and extension, obtained by hand-held dynamometer (HHD), in individuals with knee joint OA

* Corresponding author. Department of Physical Therapy, Faculty of Health and Medical Sciences, Tokoha University, 1230 Miyakoda, Kita-ku, Hamamatsu, Shizuoka 431-2102, Japan.
E-mail address: tamano@hm.tokoha-u.ac.jp (T. Amano)

and to determine the MDC using data over a 3-month follow-up.

2. Materials and methods

2.1. Study design

This was a longitudinal, observational study approved by the Research Ethics Committee of Tokoha University (approval no: R-2021-504H). All participants provided written informed consent. Reporting of outcomes adhered to the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) Guidelines.[11]

2.2. Participants

Participants were recruited from three medical facilities across Japan, between February 2019 and September 2021. We used non-random sampling method for selection of eligible patients, who were diagnosed with knee OA and received conservative therapy < 3 days/week, which is less than the recommended frequency to obtain positive strength outcomes.[10] The exclusion criteria, which were chosen because the measurement error of muscle strength tests differs for each disease, were as follows: prior knee surgery or fracture of the knee with OA; other significant joint diseases, such as multiple-joint OA or rheumatoid arthritis; neurological impairments, such as sensory disturbances or motor paralysis; and other cognitive or psychiatric disorders, such as dementia.

2.3. Variables

Clinical and physical characteristics were obtained at the baseline. Clinical characteristics included sex; age; height and body weight, from which body mass index (BMI) was derived, Kellgren-Lawrence (K-L) grade, laterality (unilateral or bilateral) of the knee OA, pharmacotherapy, implementation period of conservative therapy, and frequency of hospital visits. Physical functions included knee extension (quadriceps) and flexion strength; knee extension and flexion range of motion (ROM); subjective knee pain; five times sit-to-stand test (FTSST); and 5-meter walk test (5mWT). Measurements of physical functions were repeated at the 3-month follow-up, which were assessed by the same rater, for each participant, respectively. Six physical therapists, with 5–20 years of clinical experiences, conducted every test. For the measurements of muscle strength, the physical therapists practiced the muscle strength test adhering to our method that we had prepared until they became proficient, before the data collection.

Measurements of muscle strength was obtained with HHD instead of manual muscle testing (MMT) and isokinetic testing for the following reasons: MMT is a qualitative assessment; thus, includes between-assessor variability,[12,13] and isokinetic testing, using systems such as the Cybex (Life Fitness, Franklin Park, IL, USA), provides quantitative and reliable measures of strength but is very expensive; thus, not viable for all real-world practice settings;[14] on the other hand, HHD, using standardized methods, provides an inexpensive, highly portable, easy-to-use, and reliable quantitative measure of muscle strength for patients with knee OA. Also, previous studies have reported excellent intra-rater (intra-class correlation coefficients (ICC): 0.92 to 0.96) and inter-rater (ICC: 0.96) reliability scores of muscle strength test using HHD.[9,15]

For participants with bilateral knee OA, measures for the knee with more severe OA defined by a more severe K-L grade; greater restriction of knee joint ROM; greater pain was included in the analysis. The maximum isometric muscle strength of the extensors and flexors of the involved knee was measured using HHD (model: μTas F-1, Anima, Tokyo, Japan), with a standardized method. First, the participants sat on a chair with arms crossed over their chest and hips, and knees flexed at 90° (Figures 1 and 2). Then, the opposite foot was placed on the floor or a raised platform to maintain a stable

Figure 1. Testing method for knee extension strength. The hand-held dynamometer was held against the distal anterior surface of the lower leg of the affected side, secured using a belt attached to a bed leg.

Figure 2. Testing method for knee flexion strength. The hand-held dynamometer was held against the distal posterior surface of the lower leg of the affected side, secured using a belt attached to the rater's leg.

sitting posture during measurements. The participants would then have enough opportunity to practice performing the HHD measurement before testing to eliminate effects of learning. Maximal isometric knee flexion and extension strength was obtained at two time points of measurement, baseline, and at the end of the 3-month follow-up. For inter-subject comparison, the maximal isometric muscle strength (torque) was normalized to body weight (Nm/kg).[16] Previous studies on measurement error for quadriceps muscle strength using HHD reported absolute measures of force, N, or kg, rather than torque, Nm.[17,18] However, as muscles produce moments of force around a joint, rather than an absolute force, we used the torque measurement, normalized to body weight (Nm/kg) as the unit of muscle strength in our analysis.

Knee extension and flexion ROM was measured as the maximum tolerable range of passive movement using a goniometer. Subjective knee pain was rated on the visual analogue scale (VAS) that ranged from 0 (no pain) to 100 (worst possible pain).[19] FTSST was defined as the time taken by the participants to stand up from a chair (chair height: 43–45 cm) and sit down for five repetitions as quickly as possible.[20] The 5mWT measured the time the participants took to walk the designated in-room walkway as fast as they could. The walkway for the in-room 5mWT was an 11-meter straight line, which consisted of an initial 3-meter acceleration zone, a central 5-meter timed zone, and a final 3-meter deceleration zone.[21]

2.4. Sample size

The sample size was calculated using the Fisher z-transformation, with the following values: minimum tolerance of the reliability coefficient of the muscle strength test, 0.70; assumed value of the reliability coefficient, 0.85; number of measurements, 2; α error, 0.05; and β error, 0.70. The target sample size was 41 participants.

2.5. Analysis

The changes in the physical function measurements at the baseline and the 3-month follow-up were evaluated using a paired *t*-test. The outcome measure was knee muscle strengths. Bland-Altman plot analysis was conducted to confirm the presence or absence of systematic disagreement in muscle strength scores, including both fixed and proportional bias. The ICC, model 1,1, of strength measures were calculated at baseline, and follow-up to examine intra-rater reliability. Standard error of measurement (SEM) and MDC_{95} were calculated as follows:

$$SEM = standard\ deviation\ of\ measurements \times \sqrt{1-ICC}$$

$$MDC_{95} = \mathrm{SEM} \times 1.96 \times \sqrt{2}$$

All analyses were performed using R4.1.2 (CRAN, freeware for Windows). The significance level was set at $p < 0.05$.

3. Results

Our analysis included 52 individuals (46 women; mean age, 72.7 ± 9.7 years); the clinical characteristics of the study sample at baseline are provided in Table 1. The participants underwent a course of conventional physical therapy for 20 min/day, 1–2 days/week, within the follow-up period. The main physical therapy programs consisted of quadriceps strengthening, ROM exercises, and low-impact aerobic exercises.

The physical function data at the baseline, and at the 3-month follow-up are shown in Table 2. The mean follow-up period was 90.7 ± 4.0 days. There was no difference in knee extension and flexion

Table 1
Summary statistics of clinical characteristics (n = 52).

Characteristics	All
Sex	
Men	6 (11.5)
Women	46 (88.5)
Age, years	72.7 ± 9.7
Height, cm	152.6 ± 7.4
Body weight, kg	57.4 ± 11.5
BMI, kg/m^2	24.6 ± 4.2
K-L grade	
Grade I	18 (34.6)
Grade II	20 (38.5)
Grade III	11 (21.2)
Grade IV	3 (5.8)
Laterality	
Unilateral	20 (38.5)
Bilateral	32 (61.5)
Pharmacotherapy	
Intra-articular injection of hyaluronic acid	16 (30.8)
Intra-articular steroid injection	8 (15.4)
NSAIDs	
Adhesive skin patch	30 (57.7)
Oral agent	13 (25.0)
Ointment	8 (15.4)
Implementation period of conservative therapy	
New	6 (11.5)
1–5 months	16 (30.8)
6–11 months	10 (19.2)
≥ 12 months	20 (38.5)
Frequency of hospital visits	
1 day/week	28 (53.8)
2 days/week	24 (46.2)

Data are presented as mean ± SD or n (%).
BMI, body mass index; K-L grade, Kellgren-Lawrence grade; NSAIDs, nonsteroidal anti-inflammatory drugs.

Table 2
Comparison of physical function tests of the baseline and the 3-month follow-up.

Variable	Unit	Baseline	Follow-up	*p*-value	95% confidence interval	
					Lower	Upper
Knee extension strength	Nm	48.8 ± 16.0	49.2 ± 16.6	0.636	-1.42	2.30
	Nm/kg	0.87 ± 0.30	0.87 ± 0.30	0.761	-0.03	0.04
Knee flexion strength	Nm	28.5 ± 9.8	28.1 ± 9.1	0.523	-1.67	0.86
	Nm/kg	0.50 ± 0.16	0.50 ± 0.15	0.704	-0.03	0.02
Knee extension ROM	degrees	-6.3 ± 4.8	-6.5 ± 4.8	0.261	-0.80	0.22
Knee flexion ROM	degrees	134.5 ± 12.3	136.4 ± 12.1	0.011*	0.46	3.39
Visual analogue scale	mm	33.8 ± 22.9	30.1 ± 21.5	0.002*	-14.26	-3.24
Five times sit-to-stand test	s	8.98 ± 2.53	8.35 ± 2.34	0.001*	-1.00	-0.26
5-meter walk test	s	3.68 ± 0.98	3.67 ± 1.17	0.830	-0.17	0.14

Data are presented as mean ± SD. * $p < 0.05$. ROM, range of motion.

strength, knee extension ROM, and 5mWT between the two time points ($p \geq 0.05$). In contrast, there was a significant difference in knee flexion ROM, VAS, and FTSST between the baseline and follow-up values ($p < 0.05$).

In addition, there was no evidence of fixed or proportional bias on HHD measurements at the two time points (Table 3, Figure 3). These results made it possible to calculate the intra-rater ICC (1,1) and MDC_{95}, considering the time-dependent effects on muscle strength. The reliability of HHD measurements were high, with intra-rater ICC (1,1) values ≥ 0.85 (Table 4). The MDC_{95} of HHD values for our study sample was 0.23 Nm/kg (13.1 Nm) for knee extension and 0.17 Nm/kg (8.9 Nm) for knee flexion.

4. Discussion

To the best of our knowledge, this study is the first to determine the MDC_{95} for measurements of knee extension and flexion strengths using HHD, taking into consideration time-dependent effects over a 3-month period, which are important in older adults with knee OA. For precise interpretation of the changes in muscle strengths of patients with knee OA, one should ideally examine the measurement errors in muscle strength test in patients who did not take any resistance training exercises 3 months after the baseline. However, ethical reasons had not allowed us to exclude resistance training exercises from physical therapies. Therefore, we studied the patients who did not show any changes in lower limb muscle strength despite certain period of physical therapy, including resistance training exercises. There was significant difference in knee flexion ROM, VAS, and FTSST between the baseline and follow-up in this study, suggesting that physical functioning ability of the participants may have changed. In contrast, previous studies had reported MDC of knee flexion ROM, VAS, and FTSST to be 7.9 degrees, 28 mm, and 1.71 s in patients with knee OA, respectively.[22–24] The 95% confidence intervals of knee flexion ROM, VAS, and FTSST shown in Table 2 were smaller than the MDC of each test mentioned above. Thus, we considered the differences in measurements of knee flexion ROM, VAS, and FTSST between the baseline and follow-up in this study to be the changes within the measurement error of each test, and there were no clinically significant differences.

A study of 1,093 patients with knee OA reported that the median of quadriceps strength in the non-surgical side was 58.5 Nm.[25] Another study of 273 knee OA patients reported the knee extension and knee flexion strength were 0.75 ± 0.32 Nm/kg and 0.41 ± 0.18

Table 3
Systematic bias of muscle strength testing using hand-held dynamometer.

Variable	Unit	Constant bias 95% CI	Constant bias *p*-value	Proportional bias r	Proportional bias *p*-value
Knee extension strength	Nm	-1.42 to 2.30	0.636	0.09	0.531
	Nm/kg	-0.03 to 0.04	0.761	-0.01	0.962
Knee flexion strength	Nm	-1.67 to 0.86	0.523	-0.15	0.301
	Nm/kg	-0.03 to 0.02	0.704	-0.11	0.432

CI, confidence interval.

Table 4
Intra-rater reliability and minimal detectable change of muscle strength testing using hand-held dynamometer.

Variable	Unit	ICC (1,1)	95% CI	SEM	MDC_{95}
Knee extension strength	Nm	0.92	0.86–0.95	4.7	13.1
	Nm/kg	0.93	0.87–0.96	0.08	0.23
Knee flexion strength	Nm	0.89	0.81–0.93	3.2	8.9
	Nm/kg	0.85	0.75–0.91	0.06	0.17

CI, confidence interval; ICC, intraclass correlation coefficients; MDC, minimal detectable change; SEM, standard error of measurement.

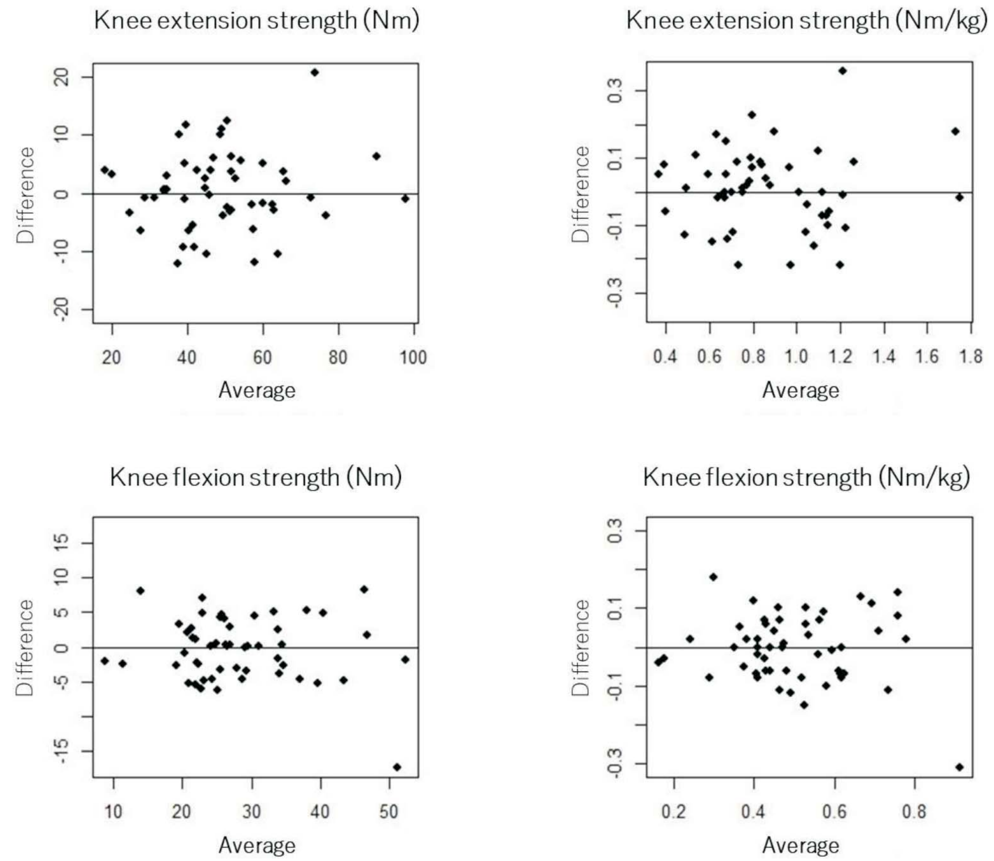

Figure 3. Bland-Altman plots for the knee extension and flexion strength.

Nm/kg, respectively.[26] Since the muscle strength values between previous studies and this study were similar, our study participants could well represent the regular population. Additionally, with no systematic bias in measures identified, the MDC_{95} values calculated over a 3-month interval could provide a useful index to evaluate the effectiveness of a program of resistance training, performed at a frequency expected to increase muscle strength. Therefore, the MDC_{95} of muscle strength obtained by HHD in our study could assist physical therapists and other professionals, involved in the strength training of individuals with knee OA, in appropriately evaluating outcomes of strength interventions as well as in tailoring programs in patient-specific ways.

Reliable methods to quantify knee extension strength are necessary to evaluate the pathophysiological effect of quadriceps strength on knee OA. This reliability cannot be achieved with MMT, with the knee extension strength in patients with knee OA performing a program of resistance training generally reported as a grade of 4 or 5.[15] Thus, precise detection of actual change in their muscle strength is not possible by MMT. Decreased quadriceps strength is associated with progression in knee OA.[27] Moreover, an increase in quadriceps strength of 30–40% can decrease OA-associated knee pain.[28] Interestingly, 0.23 Nm/kg for the MDC_{95} of quadriceps strength in this study was 26.4% of 0.87 Nm/kg for the quadriceps strength at baseline, representing a change of < 30%. The previous study reported the MDC_{90} of quadriceps strength measured by Biodex was 0.33 Nm/kg, 18.2% of mean quadriceps strength of 1.81 Nm/kg in patients with knee OA.[16] That ratio of the MDC_{90} to the mean quadriceps strength seemed to be a bit smaller than that of our present study, however, the difference of the ratio between the previous study and our present study would still be considered negligible. The use of MDC_{95} of quantitative HHD of knee extension strength addresses this gap in practice, allowing accurate clinical interpretation of the effects of resistance training exercises in patients with knee OA.

Our MDC_{95} values of 13.1 Nm and 8.9 Nm for knee extension and flexion strength, respectively, are comparable to values of 14.0 Nm and 11.2 Nm calculated for two sets of HHD data obtained on the same day for patients with OA.[8] Of note, the individuals of that study had a higher BMI than the participants in our study (mean, 28.9 kg/m^2), and greater knee extension and flexion strength of 74.3 Nm and 42.4 Nm, respectively. Reporting MDC_{95} values as a torque normalized to body weight (Nm/kg) allows for between-subject comparisons.

It has been reported that the reliability of HHD measures decreases as the force exceeds 200 N, with the use of a belt to tightly secure the dynameter to the lower leg recommended to improve reliability at these higher force values.[29] A previous study reported a high intra-rater reliability of measures of muscle strength among patients with knee OA when the HHD was tightly secured to leg.[30] The ICC (1,1) in our study was ≥ 0.85, with a reliability ≥ 0.81 and considered almost perfect.[31] Based on these findings, HHD can be considered as an inexpensive and highly reliable measure of muscle strength, with excellent portability, can be useful in various context, including home care.

The limitations of our study need to be acknowledged. First, the study findings were limited to the MDC_{95} of the muscle test using HHDs in patients with knee OA who underwent conservative therapy and cannot be generalized to muscle test assessment of any other diseases such as multiple-joint OA, rheumatoid arthritis, and psychiatric disorders. Second, only intra-rater reliability was evaluated; inter-rater reliability is also needed to be determined with the standard HHD methods used.

5. Conclusions

The HHD measurements have good reliability using standardized methods for clinical practice. The MDC_{95} values can be used to monitor change in knee strength over time and the effects of an intervention. The MDC_{95} values also have clinical utility to tailor programs of resistance strength training to optimize outcomes in patient-specific way, as well as to determine the benefits of continuing a program or to justify cessation.

Funding

This work was supported by the Grants-in-Aid for Young Scientists (B) from Scientific Research of Japan Society for the Promotion of Science, Grant Number JP18K17738.

Conflicts of interests

The authors declare no conflicts of interest.

References

1. Yoshimura N, Muraki S, Oka H, Kawaguchi H, Nakamura K, Akune T. Cohort profile: research on osteoarthritis/osteoporosis against disability study. *Int J Epidemiol*. 2010;39(4):988–995. doi:10.1093/ije/dyp276
2. Fernandes L, Hagen KB, Bijlsma JW, et al. EULAR recommendations for the non-pharmacological core management of hip and knee osteoarthritis. *Ann Rheum Dis*. 2013;72(7):1125–1135. doi:10.1136/annrheumdis-2012-202745
3. McAlindon TE, Bannuru RR, Sullivan MC, et al. OARSI guidelines for the non-surgical management of knee osteoarthritis. *Osteoarthr Cartil*. 2014; 22(3):363–388. doi:10.1016/j.joca.2014.01.003
4. Abellan van Kan G. Epidemiology and consequences of sarcopenia. *J Nutr Health Aging*. 2009;13(8):708–712. doi:10.1007/s12603-009-0201-z
5. Doherty TJ. Invited review: aging and sarcopenia. *J Appl Physiol (1985)*. 2003;95(4):1717–1727. doi:10.1152/japplphysiol.00347.2003
6. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1(8476):307–310.
7. Ludbrook J. Comparing methods of measurements. *Clin Exp Pharmacol Physiol*. 1997;24(2):193–203. doi:10.1111/j.1440-1681.1997.tb01807.x
8. Chopp-Hurley JN, Wiebenga EG, Gatti AA, Maly MR. Investigating the test-retest reliability and validity of hand-held dynamometry for measuring knee strength in older women with knee osteoarthritis. *Physiother Can*. 2019;71(3):231–238. doi:10.3138/ptc-2018-0051
9. Eymir M, Yuksel E, Unver B, Karatosun V. Hand-held dynamometry in the inpatient care setting after total knee arthroplasty: reliability of static knee strength measurements. *Am J Phys Med Rehabil*. 2021;100(6):570–575. doi:10.1097/PHM.0000000000001592
10. Turner MN, Hernandez DO, Cade W, Emerson CP, Reynolds JM, Best TM. The role of resistance training dosing on pain and physical function in individuals with knee osteoarthritis: a systematic review. *Sports Health*. 2020;12(2):200–206. doi:10.1177/1941738119887183
11. von Elm E, Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol*. 2008;61(4):344–349. doi:10.1016/j.jclinepi.2007.11.008
12. Bohannon RW. Manual muscle testing: does it meet the standards of an adequate screening test? *Clin Rehabil*. 2005;19(6):662–667. doi:10.1191/0269215505cr873oa
13. Hermans G, Gosselink R. Should we abandon manual muscle strength testing in the ICU? *Crit Care*. 2011;15(2):127. doi:10.1186/cc10038
14. Hartmann A, Knols R, Murer K, de Bruin ED. Reproducibility of an isokinetic strength-testing protocol of the knee and ankle in older adults. *Gerontology*. 2009;55(3):259–268. doi:10.1159/000172832
15. Hayes KW, Falconer J. Reliability of hand-held dynamometry and its relationship with manual muscle testing in patients with osteoarthritis in the knee. *J Orthop Sports Phys Ther*. 1992;16(3):145–149. doi:10.2519/jospt.1992.16.3.145

16. Kean CO, Birmingham TB, Garland SJ, Bryant DM, Giffin JR. Minimal detectable change in quadriceps strength and voluntary muscle activation in patients with knee osteoarthritis. *Arch Phys Med Rehabil*. 2010;91(9):1447–1451. doi:10.1016/j.apmr.2010.06.002
17. Dowman L, McDonald CF, Hill CJ, et al. Reliability of the handheld dynamometer in measuring muscle strength in people with interstitial lung disease. *Physiotherapy*. 2016;102(3):249–255. doi:10.1016/j.physio.2015.10.002
18. Lee MY, Sung KS, Ham H, Yi YG, Shin HI. Knee extensor strength measurement in patients with limited physical activity using a supine dynamometer anchoring frame. *Ann Rehabil Med*. 2020;44(6):502–509. doi:10.5535/arm.20056
19. Scott J, Huskisson EC. Graphic representation of pain. *Pain*. 1976;2(2):175–184.
20. Whitney SL, Wrisley DM, Marchetti GF, Gee MA, Redfern MS, Furman JM. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the five-times-sit-to-stand test. *Phys Ther*. 2005;85(10):1034–1045.
21. Narazaki K, Matsuo E, Honda T, Nofuji Y, Yonemoto K, Kumagai S. Physical fitness measures as potential markers of low cognitive function in Japanese community-dwelling older adults without apparent cognitive problems. *J Sports Sci Med*. 2014;13(3):590–596.
22. Mehta SP, Barker K, Bowman B, Galloway H, Oliashirazi N, Oliashirazi A. Reliability, concurrent validity, and minimal detectable change for iPhone goniometer app in assessing knee range of motion. *J Knee Surg*. 2017;30(6):577–584. doi:10.1055/s-0036-1593877
23. Naylor JM, Hayen A, Davidson E, et al. Minimal detectable change for mobility and patient-reported tools in people with osteoarthritis awaiting arthroplasty. *BMC Musculoskelet Disord*. 2014;15:235. doi:10.1186/1471-2474-15-235
24. Amano T, Suzuki N. Minimal detectable change for motor function tests in patients with knee osteoarthritis. *Prog Rehabil Med*. 2018;3:20180022. doi:10.2490/prm.20180022
25. Wada O, Kurita N, Yamada M, Mizuno K. Structural severity, phase angle, and quadriceps strength among patients with knee osteoarthritis: the SPSS-OK study. *Clin Rheumatol*. 2020;39(10):3049–3056. doi:10.1007/s10067-020-05056-w
26. Amano T, Tanaka R, Tanaka S. Clinical prediction rule for early recovery of knee range of motion after total knee arthroplasty: A prospective cohort study. *Phys Ther Res*. 2020;23(2):202–208. doi:10.1298/ptr.E10044
27. Segal NA, Glass NA, Torner J, et al. Quadriceps weakness predicts risk for knee joint space narrowing in women in the MOST cohort. *Osteoarthr Cartil*. 2010;18(6):769–775. doi:10.1016/j.joca.2010.02.002
28. Bartholdy C, Juhl C, Christensen R, Lund H, Zhang W, Henriksen M. The role of muscle strengthening in exercise therapy for knee osteoarthritis: a systematic review and meta-regression analysis of randomized trials. *Semin Arthritis Rheum*. 2017;47(1):9–21. doi:10.1016/j.semarthrit.2017.03.007
29. Thorborg K, Bandholm T, Hölmich P. Hip- and knee-strength assessments using a hand-held dynamometer with external belt-fixation are inter-tester reliable. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(3):550–555. doi:10.1007/s00167-012-2115-2
30. Koblbauer IF, Lambrecht Y, van der Hulst ML, et al. Reliability of maximal isometric knee strength testing with modified hand-held dynamometry in patients awaiting total knee arthroplasty: useful in research and individual patient settings? A reliability study. *BMC Musculoskelet Disord*. 2011;12:249. doi:10.1186/1471-2474-12-249
31. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159–174.