
TAE-HEON LEE, BS, PT1, KYEONG-SOON PARK, PhD, PT1, DONG-GEOL LEE, PhD, PT1, NAM-GI LEE, MS, PT2

1) Department of Rehabilitation Medicine, Chungnam National University Hospital
2) Department of Physical Therapy, Graduate School, Yonsei University; 234 Heoungup-Myon, Maeji-Ri, Wonju City, Kangwon-do, Republic of Korea. TEL: +82 33-760-2498, FAX: +82 33-760-2496, E-mail: ptnamgi@naver.com

Abstract. [Purpose] The purpose of this study was to establish the concurrent validity of electromyography (EMG) activity and muscle strength scores obtained by manual muscle testing (MMT), handheld dynamometer (HHD), and the gold standard stationary dynamometer (SD). [Subjects] Forty healthy young adults (17 men, 23 women) volunteered to participate in this study. [Methods] Subjects performed maximal voluntary isometric contraction (MVIC) of the quadriceps for 5 seconds in three successive trials. Surface EMG was used for recording the muscle activity during the maximal MMT, HHD, and SD measurements. [Results] The mean and peak EMG amplitudes (ICC3,k = 0.968 to 0.980) of the three MVIC methods and muscle strength scores (Pearson r = 0.868) measured by HHD and SD showed good concurrent validity. The intra-trial reliability of mean EMG activity was also good (ICC3,1 = 0.960 to 0.989), reflecting consistent measurement between trials. [Conclusion] Our EMG results imply that MMT and HHD are useful and simple methods of measuring MVIC for EMG normalization. Considering cost, time, and clinical utility, we suggest that the use of HHD to measure MVIC for EMG normalization is highly valuable and should generate more meaningful information associated with pathological conditions or interventions for all patients. Key words: Electromyography, Maximal voluntary isometric contraction, Normalization

INTRODUCTION

Surface electromyography (EMG) is a noninvasive technique and a valid and reliable indicator for estimating muscle recruitment or evaluating muscle function in healthy and pathological populations1, 2. However, EMG produces a variable signal that depends on many factors such as the thickness of subcutaneous adipose tissue, sex, subtle changes in posture, interelectrode distance, electrode size and placement, temperature, and skin impedance2, 3. Hence, comparisons of surface EMG values between and within individuals should be approached cautiously. EMG normalization is commonly used to improve reliability by decreasing variation within and between individuals in EMG studies4, 5. Maximal voluntary isometric contraction (MVIC) is the most common method of EMG normalization6–8, and is used as the standard value when comparing different subjects, days, studies, and muscles9. Some researchers reported better reliability by using the submaximal contraction method for EMG normalization10, 11. However, several researchers have suggested that the MVIC method is the most reliable when compared with normalized EMG data relative to the peak or the mean amplitude of dynamic contraction8, 12, 13. Maximal muscle strength assessment for measuring MVIC can be performed using manual muscle testing (MMT), a handheld dynamometer (HHD), and a stationary dynamometer (SD). MMT is the most widely used standard method for assessing muscle strength in clinical settings4, 14. The patient’s strength is graded according to the muscle’s ability to move against gravity, or to resist a manual force applied by the examiner using one hand with the other hand stabilizing the joint15, 16. MMT, although technically easy, cannot differentiate objectively between strength levels. Beasley (1956) reported that a variation of 25% in knee extensor strength cannot be detected by MMT17. Assessment of muscle strength with an HHD is a quantitative and objective method that can be easily manipulated in a clinical setting18. The validity and reliability of the HHD have been previously established19–22. However, muscle strength assessment using an HHD might be influenced by the tester’s strength, resistance location, and ability to hold the HHD in a stable position19, 23, 24. Researchers need to control these factors, as they may influence the reliability of results. Assessment of muscle strength with an SD or
isokinetic testing has been considered the “gold standard”\textsuperscript{18, 25}. An SD is a computerized machine used to measure muscle strength at different speeds or in different modes of muscle contraction including isokinetic, isotonic, concentric, and eccentric\textsuperscript{26}. Several researchers have suggested that an SD such as the Biodex System 3 Isokinetic Dynamometer is a reliable and valid assessment tool for measuring muscle function in both clinical and research settings\textsuperscript{27–29}. Despite supporting evidence from these studies, other researchers have identified a number of drawbacks of the SD, such as high cost, long setup time, and large apparatus\textsuperscript{26, 30}.

Comparisons between methods such as MMT, HHD, and SD for measuring MVIC have been made previously\textsuperscript{4, 26}. Lin et al. (2008) reported that the difference in EMG activity between MMT and Cybex testing of the quadriceps femoris was not significant\textsuperscript{4}. The MMT technique for measuring MVIC appears to be reliable and highly valuable, but the result is not expressed as a muscle power value. Roy et al. (2009) suggested that the correlation between muscle power scores from the HHD and SD (the gold standard) for testing isometric shoulder strength indicated good concurrent validity\textsuperscript{26}. An SD requires greater financial, time, and technical resources, whereas an HHD is portable, inexpensive, and provides a muscle power value. Considering cost, time, and clinical utility, we suggest that the use of an HHD to measure MVIC for EMG normalization is highly valuable in clinical research. However, to our knowledge, no study has compared the EMG activity between MMT, HHD, and SD measurements to assess maximal muscle strength. Therefore, the purposes of this study were, first, to establish the concurrent validity of EMG activity by comparing MMT, HHD, and SD (gold standard isokinetic dynamometry) measurements and, second, to determine the concurrent validity of the muscle strength score by comparing HHD and SD measurements in testing of maximal isometric quadriceps contraction. Our basic hypothesis was that the measurement provided by the three instruments would represent good concurrent validity as evidenced by the EMG activity and muscle strength measurements.

**SUBJECTS AND METHODS**

**Subjects**

Forty healthy young adults (17 men, 23 women) volunteered to participate in this study. Their mean age, height, and weight were 26.8 ± 3.8 years, 166.6 ± 8.6 cm, and 61.4 ± 13.2 kg, respectively. Most of the subjects were right-leg dominant (32 subjects = right, 8 subjects = left), and had no history of neurological or musculoskeletal pathology or surgery at the time of testing. The chief examiner explained the experimental procedures to the subjects and then asked them to sign an informed consent from before testing\textsuperscript{31}.

**Methods**

A procedural checklist was followed to ensure the experimental protocol was applied consistently. Each subject cycled for 3 minutes to warm up before testing\textsuperscript{32}. The dominant leg was determined by performing a simple ball kick test\textsuperscript{31, 32}, in which subjects were asked, “Which foot would you use to kick a ball?”. Subjects were seated on the Biodex chair, and their trunk and pelvis were fixed using pelvic and chest belts. Prior to placing the surface EMG electrodes, the skin was carefully prepared to reduce skin impedance by dry shaving the hair with a disposable razor, and cleansing it with a 2% alcohol swab. The surface EMG activity of the dominant leg was recorded from the quadriceps, including the vastus medialis (VM), vastus lateralis (VL), and rectus femoris (RF), by means of wireless sensors 37 mm × 26 mm × 15 mm in size (Trigno™ Wireless System, Delsys Incorporated, Boston, MA, USA). For the VM, the electrode was placed on the skin over the muscle at an oblique angle (55 degrees), 2 cm medially from the superior rim of the patella palpated during knee extension. For the VL, the electrode was placed on the VL muscle belly at an oblique angle just lateral to the midline of the knee joint, approximately 5 cm above the patella. For the RF, the electrode was positioned on the midpoint of the distance from the anterior superior iliac spine to the superior pole of the patella\textsuperscript{33}. To measure the MVIC of the quadriceps for the dominant leg, the starting posture was 45° knee flexion measured with a goniometer, which was performed by a physical therapist with at least three years’ experience. Before EMG data acquisition, all subjects were instructed to practice the maximal isometric knee extension for the quadriceps. Following a rest period of about 5 minutes, subjects performed the maximal MMT of the dominant leg by holding it against the manual resistance of a male physical therapist. A male physical therapist provided consistent verbal encouragement during the maximal performance of the knee. For EMG recording, each MMT trial lasted for 5 seconds and was repeated three times with a 3-minute rest period between each trial\textsuperscript{34}. Following the MMT trial, subjects performed maximal isometric contraction of the quadriceps with an HHD (JTech Medical, Salt Lake City, UT, USA) and SD (Biodex Medical Systems, Shirley, NY, USA). For HHD and SD testing, the positioning and conditions including trial number, resting time between trials, duration of trial, and verbal encouragement were consistent with the MMT trials. The examiner’s hand or an instrument was placed on the subject’s anterior leg just above the ankle to provide manual or mechanical resistance for the maximal MMT, HHD, and SD measurements\textsuperscript{34}. Resistance was then applied in the direction of knee flexion, essentially downward toward the Biodex chair. An SD, a Biodex System 3 Isokinetic Dynamometer, obtained the maximal muscle strength score in isometric mode. Both EMG activity and the maximal muscle strength score measured by HHD and SD were recorded simultaneously. The three MVIC methods for surface EMG recording were applied in random order, and the resting time between the three MVIC methods was 5 minutes\textsuperscript{35}. All of the EMG activity recorded by the three MVIC methods was stored in a personal computer and analyzed offline.

The raw EMG signals for the VM, VL, and RF muscles were recorded at a sampling rate of 1200 Hz and processed with a 60 Hz notch filter to reduce the noise associated with electrical interference, including the 60 Hz power lines of
electric or magnetic devices. The middle 3 seconds of each trial were extracted and processed for EMG amplitude analysis using MyoResearch software (Noraxon U.S.A. Inc., Scottsdale, AZ, USA). The root mean-square EMG amplitude for the quadriceps muscle was computed, and the EMG signal was full-wave rectified and filtered using a band pass filter at 20–300 Hz.

The descriptive statistics include means and standard deviations. Intraclass correlation coefficients (ICC\(_{3,k}\)) and their 95% confidence intervals (95% CI) were used to determine concurrent validity by comparing the EMG activity recorded using three MVIC methods: maximal MMT, HHD, and SD (gold standard isokinetic dynamometry) measurements. On the other hand, the concurrent validity between the maximal muscle strength scores obtained by the two different dynamometers, the HHD and SD, was determined using Pearson product correlation coefficient (r) and its 95% CI. Finally, the ICC\(_{3,1}\) was used to examine intra-trial reliability for measuring EMG activity. The alpha level was set at 0.05, and SPSS for Windows version 12.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

### RESULTS

The ICC\(_{3,k}\) values of the peak EMG amplitudes for the VM, VL, and RF muscles were 0.976 (VM, 95% CI = 0.958 to 0.987), 0.980 (VL, 95% CI = 0.964 to 0.989), and 0.974 (RF, 95% CI = 0.954 to 0.986), respectively. The ICC\(_{3,k}\) values for the mean EMG amplitude were 0.968 (95% CI = 0.943 to 0.983) (Table 1). The correlation between the two dynamometers was good (r = 0.869, 95% CI = 0.752 to 0.933) for the quadriceps (Table 2). Table 3 shows the intra-trial reliability by comparing the mean EMG activity between trials using maximal MMT, HHD, and SD measurements. The ICC\(_{3,1}\) values for the three measures of EMG activity were 0.968–0.987 (MMT), 0.974–0.989 (HHD), and 0.960–0.986 (SD), respectively (Table 3).

### DISCUSSION

The primary purpose of this study was to establish the concurrent validity between maximal MMT, HHD, and SD (gold standard isokinetic dynamometry) measurements to determine the simplest and most useful method of measuring MVIC in healthy young adults. To the best of our knowledge, this is the first study to investigate concurrent validity by comparing EMG activity recorded using three MVIC methods. The results of this study demonstrated that mean and peak EMG amplitudes (ICC\(_{3,k}\) = 0.968 to 0.980) and muscle strength scores (r = 0.868, p = 0.000) showed
good concurrent validity between the three MVIC methods. Intra-trial reliability was also good (ICC3,1 = 0.960 to 0.989), reflecting consistent measurement between trials.

As anticipated, this study demonstrates that MMT and an HHD are appropriate for EMG normalization in the quadriceps muscle. Our findings are consistent with previous studies that have examined the concurrent validity of EMG activity and maximal muscle strength of the quadriceps muscle measured by MVIC methods such as MMT, HHD, and SD in healthy young adults, elderly people, and adults with mental retardation5, 36–38. In EMG study, Lin et al. (2008) only compared the EMG activity measured by MMT and a Cybex dynamometer during maximal isometric quadriceps contraction. The differences in the mean EMG amplitude ratio and the median frequency between MMT and Cybex testing were not statistically significant4. In terms of quadriceps strength, Surburg et al. (1992) first examined the correlation between an HHD and Cybex II dynamometer in terms of isometric quadriceps strength using a stabilization technique with straps in adults with mental retardation (intelligence range based upon the Stanford-Binet Intelligence Test: 36 to 69) and found that significant Pearson coefficients (r) ranged from 0.72 to 0.7638. Reed et al. (1993) and Martin et al. (2006) reported that the correlation between HHD and SD measurements for elderly adults was fair (r = 0.74) and high (r = 0.91), respectively36, 37. Such fair to high concurrent validity may be attributable to a test procedure problem such as trunk compensation. Hence, our findings showing good concurrent validity also indicate the importance of the trunk compensation prevention during maximal isometric contraction of the quadriceps.

A previous study suggested that the MMT method is not sufficiently sensitive for measuring muscle strength18. Noreau and Vachon (1998) performed a comparison of three methods, MMT, HHD, and Cybex, for measuring the strength of the six upper extremity muscle groups (elbow flexors-extensors, shoulder flexors-extensors, and shoulder adductors-abductors) in 38 individuals with spinal cord injury. The findings showed variable levels of association between the strength values measured by MMT (grade scale) and HHD (kilograms) with the Spearman coefficient (r) ranging from 0.26 to 0.95. The strength values measured by HHD and Cybex revealed moderate to strong correlations in individuals with paraplegia (r = 0.70 to 0.90) and tetraplegia (r = 0.57 to 0.96). They argued that an objective method for measuring muscle strength in clinical settings should be strongly encouraged to increase the reliability of outcome measures in rehabilitation18. Therefore, we suggest that the HHD method to measure MVIC in the quadriceps is more beneficial than MMT for EMG normalization because it can provide muscle strength scores simultaneously. Clinically, the major function of the quadriceps is to generate knee extension strength and to stabilize the patella19. The normalized EMG data of the HHD method is important to understand quadriceps muscle function such as muscle strength and activity characteristics during dynamic movements in people with knee problems, including patellofemoral syndrome, osteoarthritis, and knee instability, such as anterior cruciate ligament injury. That is, the HHD method for EMG normalization may provide more meaningful information associated with pathological conditions or interventions for all patients in clinical settings.

One major shortcoming was identified in our research that should be taken into consideration for clinical study in the future. The issue is that the difference in EMG activity between MMT, HHD, and SD was examined only for the superficial quadriceps muscle in healthy young adults; hence, our results cannot be generalized to other muscles and populations. Further studies should focus on investigating the concurrent validity by comparing EMG activity between maximal MMT, HHD, and SD measurement for testing other muscles such as upper extremity muscles, and in other populations including geriatric populations with muscle atrophy, and pathologic populations with musculoskeletal and neurological impairments.

REFERENCES


20) Bohannon RW: Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. Arch Phys Med Rehabil, 1997, 78: 26–32. [Medline] [CrossRef]


