COMPARISON OF METHODS FOR EVALUATING UPPER LIMB STRENGTH BY HAND-HELD DYNAMOMETRY

ABSTRACT

Introduction: The upper limbs are segments of the human body responsible for primary activities of daily life, and the muscles are essential structures for performing these activities. There have been few studies on intra- and inter-examiner reliability of the hand-held dynamometer (HHD) in healthy subjects, and none have been published that compare dynamometric evaluation methods in the main muscles in this segment. Objective: Evaluate intra-examiner and inter-examiner assessment reliability of the hand-held dynamometry of upper limb muscles in healthy individuals, as well as comparing the assessment reliability between fixed and non-fixed methods. Methods: Healthy subjects aged over 18 years were recruited for the study. The isometric contraction for ten muscle groups of the dominant upper limb was tested. For the fixed method, we used a system of suction cups, connected to the HHD by an inelastic belt. For the non-fixed method, the examiner supported the device by hand. The isometric contraction was sustained for three seconds. Each measurement was repeated three times, considering the highest value obtained. The reliability was calculated using the intraclass correlation coefficient (ICC). The dispersion between measurements was expressed by a Bland-Altman plot. Results: The sample consisted of 25 volunteers, all right-handed. The intra-examiner ICC was 0.89-0.99 for the non-fixed method, and 0.43 to 0.85 for the fixed method. Inter-examiner reliability showed equivalent behavior. This study showed that evaluation of upper limb muscle strength using an isometric dynamometer has excellent intra-examiner and inter-examiner reliability. The supine position was chosen due to the need to propose a feasible protocol for clinical practice that could be replicated for the majority of publics and in different environments. The non-fixed method showed better reliability overall, demonstrating the feasibility of this tool without the need for adaptations, additional devices, or increased operating costs for this evaluation. Conclusion: Comparison between the fixed and non-fixed HHD methods demonstrated superiority of the non-fixed method in terms of reliability. Level of evidence II; Investigation of a diagnostic exam - Development of diagnostic criteria with consecutive patients.

Keywords: Muscle strength dynamometer; Muscular contraction; Muscle strength; Diagnosis; Data accuracy.

RESUMO

Introdução: Os membros superiores são segmentos do corpo humano responsáveis por atividades primordiais do nosso cotidiano, e os músculos são estruturas imprescindíveis para isso. Ainda são escassos nos estudos sobre a confiabilidade intra e interexaminadores da dinamometria Hand-Held em indivíduos saudáveis, sendo inédita a comparação entre os métodos de avaliação da dinamometria nos principais músculos desse segmento. Objetivo: Avaliar a confiabilidade da avaliação intraexaminador e interexaminador da dinamometria manual de músculos do membro superior em indivíduos saudáveis, bem como comparar a confiabilidade da avaliação entre métodos fixos e não fixos. Métodos: Foram recrutados indivíduos saudáveis, maiores de 18 anos. A contracção isométrica para dez grupos musculares do membro superior dominante foi realizada. Para o método fixado, foi empregado um sistema de ventosas conectado ao Dinamômetro Hand-Held (DHH) por um cinto inelástico. No método não fixado, o examinador apoiou o aparelho com a mão. A contracção isométrica foi sustentada por três segundos. Cada medida foi repetida três vezes, considerando o maior valor obtido. A confiabilidade foi calculada através do coeficiente de correlação intraclass (CCI). A dispersão entre as medidas foi expressa pelo diagrama de Bland-Altman. Resultados: A amostra foi composta por 25 voluntários, todos destros. O coeficiente de correlação intraclass (CCI) dos intraexaminadores para o método não fixado foi de 0,89 a 0,99 e, para o método fixado, situou-se entre 0,43 e 0,85. A confiabilidade interexaminadores teve comportamento equivalente. O presente estudo demonstrou que a avaliação da força dos músculos dos MMSs com dinamômetro isométrico apresenta excelente confiabilidade tanto intra quanto interexaminadores. A escolha do posicionamento supino vem da necessidade de propor um protocolo factível na prática clínica, replicável para a maioria dos públicos e em ambientes diversos. O fato de o método não fixado demonstrar maior confiabilidade, em geral, expõe a viabilidade do uso dessa ferramenta sem necessidade de adaptações, dispositivos adicionais ou aumento do custo operacional nessa avaliação. Conclusão: A comparação entre os métodos fixados e os não fixados da dinamometria Hand-Held demonstrou superioridade do método não fixado quanto à confiabilidade. Nível de evidência II; Estudos diagnósticos - Investigação de um exame para diagnóstico - Desenvolvimento de critérios diagnósticos com pacientes consecutivos.

Descritores: Dinamômetro de força muscular; Contração muscular; Força muscular; Diagnóstico; Confiabilidade dos dados.
INTRODUCTION

Movement production is directly related to the ability of the muscle to produce tensile strength, which, in turn, is influenced by its cross-sectional area, neural activation, bioenergetic reserve, and length and capacities of stretching and shortening of its fibers.\(^1\)\(^2\) It is known that muscle strength deficiency has a negative impact on functional performance and autonomy, making it difficult to perform basic and instrumental activities of daily living (ADL).\(^3\)\(^4\)

The upper limbs (UL) are segments of the human body responsible for allowing essential activities of our daily life, such as eating, performing work activities, hygiene, gestural communication and effective interaction with the various technological devices. Much more than functions, the upper limbs, having adequate strength, coordination and precision of movements, allow the human species to perform multiple activities, of different possibilities and complexities, and each individual to be unique in their expressions and social participation.\(^5\)\(^6\)

The graduation of muscle strength is an essential tool to adequate physical training prescription, guidance on the diagnosis of muscle dysfunctions and disabilities in sick individuals, and also regarding guidance on preventive programs for injuries arising from imbalances between antagonist muscle chains. However, it is worth mentioning that graduating a specific muscle group strength is as important as guaranteeing the veracity and reliability of this measurement.\(^5\)\(^6\)\(^7\)\(^8\)\(^9\)\(^10\)

The Hand-Held Dynamometer (HHD) is a portable device, capable of grading muscle strength through sustained maximum isometric contraction. Its size and weight enable easy handling during evaluation, which makes its use reproducible. Such characteristics allow it to be used in the most diverse environments and audiences. However, there is still little evidence of the reliability of this instrument, which uses simple and feasible protocols for clinical practice that addresses different muscles of UL.\(^8\)\(^9\)\(^10\)\(^11\)\(^12\)

This research aimed to evaluate intra-examiner and inter-examiner assessment reliability of the hand-held dynamometry of upper limb muscles in healthy individuals, as well as comparing the assessment reliability between fixed and non-fixed methods.

MATERIALS AND METHODS

Participants

Healthy individuals were recruited by direct call, via text message, or social network. Before recruitment, a sample calculation was performed respecting 10% of variation between measurements, 0.05 α and 80% power, and 25 participants were included in the research.

Inclusion was for individuals of both sexes above 18 years of age, who voluntarily agreed in participating in the research and signed the informed consent form. Individuals were excluded when presented acute osteoarticular disease or symptoms; reduced functional range of motion (ROM);\(^13\) severe heart disease or neuromuscular diseases, and cognitive limitation that restricted the understanding of motor commands during assessment.

Randomization

In order to eliminate bias, the order of assessment between fixed and non-fixed methods was randomized for all patients. Through simple randomization, part of the participants started the Hand-Held dynamometry assessment using the fixed method and the others using the non-fixed method.

Instruments

Muscle strength assessment was performed using a previously calibrated Lafayette Hand-Held Dynamometer, model 01165 (Lafayette, Sagamore, USA). An ISP goniometer (São Paulo, BR) was also used to properly mark the articular position of the segments for each evaluated movement.\(^14\) All patients had the proximal segment (trunk, arm or forearm) stabilized by using a inelastic belt in order to null the effect of synergistic muscle chains and their irradiation of strength.\(^15\)
Table 1. HHD assessment positions.

| Joint       | Movement | Body position                              | HHD                  |
|-------------|----------|--------------------------------------------|----------------------|
| Shoulder    | Flexion17| Supine, shoulder 90° of flexion, elbow and wrists 0°, forearm pronated. | Posterior forearm    |
|             | Extension17| Supine, shoulder 90° of flexion, elbow and wrists 0°, forearm pronated. | Anterior forearm     |
| Abduction14,18| Supine, 45° abduction shoulder, elbow and wrists 0°, forearm in intermediate position. | Posterior forearm    |
| Adduction14,18| Supine, 45° abduction shoulder, elbow and wrists 0°, forearm in intermediate position. | Anterior forearm     |
|             | Internal rotation14 | Supine, abduction shoulder 90°, flexion elbow 90° and wrists 0°, supinated forearm. | Anterior forearm     |
|             | External rotation14 | Supine, abduction shoulder 90°, flexion elbow 90° and wrists 0°, supinated forearm. | Posterior to the forearm |
| Elbow       | Flexion19| Supine, shoulder and wrist 0°, elbow 90° of flexion, supinated forearm. | Anterior forearm     |
|             | Extension19| Supine, shoulder and wrist 0°, elbow 90° of flexion, foreama pronated. | Anterior forearm     |
| Wrist       | Flexion20| Supine, abduction shoulder 30°, elbow and wrist 0°, supinated forearm and supported on stretcher with wrist out. | Anterior carpal surface |
|             | Extension20| Supine, abduction shoulder 30°, elbow and wrist 0°, forearm pronated and supported on stretcher with wrist out. | Anterior carpal surface |

Table 2. Anthropometric characteristics of the sample (n = 25).

|                          | n (%) | Mean (SD) |
|--------------------------|-------|-----------|
| Gender (female)          | 15 (60)|           |
| Age (years)              |       | 33.1 (13.4)|
| Race Brown               |       |           |
| White                    | 7 (28) |           |
| Black                    | 5 (20) |           |
| Weight (kg)              |       | 72.6 (18.3)|
| Height (m)               | 1.7 (0.1) |     |
| BMI                      | 24.9 (5.0) |     |
| Dominance (right-handed) | 25 (100) |     |
| IPAQ: Sedentary          | 9 (36) |           |
| Active                   | 7 (28) |           |
| Irregularly active       | 4 (16) |           |
| Very active              | 3 (12) |           |
| Other                    | 2 (08) |           |
| Physical activity frequency (days) | 3.5 (1.5) |     |

Statistical Method

Tabulation and data analysis were performed with SPSS (Statistical Package for the Social Sciences) software, version 21.0, using descriptive statistics, and data presented in tables and graphs. Qualitative data were exposed in absolute and relative frequency; quantitative data were expressed as mean and standard deviation. Student’s t test was used to evaluate the difference between mean peak torque obtained between the methods, considering a statistically significant value of p <0.05.

Reliability was calculated using the intraclass correlation coefficient (ICC) and was categorized using the classification proposed by Weir (2005):22 excellent for values between 1.0 and 0.81; very good from 0.80 to 0.61; good from 0.60 to 0.41; reasonable from 0.40 to 0.21, and poor from 0.20 to 0.00. The dispersion between intra and inter-examiner measurements was expressed using the Bland-Altman plot for non-fixed and fixed measurements.

RESULTS

The sample consisted of 25 volunteers, and their anthropometric characteristics are shown in Table 2. It was observed that, in general, the peak torque in the non-fixed method was greater than in the fixed method. However, no significant difference was found between means, except for elbow flexion (p = 0.049), as shown in Table 3. The Bland-Altman graph for intra-examiner reliability is presented in Figure 1.

Table 4 reflects the intra-examiner reliability for non-fixed and fixed groups, with all ICC categorized as excellent. The Bland-Altman graph for inter-examiner reliability is presented in Figure 2, ratifying the difference in reliability between groups for the highest ICC. The inter-examiner reliability is shown in Table 5, observing that the non-fixed method maintained an excellent categorization, and the fixed method presented varied reliability, between excellent and reasonable, for the 10 joints of the upper limbs evaluated.

DISCUSSION

This study demonstrated that the strength assessment of upper limb muscles with an isometric dynamometer presents excellent reliability for both intra-examiner and inter-examiner assessments. This finding seems to relate to the structured protocol, as well as to the constant training of the collection group, composed of physical therapists and experts in anatomy and biomechanics. The study by Saccol et al.21 also evaluated the reliability of the Hand-Held dynamometry of the internal and external rotators of the shoulder, in supine position, similarly to which was adopted in the protocol of this study and in sitting position, with fixation in a rigid device. The results found reflect levels of reliability.
that vary between good and very good in the classification adopted by Weir.\textsuperscript{22} In this study, the fixed method found levels of reliability similar to those of the study by Saccol et al.\textsuperscript{21} In turn, the non-fixed method demonstrated greater reliability than that of the mentioned study. The justification for better results with a similar protocol can be attributed to the fact that Saccol et al.\textsuperscript{21} use examiners without clinical experience, and, in this work, the volunteers were evaluated by experienced and previously trained examiners.

The comparison between fixed and non-fixed methods demonstrated the superiority of the non-fixed method regarding both intra-examiner and inter-examiner assessments. This finding is similar to that found by Davis et al.\textsuperscript{15} in a study that assessed Hand-Held dynamometry reliability for plantar flexion. Regarding the fact that higher ICC were found for the non-fixed method, in comparison with the fixed method, it is worth mentioning that both methods showed excellent reliability. Greater reliability results for the non-fixed method seem to diverge from the trend shown in the study by Almeida et al.,\textsuperscript{16} which evaluated the rectus femoris of 70 participants before the reconstruction of the anterior cruciate ligament, and demonstrated an intra-examiner reliability of 0.98 (0.980-0.99) with the fixed method. It is important to mention that the study did not express inter-examiner reliability, nor did it compare the non-fixed method.

For UL, there is a scarcity of studies comparing the reliability between fixed and non-fixed methods for most movements in this segment, as seen in a recent systematic review.\textsuperscript{1} This study was based on the results found for lower limbs and on fundamentals of biomechanics according to which force vectors with opposite directions would null each other in the isometric movement, as long as there is no visible angular movement. This hypothesis was reinforced by the superior reliability found in the non-fixed method compared to the fixed method. The difference between the mean peak torque was not significant between the methods, with the exception of dynamometry for elbow flexion:

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171.4 \ (26.1) \times 110.2 \ (32.8), \text{ with } p=0.049.
\]

The choice of supine position is due to the need to propose a feasible protocol in clinical practice, replicable for most audiences and in different environments, making the measurement of UL muscle strength more accessible and explored. This study assesses the reliability of this instrument and the protocol for evaluating the main muscles of UL. This initiative to propose the assessment of reliability for 10 of the main muscles of UL is innovative. In view of the satisfactory results of inter and intra-examiner reliability, the results suggest that portable isometric dynamometry is a potential tool for the assessment of healthy individuals by previously trained examiners. The margin of this impression, in the review of the European consensus on the definition and diagnosis of Sarcopenia,\textsuperscript{1} published in 2018, still demonstrates limitations in tests and methods to quantify the magnitude of strength loss, and it is restricted to the assessment of hand grip and chair stand test. This study focuses on the possibility that this tool could be a viable alternative for a more extensive and comprehensive diagnosis of UL muscle strength.

In a study with swimmers, Awatani et al.\textsuperscript{23} measured the reliability of HHD as a non-fixed method for internal and external rotators of the shoulder in swimmers without acute pain. In the mentioned study, the authors found, for internal rotators, an intra-examiner reliability of 0.94 (0.81-0.98), lower than the inter-examiner reliability of 0.96 of this study – 0.96 (0.87-0.99) –, higher than the 0.93 reliability in this study. All measures, however, are within the "excellent" reliability classification proposed by Weir.\textsuperscript{22} For external rotation, all reliability measurements in this study were superior to those found by Awatani et al.\textsuperscript{23} Hand-Held dynamometry excellence for shoulder is reinforced in the study by Candogan et al.,\textsuperscript{24} who evaluated, with the non-fixed method, several shoulder movements in patients with ongoing inflammatory process and found reliability, expressed by ICC, between 0.85 and 0.99, for test and retest and between examiners.

Dowman et al.\textsuperscript{25} evaluated, with the non-fixed method, the reliability of HHD for elbow flexors and knee extensors in patients with interstitial lung disease. For elbow flexors, the assessment protocol was similar to that of this study. As a result, intra-examiner reliability of 0.98 was found, with 95% CI (0.96-0.99), similar to that found in this study, with ICC of 0.97. Regarding inter-examiner reliability, Dowman et al.\textsuperscript{25} found values higher than the ones in this study, that is, 0.95 (0.88-0.99) against 0.83 in this study, with an excellent reliability rating for both studies, which reinforces the importance of this measurement instrument for elbows and in diverse populations.

Reliability for wrist flexion and extension using the fixed method was considered excellent for test and retest, and also for comparison of measurements between examiners in the non-fixed method. In turn, ICC of the fixed method oscillated between good and reasonable for wrist flexion, and between very good and excellent for wrist extension. Similar behavior was found in the study by Rheault et al.,\textsuperscript{20} who assessed the intra-examiner reliability of the Hand-Held dynamometry during wrist flexion and extension in twenty volunteers. In the abovementioned study, the assessment protocol was similar to that used in this study, but it did not use verbal stimulus during the measurement and did not stabilize the distal segment to control compensations. However, Rheault et al.\textsuperscript{20} found ICC of 0.91 for wrist extensors and ICC of 0.85 for wrist flexors. Such results were equivalent to the intra-examiner reliability found in this study.

This study is a pioneer in assessing the reliability of 10 muscles of UL, demonstrating its clinical importance. The fact that the non-fixed method generally presents greater reliability exposes the feasibility of using this tool without the need for adaptations, additional devices or increased operational cost in the assessment. Such fact may explain the increased use of this tool in gyms, clubs and performance clinics. However, there is a need for further studies on using Hand-Held dynamometry in young populations, as well as the validation of this method and delimitation of

Table 3. Mean and standard deviation of the peak torque of the muscle groups evaluated (n = 25).

| Joint     | Movement | ICC     | 95% CI        | Reliability* | ICC     | 95% CI        | Reliability* |
|-----------|----------|---------|---------------|--------------|---------|---------------|--------------|
| Shoulder  | Flexion  | 0.99    | [0.97-0.99]   | Excellent    | 0.64    | [0.18-0.92]   | Very good    |
|           | Extension| 0.93    | [0.80-0.98]   | Excellent    | 0.56    | [0.17-0.91]   | Good         |
| Abduction | Flexion  | 0.98    | [0.93-0.99]   | Excellent    | 0.76    | [0.20-0.95]   | Very good    |
| Adduction | Flexion  | 0.98    | [0.94-0.99]   | Excellent    | 0.85    | [0.29-0.97]   | Excellent    |
| Internal rotation | Flexion | 0.96    | [0.87-0.98]   | Excellent    | 0.95    | [0.75-0.99]   | Excellent    |
| External rotation | Flexion | 0.98    | [0.90-0.99]   | Excellent    | 0.82    | [0.12-0.96]   | Excellent    |
| Elbow     | Flexion  | 0.97    | [0.93-0.99]   | Excellent    | 0.43    | [0.04-0.88]   | Good         |
|           | Extension| 0.99    | [0.98-0.99]   | Excellent    | 0.84    | [0.20-0.96]   | Excellent    |
| Wrist     | Flexion  | 0.91    | [0.75-0.97]   | Excellent    | 0.52    | [0.36-0.90]   | Good         |
|           | Extension| 0.89    | [0.67-0.96]   | Excellent    | 0.71    | [0.43-0.94]   | Very good    |
Figure 1. Bland Altman graphs show intra-examiner reliability between non-fixed (A) and fixed (B) methods.

Table 4. Dynamometry intra-examiner reliability with non-fixed and fixed methods (n = 25).

| Joint | Movement  | Non-fixed | Fixed |
|-------|-----------|-----------|-------|
|       |           | Test      | Retest| Examiner2| Test      | Retest| Examiner2|
| Shoulder | Flexion   | 96.0(22.6)| 97.3(24.2)| 81.8 (11.8)| 71.5(15.5)| 61.0(20.0)| 90.7(17.2) |
|         | Extension | 112.1(25.1)| 106(24.8)| 96.9(17.0)| 76.5(22.0)| 82.4(25.3)| 102.1(16.8) |
|         | Abduction | 92.3(13.1)| 89.1(19.3)| 79.8(20.2)| 74(16.6)| 68.6(14.0)| 81.2(14.9) |
|         | Adduction | 115.7(13.8)| 108.9(28.1)| 101.5(27.7)| 69.0(20.5)| 75.9(16.4)| 96.7(12.0) |
|         | Internal rotation | 112.5(21.4)| 114.7(18.5)| 109.9(21.0)| 95.2(17.4)| 106(13.6)| 75.6(21.4) |
|         | External rotation | 115.5(22.3)| 115.9(25.6)| 114.2(27.7)| 94.5(26.3)| 91.1(24.1)| 71.6(17.2) |
| Elbow  | Flexion   | 171.4(26.1)| 166.6(24.5)| 147.2(25.4)| 110.2(32.8)| 132.4(28.0)| 125.9(28.0) |
|         | Extension | 125.8(26.8)| 124.6(25.3)| 103.1(19.2)| 107.1(27.2)| 96.7(30.7)| 117.8(37.8) |
| Wrist  | Flexion   | 72.4(13.8)| 69.1(18.3)| 96.5(13.9)| 68.6(15.2)| 84.9(15.2)| 92.6(17.9) |
|         | Extension | 82.5(15.5)| 81.2(15.6)| 76.1 (15.8)| 59.4(14.7)| 74.8(14.4)| 80.2(13.7) |
Figure 2. Bland Altman graphs show inter-examiner reliability between non-fixed (A) and fixed (B) methods.

Table 5. Dynamometry inter-examiner reliability between non-fixed and fixed methods (n = 25).

| Joint          | Movement  | Non-fixed | Fixed          |
|----------------|-----------|-----------|----------------|
|                |           | ICC       | 95% CI         | Reliability* | ICC       | 95% CI         | Reliability* |
| Shoulder       | Extension | 0.86      | [0.66 – 0.89]  | Excellent    | 0.71      | [0.42 – 0.91]  | Very good     |
|                | Abduction | 0.82      | [0.60 – 0.92]  | Excellent    | 0.75      | [0.49 – 0.92]  | Very good     |
|                | Adduction | 0.80      | [0.55 – 0.92]  | Excellent    | 0.83      | [0.52 – 0.96]  | Very good     |
|                | Internal  | 0.92      | [0.79 – 0.97]  | Excellent    | 0.59      | [0.32 – 0.86]  | Good          |
|                | External  | 0.90      | [0.76 – 0.93]  | Excellent    | 0.85      | [0.59 – 0.92]  | Excellent     |
| Elbow          | Flexion   | 0.72      | [0.50 – 0.86]  | Excellent    | 0.62      | [0.34 – 0.84]  | Very good     |
|                | Extension | 0.81      | [0.57 – 0.92]  | Excellent    | 0.81      | [0.54 – 0.91]  | Very good     |
| Wrist          | Flexion   | 0.85      | [0.52 – 0.90]  | Excellent    | 0.30      | [0.05 – 0.63]  | Reasonable    |
|                | Extension | 0.84      | [0.51 – 0.90]  | Excellent    | 0.82      | [0.53 – 0.95]  | Excellent     |

*Reliability classification.
CONCLUSIONS

Reliabilty of assessing muscle strength measurement in the upper limb using Hand-Held dynamometry is excellent for test and retest, as well as for inter-examiner measurement in an assessment protocol in supine position, with previously trained examiners. Comparing fixed and non-fixed methods to assess Hand-Held dynamometry demonstrated superiority of the non-fixed method for inter- and intra-examiner reliability. Only for elbow extensors and external shoulder rotators Hand-Held dynamometry seems to show equivalence between the two methods.

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