Diagnostic accuracy of four handheld dynamometer tests for identifying individuals with hamstring interlimb strength asymmetry

Acurácia diagnóstica de quatro testes com dinamômetro manual para identificar indivíduos com assimetria de força dos isquiotibiais entre os membros

Vinícius de Borba Capaverde
Felipe Xavier de Lima e Silva
Gabriel dos Santos Oliveira
Augusto Camillo Tamujo
João Breno Araujo Ribeiro-Alvares
Bruno Manfredini Baroni *

Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil

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***Correspondence:** bmbaroni@yahoo.com.br

Abstract

Introduction: Handheld dynamometer (HHD) strength tests are widely used in clinical settings. The limb symmetry index (LSI) is a key parameter for guiding rehabilitation progression and return-to-sport decisions following hamstring muscle injuries. However, it remains unclear whether HHD-derived results can accurately identify individuals with interlimb strength asymmetry. **Objective:** To evaluate the diagnostic accuracy of four HHD tests for identifying individuals with hamstring interlimb strength asymmetry, using isokinetic dynamometry as the reference standard. **Methods:** Thirty physically active young men underwent concentric and eccentric isokinetic tests at 60°/seconds and four isometric HHD tests (test A: prone, knee at 90°; test B: prone, knee at 30°; test C: supine, knee at 90°; test D: seated, knee at 90°) in random order on two separate days. LSI values derived from isokinetic dynamometry were used as the reference standard. Interlimb strength asymmetry was defined as LSI < 90% or > 110%. Sensitivity, specificity, predictive values, overall accuracy, and area under the receiver operating characteristic (ROC) curve were calculated. **Results:** LSI values obtained from HHD tests showed no significant or only weak correlations with isokinetic measures. Diagnostic accuracy ranged from 46.7 to 60% for identifying concentric asymmetry and from 46.7 to 63.3% for eccentric asymmetry. The area under the ROC curve values ranged from 0.418 to 0.696, indicating limited discriminatory ability. **Conclusion:** None of the four hamstring HHD tests demonstrated sufficient accuracy to identify individuals with interlimb strength asymmetry when compared with concentric or eccentric assessments performed on an isokinetic dynamometer.

Keywords: Knee flexor muscles. Limb symmetry index. Isometric. Isokinetic.

Resumo

Introdução: *Testes de força com dinamômetro manual (*DM*) são amplamente utilizados em contextos clínicos. O índice de simetria entre membros (ISM) é um parâmetro-chave para orientar a progressão da reabilitação e as decisões de retorno ao esporte após lesões dos músculos isquiotibiais. Entretanto, ainda não está claro se os resultados derivados do DM conseguem identificar com precisão indivíduos com assimetria de força entre membros.* ***Objetivo:*** *Avaliar a acurácia diagnóstica de quatro testes de DM para identificar indivíduos com assimetria de força dos isquiotibiais entre membros, utilizando a dinamometria isocinética como padrão de referência.* ***Métodos:*** *Trinta homens jovens fisicamente ativos foram submetidos a testes isocinéticos concêntrico e excêntrico a 60°/segundos, bem como a quatro testes isométricos com DM (teste A: prono, joelho a 90°; teste B: prono, joelho a 30°; teste C: supino, joelho a 90°; teste D: sentado, joelho a 90°), em ordem aleatória, em dois dias distintos. Os valores de ISM obtidos na dinamometria isocinética foram utilizados como padrão de referência. A assimetria de força entre membros foi definida como ISM <90% ou >110%. Foram calculados sensibilidade, especificidade, valores preditivos, acurácia global e a área sob a curva característica de operação do receptor (ROC).* ***Resultados:*** *Os valores de ISM obtidos nos testes com DM não apresentaram correlações significativas ou apresentaram apenas correlações fracas com as medidas isocinéticas. A acurácia diagnóstica variou de 46,7 a 60% para a identificação de assimetria concêntrica e de 46,7 a 63,3% para assimetria excêntrica. Os valores de área sob a curva ROC variaram de 0,418 a 0,696, indicando capacidade discriminatória limitada.* ***Conclusão:*** *Nenhum dos quatro testes de HHD para isquiotibiais demonstrou acurácia suficiente para identificar indivíduos com assimetria de força entre membros quando comparados às avaliações concêntricas ou excêntricas realizadas em dinamômetro isocinético.*

Palavras-chave: *Músculos flexores do joelho. Índice de simetria entre membros. Isométrico. Isocinético.*

Introduction

Maximum strength is closely linked to human physical performance, influencing a range of outcomes from the disability status of older adults[1] to athletic success of elite athletes.[2] Accordingly, muscle-strengthening interventions are widely recommended to improve health across different populations, including young individuals, adults,[4] older adults,[5] and those with various health conditions.[6-8] In the context of musculoskeletal injury rehabilitation, enhancing strength is a typical goal in conservative approaches[9,10] and following orthopedic surgeries.[11,12] Furthermore, muscle-strengthening interventions have been proven effective in preventing acute and overuse sport injuries.[13,14] Therefore, muscle strength seems to play a crucial role in promoting health, enhancing sports performance, facilitating rehabilitation, and preventing musculoskeletal injuries.

Hamstring muscle strength has received increasing attention from orthopedic and sports physical therapists. Given that strength deficits are widely perceived by clinicians as key risk factors for hamstring strain injuries (HSIs),[15,16] a perspective supported by some cohort studies,[17-21] assessing hamstring strength is essential for identifying athletes who may be more susceptible. Weekly strength monitoring appears to contribute meaningfully to reducing HSI risk in football players,[22] further reinforcing the relevance of hamstring strength testing. Such assessments are also strongly endorsed by clinical practice guidelines for HSI rehabilitation,[23] as they help estimate recovery timelines, monitor rehabilitation progress, and guide return-to-sport decisions.[24-26] In addition, hamstring strength testing is also recommended in return-to-sport decision-making following knee injuries, particularly in individuals who have undergone anterior cruciate ligament (ACL) reconstruction.[27] Therefore, valid and reliable tests are essential for accurately assessing hamstring strength.

The isokinetic dynamometer, regarded as the gold standard for evaluating muscle capacity in humans through torque measurements, is an electromechanical device with high test–retest reliability.[28] Nevertheless, its high cost, lack of portability, and time-consuming protocols make isokinetic dynamometer assessments impractical for most sports teams and rehabilitation centers. In contrast, handheld dynamometers (HHDs) represent a feasible alternative in clinical settings due to their lower cost, portability, and shorter testing protocols.[29] HHD tests demonstrate moderate to high reliability depending on the body position and joint angle assessed.[26,30-34]

The equivalence of muscle strength between the limbs is a key outcome in clinical decision-making. Although several equations have been proposed for its calculation, the Limb Symmetry Index (LSI) is typically expressed

as the percentage of strength produced by the theoretically weaker limb (e.g., injured limb) relative to the stronger one (e.g., uninjured limb).[35] A 90% LSI cutoff is traditionally applied to identify individuals with poor interlimb strength symmetry — hereafter referred to as interlimb strength asymmetry — regardless of the assessment method used (e.g., isokinetic dynamometry or HHD tests).[35] However, from a clinical perspective, it is important to determine whether results obtained with HHD can accurately identify individuals with interlimb strength asymmetry as determined by the gold-standard isokinetic dynamometry. Therefore, this study aimed to evaluate the diagnostic accuracy of four HHD tests for identifying individuals with hamstring interlimb strength asymmetry, using isokinetic dynamometry as the reference standard.

Methods

In this cross-sectional study, volunteers completed two maximal strength testing sessions: one using an isokinetic dynamometer and the other using an HHD. Data were collected at the Physiotherapy Laboratory of the Federal University of Health Sciences of Porto Alegre (Porto Alegre, Brazil) between August 2023 and March 2024. This study was approved by the institutional ethics committee (#5.949.807), and all volunteers provided informed consent before participating in the study.

Participants

Volunteers were recruited through advertisements on social media linked to the university community. To be eligible for inclusion, volunteers had to be male, aged between 18 and 35 years, and regularly engaged in vigorous physical exercise at least twice per week (e.g., individual sports, team sports, resistance training). Participants declared that they were currently free from any injuries and were fit to undergo the tests. Athletes were excluded if they: had sustained a knee time-loss injury within the past year; had sustained a HSI within the past six months; or were unable to attend the testing sessions for any reason.

A priori sample size estimation was based on previous studies investigating the validity and reliability of handheld dynamometry compared to isokinetic dynamometry, which have typically included samples of approximately 30 participants.[36-38] These studies reported moderate to high associations between measurement methods, suggesting that similar sample sizes are sufficient to detect clinically relevant relationships.

Procedures

Isokinetic dynamometry and HHD tests were conducted on two separate days, 4 to 7 days apart. Participants were instructed to avoid any vigorous physical activities involving the lower limbs for up to 48 hours before the testing sessions. The researchers conducting the isokinetic dynamometry were blinded to the participants' performance in the HHD tests, and the researcher conducting the HHD tests was likewise blinded to the isokinetic dynamometry results. The session order was randomized, with half of the participants starting with the isokinetic dynamometry session and the other half beginning with the HHD testing session. On the first day, all participants completed a medical history review and eligibility assessment. In both sessions, participants performed a general warm-up consisting of 10 minutes on a stationary bike.

Isokinetic dynamometry

A standardized isokinetic testing protocol was conducted for assessing concentric and eccentric knee flexor peak torques on the Biodex System 4 Pro isokinetic dynamometer (Biodex Medical Systems, USA).[39] All assessments were conducted by two physiotherapists with six years of experience in isokinetic testing across a series of projects within our research group.

After the general warm-up, participants were positioned seated on the isokinetic dynamometer according to the manufacturer's recommendations. Participants performed ten concentric knee flexion/extension repetitions at 90°/s with a submaximal effort level for specific warm-up and familiarization with the equipment. Thereafter, they performed two attempts of three consecutive maximum contractions in the concentric-concentric mode (60°/s; 0–90° of knee flexion) and two attempts of three consecutive maximal contractions in the eccentric-eccentric mode (60°/s; 30–90° of knee flexion). Attempts were separated by one minute of rest. Verbal encouragement was provided by the researchers during all repetitions to ensure maximal effort from the participants. The highest concentric and eccentric torque values were considered representative of maximal concentric and eccentric strength and were used for statistical analyses.

Handheld dynamometer tests

All assessments were performed using a calibrated HHD (SP Tech, Medeor Medtech, Florianópolis, Santa Catarina, Brazil). Participants were assessed in four positions, labeled as tests A, B, C, and D (Figure 1). Tests A, B, and C were performed with the subject lying on a physiotherapy table, while test D was conducted with the subject seated on a jump box.

In test A,[33] the participants were assessed lying prone, with the hip neutral and the knee flexed to approximately 90° (0° = full knee extension). A strap was applied across the participants' gluteal region and secured underneath the physiotherapy table to stabilize the the participants and prevent compensatory movements during the test. The participants were asked to flex the knee while the examiner held the HHD just above the malleoli while avoiding any movement during the test. Test B[30] was similar to test A except for the knee, flexed to approximately 30° (0° = full knee extension). In test C,[26] the participants were assessed while lying supine, with the hip and knee flexed to approximately a 90° angle. A belt was used to ensure that the hip remained fixed during the test. The participants were asked to flex the knee against the HHD, which was positioned between their heel and a jump box placed on the physiotherapy table. Wedges were used on the box to ensure the knee was approximately at 90°. In test D,[32] the participants were assessed sitting on a jump box with the hip and knee flexed to approximately 90°. The participants were asked to press the HHD positioned between the heel and the box.

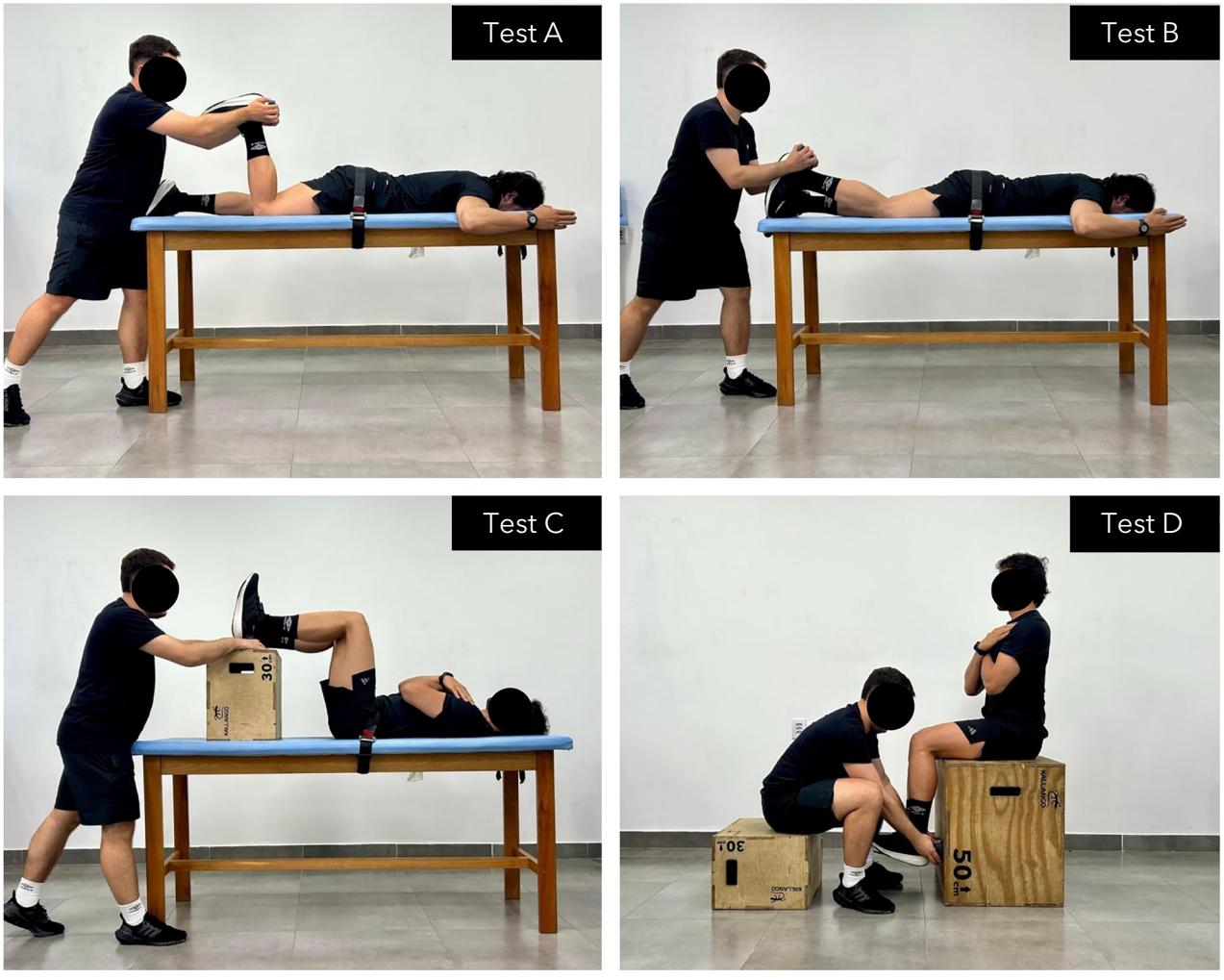

Figure 1 - Handheld dynamometer hamstring tests.

All HHD tests were conducted by a single physiotherapist. In addition to the specific training for this study, the physiotherapist had five years of prior experience with HHD, routinely using the device in their clinical practice at a top-tier Brazilian football academy and a private sports rehabilitation center. The order of the HHD tests was randomized using the website random.org. In each position, participants performed three maximal isometric contractions, each lasting five seconds, with a 30-second recovery interval between attempts. Verbal encouragement was provided during all repetitions to promote maximal effort. The highest force value measured in each position was considered for statistical analyses. Torque values were calculated by multiplying force values by the lever arm length, defined as the distance between the knee joint and the point of HHD application for each participant.

Statistical analysis

Descriptive statistics were used to describe the participants' characteristics and outcomes through mean, standard deviation (SD), and 95% confidence interval (CI). The LSI was calculated using the following equation: (non-dominant limb/dominant limb) × 100.[35] Participants were classified as positive (i.e., LSI < 90% or > 110%) or negative (i.e., LSI ≥ 90% and ≤ 110%) based on the isokinetic tests. Participants were then classified as true positives or true negatives when the HHD test results aligned with the isokinetic test results, and as false positives or false negatives when the HHD test results conflicted with those of the isokinetic test.

The diagnostic accuracy of the HHD tests compared to isokinetic tests for identifying individuals with interlimb strength asymmetry was evaluated by calculating sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy. Sensitivity measures the proportion of actual positives that are correctly identified (Equation 1). Specificity measures the proportion of actual negatives that are correctly identified (Equation 2). PPV measures the proportion of positive test results that are true positives (Equation 3). NPV measures the proportion of negative test results that are true negatives (Equation 4). Overall accuracy measures the proportion of all test results that are correctly identified (Equation 5). In the following equations, TP denotes true-positive cases, TN denotes true-negative cases, FP denotes false-positive cases, and FN denotes false-negative cases.

Equation 1: Sensitivity = TP ÷ (TP + FN)

Equation 2: Specificity = TN ÷ (TN + FP)

Equation 3: PPV = TP ÷ (TP + FP)

Equation 4: NPV = TN ÷ (TN + FN)

Equation 5: Overall accuracy = (TP + TN) ÷ (TP + TN + FP + FN)

The area under the curve (AUC) of receiver operating characteristic (ROC) curves was calculated to determine the inherent ability of each HHD test to discriminate between those with and without interlimb strength asymmetry based on isokinetic tests. An AUC of 0.5 indicates no discriminatory ability, while an AUC of 1 indicates perfect discrimination.[40] Additionally, Bland-Altman analysis was performed to assess the agree-ment between HHD- and isokinetic-derived LSI values, including the calculation of mean bias and 95% limits of agreement.

Results

Thirty physically active men (mean age 27 ± 5 years; body mass 80 ± 10 kg; height 177 ± 5 cm; body mass index 25 ± 3 kg/m²) completed the full study schedule. Participants were regularly engaged in strength training, functional training, and/or sports such as football, seven-a-side football, futsal, volleyball, footvolley, tennis, boxing, and running. The weekly frequency of their activity was distributed as follows: two exposures (13%), three (20%), four (20%), five (40%), and six (7%).

Table 1 presents the peak torque and force values, as well as the LSI, measured with the two isokinetic tests and the four isometric HHD tests. LSI values measured using isokinetic dynamometry showed no significant correlations with those obtained from the HHD tests, except for a significant but weak correlation between Test B and concentric LSI (Figure 2).

Diagnostic accuracy for HHD tests ranged between 46.7% and 60% for identifying individuals with concentric asymmetry and between 46.7 and 63.3% for th

ose with eccentric asymmetry, as shown in Table 2. ROC curve analysis demonstrated the limited discriminatory ability of HHD tests, with AUC between 0.418 and 0.696 (Table 3; Supplementary Material: Figure 1). Bland-Altman analysis showed small mean differences for concentric LSI but wide limits of agreement across all comparisons, with larger systematic differences observed for eccentric LSI, indicating poor agreement between methods (Table 3; Supplementary Material: Figure 2).

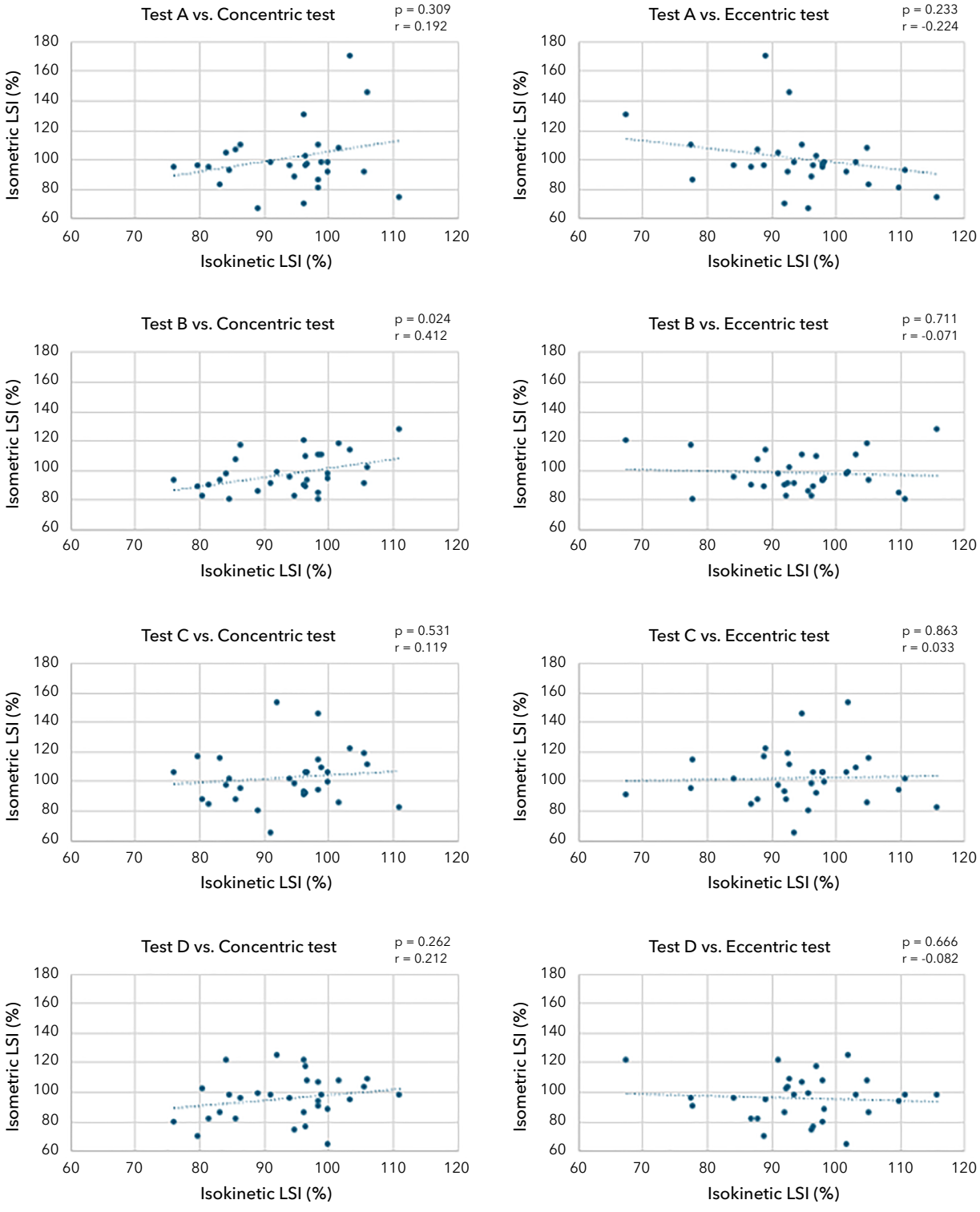

Figure 2 - Scatter plots showing correlations between limb symmetry index (LSI) from the isometric handheld dynamometer tests and isokinetic tests.

Table 1 - Measures from the isokinetic tests and the isometric handheld dynamometer (HHD) tests

Tests	Peak torque (Nm) or force (N)		Limb symmetry index (%)	
	Mean ± SD	95% CI	Mean ± SD	95% CI
Isokinetic concentric				
Peak torque	132 ± 28	125 to 139	94 ± 9	90 to 97
Isokinetic eccentric				
Peak torque	226 ± 77	206 to 246	95 ± 10	91 to 99
HHD test A				
Peak force	172 ± 34	163 to 180	101 ± 29	90 to 112
Peak torque	76 ± 16	72 to 80	-	-
HHD test B				
Peak force	276 ± 51	263 to 289	98 ± 13	93 to 103
Peak torque	122 ± 22	117 to 128	-	-
HHD test C				
Peak force	298 ± 55	284 to 312	102 ± 18	95 to 109
Peak torque	132 ± 26	126 to 139	-	-
HHD test D				
Peak force	213 ± 43	202 to 224	96 ± 15	90 to 101
Peak torque	95 ± 20	89 to 100	-	-

Note: CI = confidence interval; N = Newtons; Nm = Newton-meters; SD = standard deviation.

Table 2 - Diagnostic accuracy of the isometric handheld dynamometer (HHD) tests in relation to the isokinetic tests

Tests	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Overall accuracy (%)
Isokinetic concentric					
vs. HHD test A	36.4 (15.2 - 64.6)	52.6 (31.7 - 72.7)	30.8 (12.7 - 57.6)	58.8 (36.0 - 78.4)	46.7 (30.2 - 63.9)
vs. HHD test B	54.5 (28.0 - 78.7)	52.6 (31.7 - 72.7)	40.0 (19.8 - 64.3)	66.7 (43.7 - 83.7)	53.3 (36.1 - 69.8)
vs. HHD test C	63.6 (35.4 - 84.8)	57.9 (36.3 - 77.0)	46.7 (24.8 - 69.9)	73.3 (48.0 - 89.1)	60.0 (42.3 - 75.4)
vs. HHD test D	54.5 (28.0 - 78.7)	57.9 (36.3 - 77.0)	57.9 (28.0 - 78.7)	68.8 (44.4 - 85.8)	56.7 (39.2 - 72.6)
Isokinetic eccentric					
vs. HHD test A	40.0 (16.3 - 67.7)	55.0 (31.5 - 76.9)	30.8 (12.7 - 57.6)	64.7 (41.3 - 82.7)	50.0 (32.4 - 67.6)
vs. HHD test B	70.0 (39.7 - 89.2)	60.0 (36.1 - 80.9)	46.7 (24.8 - 69.9)	80.0 (54.8 - 93.0)	63.3 (45.5 - 78.1)
vs. HHD test C	60.0 (31.3 - 83.2)	55.0 (31.5 - 76.9)	40.0 (19.8 - 64.3)	73.3 (48.0 - 89.1)	56.7 (39.2 - 72.6)
vs. HHD test D	40.0 (16.3 - 67.7)	50.0 (27.2 - 72.8)	28.6 (11.7 - 54.6)	62.5 (38.6 - 81.5)	46.7 (30.2 - 63.9)

Note: Values are presented as percentages, with 95% confidence intervals shown in parentheses. NPV = negative predictive value; PPV = positive predictive value.

Table 3 - Receiver operating characteristic (ROC) and Bland–Altman analyses for agreement and diagnostic performance of handheld dynamometer (HHD) tests compared with isokinetic dynamometry

Tests	ROC curve	Bland–Altman analysis		
	AUC	MD +1.96 SD	MD	MD -1.96 SD
Isokinetic concentric				
vs. HHD test A	0.696	1.340	0.694	0.048
vs. HHD test B	0.564	0.800	0.113	-0.573
vs. HHD test C	0.670	0.656	-0.004	-0.664
vs. HHD test D	0.606	1.080	0.471	-0.137
Isokinetic eccentric				
vs. HHD test A	0.418	3.679	1.867	0.054
vs. HHD test B	0.442	3.071	1.286	-0.499
vs. HHD test C	0.539	2.988	1.168	-0.651
vs. HHD test D	0.598	3.250	1.644	0.038

Note: AUC = area under the curve; MD = mean difference; SD = standard deviation.

Discussion

This was the first study to evaluate the diagnostic accuracy of multiple hamstring HHD tests, using concentric and eccentric isokinetic dynamometry as the gold standard. The main findings indicated that none of the HHD tests demonstrated sufficient diagnostic accuracy to identify individuals with interlimb strength asymmetry when compared with concentric or eccentric assessments performed on an isokinetic dynamometer.

The diagnostic accuracy metrics indicate that HHD tests have limited ability to correctly classify individuals with interlimb strength asymmetry. Sensitivity and specificity values were generally low to moderate and highly variable across tests, while overall accuracy ranged from 46.7% to 63.3%, indicating a substantial rate of misclassification. Although some tests showed relatively higher sensitivity or NPV, these findings were inconsistent and accompanied by wide confidence intervals, indicating considerable uncertainty. In line with these results, ROC analysis demonstrated limited discriminatory ability, with AUC values ranging from poor to, at best, modest, while Bland–Altman analyses revealed considerable variability between methods, with wide limits of agreement and the presence of systematic bias in some comparisons. Together, these findings indicate that HHD tests show poor agreement with isokinetic dynamometry and limited accuracy for detecting interlimb strength asymmetry at the individual level.

The four HHD tests analyzed in this study are widely used in clinical settings, and their test-retest reliability has been previously demonstrated, with intraclass correlation coefficient (ICC) values ranging from 0.71 to 0.92.[26,30-34] These values are slightly lower than those reported for isokinetic dynamometry, which shows ICC values ranging from 0.86 to 0.96 and from 0.85 to 0.92 for concentric and eccentric assessments of hamstring peak torque, respectively.[28] It is plausible that the evaluator's need to manually stabilize the device in some HHD tests negatively affects reproducibility. However, it is worth noting that tests C and D do not require the evaluator to apply resistance to maintain the isometric contraction, as the dynamometer is pressed against a box. This configuration reduces evaluator dependency and facilitates test execution for clinicians, particularly in contexts requirring multiple con-secutive assessments, such as sports team monitoring. Nevertheless, the diagnostic accuracy of tests C and D was not superior to that observed for tests A and B.

Interlimb strength asymmetry has been widely investigated due to the potential impact of muscle imbalances on performance and injury risk.[35] Its association with injury risk has been highlighted in a cohort study of professional football players,[41] in which those presenting preseason isokinetic strength asymmetries who did not undergo compensatory training showed an increased risk of HSIs throughout the season, whereas players who received compensatory training until strength normalization

exhibited a risk comparable to those without preseason asymmetries. De Vos et al.[42] found that an isometric hamstring strength deficit at return to sport was a significant independent predictor of re-injury in athletes who sustained a HSI, supporting the widespread adoption of strength testing as a discharge criterion by clinicians.[43] Therefore, given the clinical relevance attributed to interlimb strength asymmetry, the findings of the present study warrant careful consideration.

None of the four hamstring HHD tests demonstrated sufficient diagnostic accuracy to identify individuals with interlimb strength asymmetry, as determined by isokinetic testing. From a practical standpoint, this indicates that the choice of strength test included in an assessment battery may influence clinical decision-making. For example, an athlete who meets the LSI ≥ 90% criterion on an isometric HHD test — and would therefore be cleared to return to sport following an injury — might not meet this criterion if assessed using the gold-standard isokinetic dynamometer, and vice versa. Therefore, in contrast to the acceptable levels of diagnostic accuracy previously reported for quadriceps HHD tests,[40,44] our findings suggest that LSI values derived from hamstring HHD tests are not suitable for screening isokinetic strength asymmetries and should not be used as reliable substitutes for isokinetic dynamometry.

Some limitations of the present study should be acknowledged. First, the study was conducted with healthy young men who regularly participated in sports, which limits the generalizability of our findings to other populations, such as individuals undergoing rehabilitation after musculoskeletal injuries or elite athletes. The inclusion of a non-injured population likely resulted in a lower prevalence and magnitude of interlimb strength asymmetry, which may have influenced diagnostic accuracy metrics. Therefore, caution is warranted when extrapolating these findings to clinical populations. Future studies should investigate the diagnostic accuracy of HHD tests in individuals undergoing rehabilitation, especially those in the final stages of return to sport, in whom asymmetries are typically more pronounced and clinically relevant. Second, volunteers executed the HHD and isokinetic tests on different days to avoid the detrimental effect of acute fatigue from one protocol on the other. However, the impact of external factors (e.g., sleep, rest, nutrition, motivation) on performance during each data collection day should not be overlooked.

Lastly, isometric strength measurements using HHD can be highly dependent on the evaluator's ability to counteract the force exerted by the participant. This examiner-dependent nature, although a potential confounding factor in HHD tests A and B, also reflects the real-world conditions in which these tests are typically performed in clinical practice, where such influence is inherent and unavoidable.

Conclusion

This study found that none of the four hamstring HHD tests demonstrated sufficient accuracy to identify individuals with interlimb strength asymmetry when compared with concentric or eccentric isokinetic dynamometry as the reference standard. Notably, even the tests with reduced examiner dependency (tests C and D), which incorporate external stabilization, did not demonstrate superior diagnostic performance. This finding suggests that the limited accuracy observed is unlikely to be explained solely by examiner-related factors, but may instead reflect inherent limitations of isometric testing in capturing the dynamic muscle performance assessed by isokinetic dynamometry. Therefore, clinicians should exercise caution when using hamstring HHD-derived LSI values to guide decisions, as reliance on these tests alone may lead to misclassification of interlimb strength asymmetry when compared with gold-standard isokinetic dynamometry.

Authors´ contributions

VBC and BMB contributed to the conceptualization and methodology. VBC, FXLS, and GSO contributed to the investigation and data curation. VBC and JBARA contributed to the formal analysis. VBC was responsible for project administration and writing the original draft, while BMB was responsible for supervision. All authors participated in the discussion of the results, review and editing of the manuscript, and approved the final version.

Data availability statement

Data are available from the corresponding author upon reasonable request.

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Supplementary Material

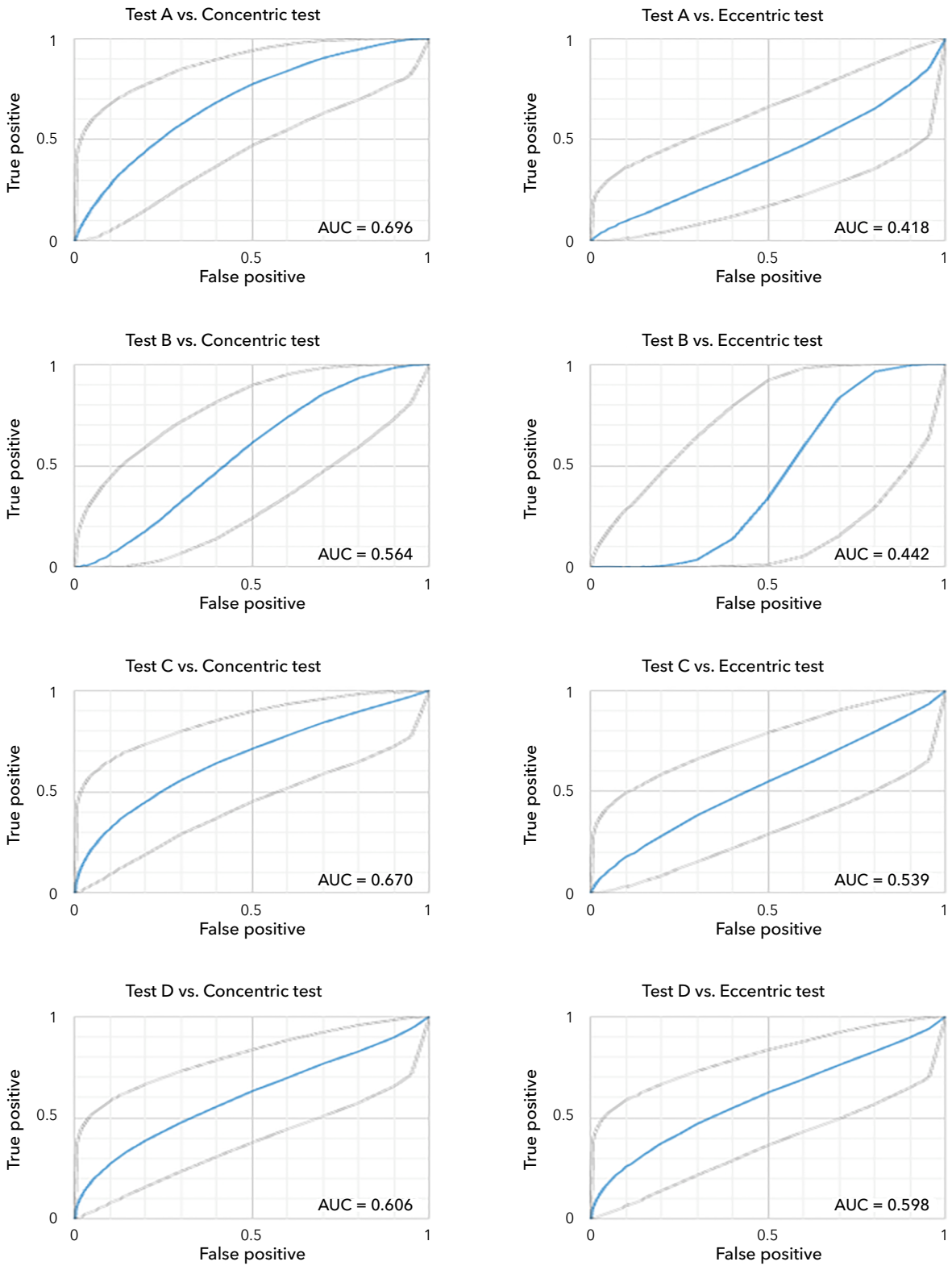

Figure 1 - Receiver operating characteristic (ROC) curves comparing isometric handheld dynamometer tests (A, B, C, and D) with isokinetic (concentric and eccentric) tests. Blue curves represent test performance and gray diagonal lines represent chance level.

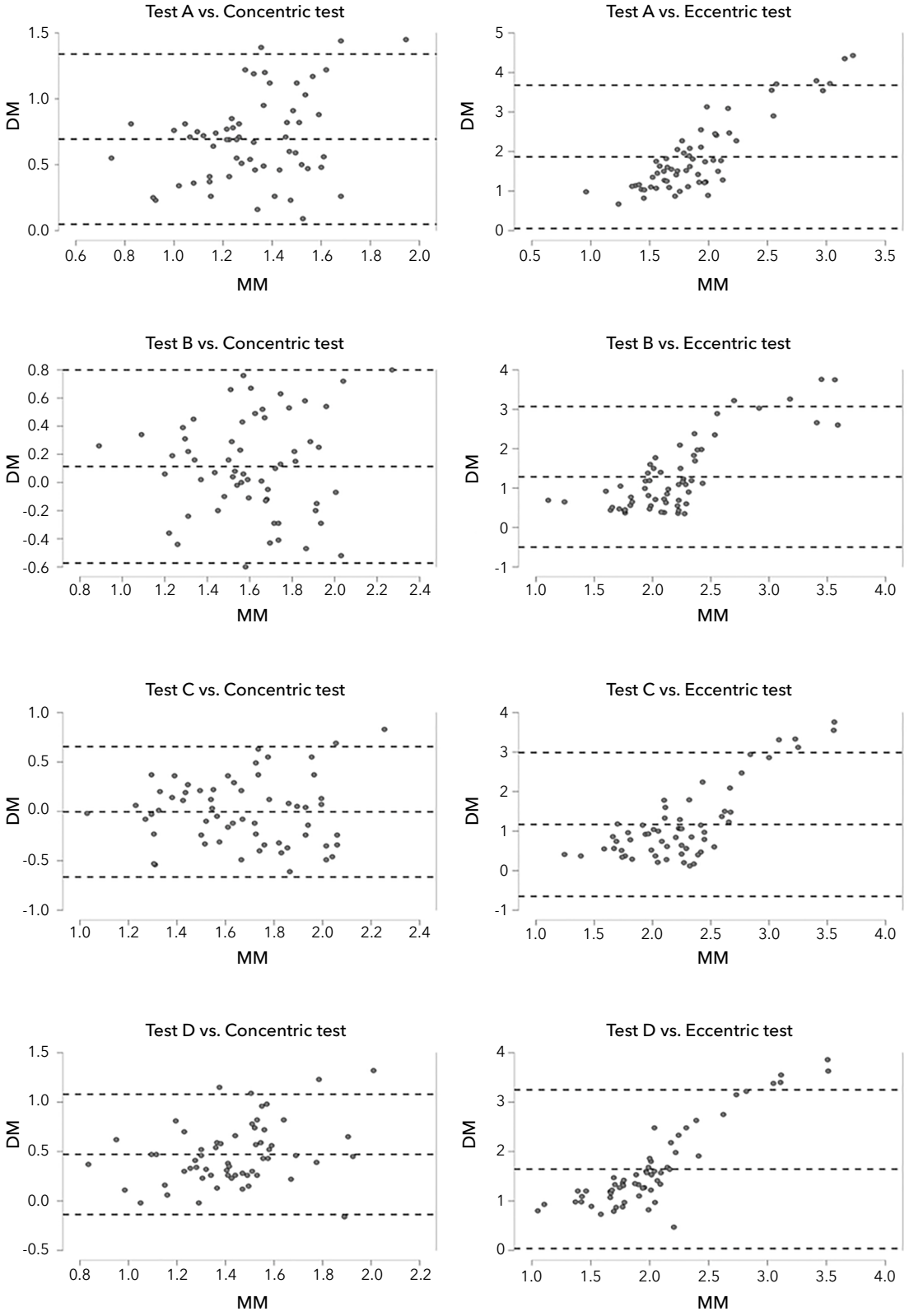

Figure 2 - Bland–Altman plots comparing isometric handheld dynamometer tests (A, B, C, and D) with isokinetic (concentric and eccentric) tests. Dots represent individual differences between methods plotted against the mean of measurements (MM). Dashed horizontal lines represent the mean difference and the limits of agreement (±1.96 standard deviation). DM = difference of measurements.