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Low-Cost Continuous Force Measurement Systems for Quadriceps and Hamstrings Strength Assessment: A Scoping Review and Perspective for Clinical Application in Physiotherapy

Aparna A. Bachkaniwala[1], Vivek H. Ramanandi[2], Anjan R. Desai[3]

[1]Assistant Professor, Department of Neurological Physiotherapy, SPB Physiotherapy College, Surat, Gujarat (India); [2]Associate Professor & HOD, Department of Neurological Physiotherapy, SPB Physiotherapy College, Surat, Gujarat (India); [3]Professor & Principal, SPB Physiotherapy College, Surat, Gujarat (India).

ABSTRACT

Accurate assessment of muscle strength is vital in physiotherapy for diagnosis, prognosis, and evaluating interventions. While methods like manual muscle testing (MMT), handheld dynamometry (HHD), and isokinetic dynamometry exist, limitations such as subjectivity (MMT), examiner influence (HHD), cost, and lack of portability (isokinetic/fixed systems) persist. This scoping review examines the literature on quadriceps and hamstrings strength assessment methods, focusing on the potential, development, and validation requirements of low-cost Continuous Force Measurement Systems (CFMS). A literature search was conducted using PubMed, MEDLINE, and Google Scholar for English-language studies published between January 2000 and December 2024. Data regarding study design, assessment methods, equipment, psychometric properties, and key findings were extracted and synthesized. The review confirmed the limitations of existing methods and indicated a growing interest and feasibility in developing low-cost CFMS using readily available sensors and microcontrollers. These systems offer the potential for continuous data capture, including Rate of Torque Development (RTD), providing deeper insights into neuromuscular function than peak force alone. Preliminary studies demonstrate promising results for custom-built, affordable systems. Low-cost CFMS presents a promising avenue to enhance quantitative muscle strength assessment in physiotherapy while combining the objectivity with affordability and portability, facilitating wider adoption in clinical practice, education, and research.

Key Words: Dynamometry, Hamstrings, Low-Cost Technology, Muscle Strength, Physiotherapy, Quadriceps.

INTRODUCTION

Muscle strength assessment is fundamental in physiotherapy, guiding clinical decisions related to neurological deficits, functional capacity, and overall physical health.[1] Objective and reliable strength assessment is essential for diagnosing weakness, monitoring disease progression or recovery, and evaluating therapeutic interventions.[2] While manual muscle testing (MMT) is commonly used due to its simplicity, it has limitations including subjectivity and reduced sensitivity, especially in differentiating higher strength grades.[3,4]

Quantitative tools like handheld dynamometers (HHDs), fixed dynamometry systems, and isokinetic dynamometers have been developed to address these limitations.[5,6] HHDs offer improved objectivity and reliability compared to MMT; however, examiner strength can influence measurements.[7,8] Fixed systems offer high accuracy by standardizing positioning and minimizing examiner influence but are often costly and lack portability.[6,8] Isokinetic dynamometry remains the gold standard for comprehensive dynamic and isometric assessment but its high cost and complexity restrict its use primarily to research and specialized centres.[9] This highlights the need for accessible, accurate, and affordable strength measurement tools for broader clinical and research applications, particularly in resource-limited settings. Recent technological advancements have spurred the development of low-cost force measurement systems.[10,11]

This scoping review aims to synthesize current quadriceps and hamstrings strength assessment methods, evaluate the evidence for low-cost Continuous Force Measurement Systems (CFMS), and discuss their implications for physiotherapy practice. The CFMS concept aims to combine the

Corresponding Author:
Vivek H. Ramanandi, SPB Physiotherapy College, Affiliated to Veer Narmad South Gujarat University, Mora Bhagal, Rander Road, Surat. Gujarat (India); E-mail: vivekramanandi1@gmail.com

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objectivity and continuous data of fixed dynamometry with improved affordability and portability.

MATERIALS & METHODS

A scoping review was conducted using PubMed, MEDLINE, and Google Scholar to identify relevant studies published in English from January 2000 to December 2024. Search terms included combinations of "muscle strength assessment," "dynamometry," "force measurement," "quadriceps strength," "hamstrings strength," "maximal voluntary isometric contraction," "rate of force development," "continuous force measurement," "low-cost strength assessment," and "physiotherapy". Reference lists of included articles and relevant reviews were also screened.

Studies were included if they focused on human muscle strength assessment methods, particularly for quadriceps or hamstrings; described the development, testing (reliability, validity), or application of force measurement systems; discussed the psychometric properties or clinical utility of these tools; or specifically addressed low-cost alternatives to commercial dynamometers. Studies were excluded if they focused solely on animal models, upper limb, or trunk strength without lower limb comparison, were not available in English, or were conference abstracts or non-peer-reviewed sources.

Two authors independently screened titles and abstracts, and full texts of potentially relevant articles were retrieved and assessed. Disagreements were resolved through discussion and consensus, involving a third reviewer if needed. A data extraction form, guided by COSMIN checklist principles, was used to collect data on study characteristics, participant details, muscle groups assessed, assessment tools used, equipment details (for novel systems), reliability measures (Intraclass Correlation Coefficient [ICC], Standard Error of Measurement [SEM], Coefficient of Variation [CV]), validity measures, and key findings regarding feasibility, cost, or clinical applicability.[12] The extracted data were synthesized narratively.

RESULTS

The literature search yielded 39 potentially relevant articles, of which 12 met the inclusion criteria after screening and full-text review. The synthesis of findings is presented below in table-1.

Current Muscle Strength Assessment Methods: Capabilities and Limitations

Manual Muscle Testing (MMT) is prevalent but subjective and has ceiling effects, limiting its ability to detect subtle strength changes.[3,4] Handheld Dynamometry (HHD) offers improved objectivity and reliability (ICCs often >0.80).[2,7] However, accuracy can be affected by examiner strength, especially in assessing the strong muscle groups, potentially underestimating force.[8] Stabilization and consistent technique are crucial for HHD but can be challenging.[13] Fixed dynamometry systems provide high accuracy and reliability by standardizing positioning, but they are costly, lack portability, and often require specialized setup.[6,8] Isokinetic dynamometry is considered a gold standard, providing reliable and valid measures of various strength parameters.[2,9] However, its high cost, complexity, and lack of portability limit its clinical use.[5]

Development and Potential of Low-Cost CFMS

The review identified evidence supporting the feasibility of developing affordable force measurement systems. These systems typically use low-cost sensors (e.g., strain gauges, load cells), amplifiers, microcontrollers (e.g., Arduino, Raspberry Pi), and data acquisition interfaces.[10,11] Irmak and Irmak (2014) demonstrated a functional continuous force measurement tool for under $100 USD.[11] Bhaskar et al. (2007) developed low-cost EMG systems, highlighting the potential for affordable electronic design in physiological measurement.[1]

Potential advantages of low-cost CFMS include affordability, objectivity, continuous measurement, portability, and digital data output.[11] Affordability increases accessibility compared to already available commercial systems, while objectivity provides quantitative force data, thereby reducing subjectivity. Continuous measurement and digital data facilitate capturing the entire force-time curve, allowing for assessment of force steadiness, fatigue, and Rate of Torque Development (RTD).[1] Portability and digital data enables use in various settings while allowing for easy storage, analysis, and tracking.

Rate of Torque Development (RTD)

Recent literature emphasizes the functional importance of RTD, which is the rate at which muscles generate force.[1] It is crucial for activities requiring rapid force production and provides insights beyond peak strength production.[14] Early-phase RTD (<100ms) is linked to neural drive, while later-phase RTD reflects intrinsic muscle properties.[1] Isokinetic systems can accurately measure RTD, but HHDs have limitations, especially for early RTD, due to lower sampling rates and manual application variability. CFMS with adequate sampling frequency (>500 Hz) could accurately capture RTD, offering comprehensive neuromuscular assessment at a lower cost.[1]

Accuracy and Reliability Considerations

Validation is critical for any new measurement device. Validation for CFMS should include concurrent validity (comparison against a gold standard), reliability (test-retest reliability), and sensitivity to change.

DISCUSSION

This scoping review highlights a persistent gap between the need for objective muscle strength assessment in routine physiotherapy and the limitations of currently available tools, particularly concerning cost and portability. The development of low-cost Continuous Force Measurement Systems (CFMS) emerges as a viable and promising solution to bridge this gap.

Synthesizing the Potential of Low-Cost CFMS

CFMS can potentially make it easy to use quantitative strength assessment by integrating affordable sensor technology with accessible computing platforms. Continuous force data, including RTD, is a significant advantage.[1] Accurate RTD measurement provides valuable insights into neuromuscular function, potentially aiding in early detection of deficits and tracking training adaptations.[14] This is relevant in rehabilitation and sports physiotherapy. Studies have demonstrated the technical and cost-effectiveness of such systems. This is crucial for various settings, including physiotherapy education, outpatient clinics, and community-based rehabilitation, especially in resource-constrained environments.[1, 11]

Implications for Physiotherapy Practice, Education, and Research

In clinical practice, CFMS can enable precise tracking of patient progress, objective evaluation of intervention efficacy, and identification of subtle strength deficits. RTD measurement can enhance assessment of functional recovery and fall risk. In education, affordable CFMS devices can provide students with hands-on experience in quantitative assessment. In research, low-cost CFMS can facilitate larger-scale studies on muscle strength and RTD across diverse populations.

Key Considerations and Future Directions

Successful implementation of any newer technique or technology requires addressing several factors: rigorous validation, standardization of testing protocols, user-friendly software, durability and calibration of components, and integration with other technologies. Future research should focus on comparisons with established methods, longitudinal studies, validation in diverse patient populations, and usability testing.[15-17]

Limitations

This review is subject to publication bias and may have missed some relevant studies, particularly non-English or grey literature. The review primarily focuses on the potential and requirements for CFMS, as widespread validated systems are not yet common.

CONCLUSION

Low-cost Continuous Force Measurement Systems (CFMS) have the potential to transform muscle strength assessment in physiotherapy. By offering an affordable, objective, and portable alternative that captures continuous force data, including RTD, CFMS can enhance clinical decision-making, education, and research. Addressing validation, standardization, and user-centric design is crucial for realizing this technology's full potential.

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Conflict of Interest

The authors declare no conflict of interest.

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Authors' Contribution

Aparna A. Bachkaniwala contributed to the conception and design of the study, conducted the literature search, data extraction, and drafted the manuscript. Vivek H. Ramanandi assisted with methodological guidance, data analysis, interpretation of results, and critically reviewed and revised the manuscript for important intellectual content. Anjan R. Desai supervised the project, and contributed to the final revision and approval of the manuscript. All authors read and approved the final version of the manuscript.

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Table 1: Comparison of Muscle Strength Assessment Methods

Assessment Method	Objectivity	Reliability	Sensitivity to Change	Examiner Influence	Portability	Cost	Continuous Measurement Capability	Rate of Torque Development (RTD) Measurement	Typical Applications
Manual Muscle Testing (MMT)	Moderate	Moderate	Low	High	Low	Low	No	No	Clinical Assessment
Hand Held Dynamometry (HHD)	High	High	Moderate	Moderate	Medium	Medium	No	No	Research & Clinical Settings
Fixed Dynamometry	High	High	High	Low	Low	High	Yes	No	Clinical Rehabilitation
Iso-kinetic Dynamometry	High	High	High	Low	Low	High	Yes	Yes	Sports Medicine & Rehabilitation
Low-cost Continuous Force Measurement System (CFMS)	Moderate	Variable	Moderate	Moderate	High	Low	Yes	No	Research & Clinical