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Objective Parameters of Movement, Biomechanical Predictors for Functional Recovery

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Introduction: Objective parameters of movement inform on joint loading, compensatory strategies and neuromotor control, being frequently associated with rehabilitation outcomes. Objectives: This review aims to critically analyze the existing evidence on the role of biomechanical parameters as predictors of functional recovery as well as to identify those of them with demonstrated clinical relevance. Methods: A structured narrative review of the literature available in PubMed/MEDLINE was performed, in which studies that aimed at the relationship between objective biomechanical parameters and functional outcomes were analyzed, excluding those without clinical relevance. Results: Quadriceps strength, knee flexion angle, knee flexion moment and knee adduction moment were identified as the main biomechanical predictors in orthopedic pathology. In neurology, hip extensor strength and trunk control have been associated with gait recovery after stroke, and gait speed, stance time, and foot-ground contact angle have been correlated with Parkinson's disease severity. Conclusions: Objective biomechanical parameters of movement are valuable tools for predicting and monitoring functional recovery, but will need to be integrated into multimodal models.

Keywords: *predictive biomechanical parameters; orthopedics; neurology*

Introduction

Clinical scales and standardized functional tests are used to assess functional recovery in physiotherapy, but these tools do not always capture the biomechanical mechanisms that determine long-term progression (Barak & Duncan, 2006). In contrast, objective movement parameters can provide valuable information about joint loading, compensatory strategies and neuromotor efficiency (Alderink & Õunpuu, 2025). For example, the role of mechanical loading in the progression of osteoarthritis has been conceptually supported by the analysis of pathobiomechanical mechanisms, especially gait analysis and cartilage morphology (Andriacchi et al., 2004). In neurology, movement variability has an optimal state for functional mobility and is a marker of neuromotor adaptability with implications in rehabilitation and motor control (Stergiou & Decker, 2011). It has been proposed to standardize methods for assessing gait symmetry in stroke patients (Patterson et al., 2010), thus opening the possibility of identifying predictive biomechanical parameters. In stroke patients, hemiparetic gait is characterized by asymmetry in stride length between the lower limbs (Balasubramanian et al., 2007), which also

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provides a conceptual framework for identifying these parameters. Reducing the dimensionality of gait analysis data may contribute to this goal (Olney, Griffin & McBride, 1998). In Parkinson's disease, the rationale for searching for predictive biomarkers is that the parameters that reflect biomechanical changes in gait are stride length, gait variability, and fractal scaling of gait (step amplitude reduction) (Hausdorff, 2009), and that the Parkinsonian gait pattern is slow, short-stepped, and shuffling, and that biomechanical analysis is needed to investigate complex functional gait tasks, rather than limiting assessment to straight-line walking (Morris et al., 2001). Therefore, the aim of this review is to critically analyze the existing evidence regarding the correlation of biomechanical parameters with rehabilitation outcomes, but also to identify predictors with proven clinical relevance.

Methodology

A structured narrative review of the literature on the predictive value of objective biomechanical parameters of movement in functional recovery was conducted. The literature search was performed in the PubMed/MEDLINE database, as it is recognized for its extensive coverage of the biomedical literature (Lu, 2011). Scientific works that investigated objective biomechanical parameters and their relationship with rehabilitation outcomes were considered relevant. Purely descriptive studies (Riley et al., 2013), studies on animal models, editorial articles, letters or opinions, studies without clinical relevance were not taken into account. Relevant data regarding the type of pathology, the biomechanical parameters analyzed and the functional outcomes reported were synthesized from the selected studies (Steyerberg et al., 2013). The results were synthesized narratively due to the diversity of the pathologies investigated, the methodologies and the biomechanical parameters analyzed.

Results

Biomechanical Predictors in Orthopedic Pathology

<u>Anterior Cruciate Ligament (ACL) Reconstruction</u>

The alteration of knee biomechanics after ACL rupture may also be due to a quadriceps strength deficit, with greater asymmetry of movement in the sagittal plane and lower symmetry of the external moment, so that quadriceps strength is a biomechanical parameter predictive of knee function after Anterior Cruciate Ligament Reconstruction (ACLR) (Palmieri-Smith & Lepley, 2015). In fact, the parameter discussed would be quadriceps strength symmetry, relevant for assessing recovery after ACLR being also knee flexion angle and external moment symmetry (Palmieri-Smith & Lepley, 2015)). Biomechanical changes in gait after anterior cruciate ligament reconstruction (ACLR) have been associated with an increased risk of developing secondary osteoarthritis (Riera et al., 2025). In this sense, rate of torque development (RTD) is a biomechanical parameter that can reveal the risk of developing osteoarthritis (Blackburn et al., 2016). Asymmetries of loading between the operated and the contralateral limb can persist up to 6–12 months postoperatively and the most sensitive functional parameters are knee flexion angle and knee flexion moment (Neal et al., 2022).

Total Knee Arthroplasty (TKA)

In the case of unilateral knee arthroplasty, the preoperative biomechanical status can influence postoperative recovery, in the sense that the gait biomechanical parameters evaluated before the intervention have been identified as predictors of gait biomechanics at 6 months postoperatively (Capin et al., 2025). Quadriceps strength is the main predictor of rehabilitation at one year, explaining the variations in Timed Up and Go (TUG) and Stair Climbing Test (SCT) (Mizner et al., 2005).

Knee Osteoarthritis

In patients with medial compartment knee osteoarthritis, knee adduction moment (KAM) values during walking are a predictive biomechanical parameter for disease progression, monitored radiologically (Miyazaki et al., 2002). In patients with OA, KAM is little influenced by resistance training (Li et al., 2021), suggesting that it is a stable biomechanical parameter.

Biomechanical Predictors in Neurological Pathology

Stroke

Recovery of walking ability after stroke can be predicted by hip extensor strength (muscle biomechanical parameter) and trunk control (motor/postural control parameter) (Selves, Stoquart, & Lejeune, 2020).

Parkinson's Disease

For Parkinson's patients, inertial measurement units (IMUs) show that biomechanical gait parameters such as gait velocity, stance time, and strike angle are correlated with disease severity (Youssef et al, 2026) and may become predictors of disease severity in the future.

Discussions

The presented results are supported by studies from the recent scientific literature that highlight the integration of biomechanical parameters in multimodal models of functional assessment, for example, the inclusion of gait parameters derived from objective measurements of gait kinematics improves the ability to estimate functional decline in patients with osteoarthritis (Kobsar et al., 2015). In the case of ACL reconstruction, the persistence of deficits in neuromuscular control determines increased risks of re-injury, therefore biomechanical parameters must be interpreted in a three-dimensional and functional context (Paterno et al., 2014). Regarding neurological diseases, measuring biomechanical parameters of gait with an accelerometer can assess the progression of Parkinson's disease (Del Din et al., 2016). On the other hand, the analysis of running biomechanics with the aim of identifying injury risks has the disadvantages of the heterogeneity of the evaluation conditions and the inconsistencies in the names and definitions of biomechanical variables (Lopes, Mascarinas & Hespanhol, 2023). The lack of standardization in biomechanical testing between scientific studies also limits the determination of predictive biomechanical variables in the case of primary ACL injuries (Straub & Powers, 2025). Therefore, it is possible that the results often cannot be generalized and that well-defined clinical thresholds cannot be established. Several future research directions are thus outlined, namely the development of integrated predictive models that combine biomechanical parameters with clinical and imaging data, the use of portable technologies for continuous monitoring of movement in the everyday environment, as well as research into the links between movement variability and functional adaptability in different pathologies.

Conclusions

In anterior cruciate ligament reconstruction (ACLR), the biomechanical parameters predictive of recovery are quadriceps strength, quadriceps strength symmetry, knee flexion angle, external moment symmetry, rate of torque development, knee flexion angle and knee flexion moment. For knee osteoarthritis, the biomechanical parameter predictive is knee adduction moment (KAM), and in total knee arthroplasty (TKA) preoperative gait biomechanical parameters and quadriceps strength have been highlighted. In stroke (CVA), the biomechanical parameters predictive of recovery of walking ability are hip extensor strength and trunk control, and in Parkinson's disease, gait biomechanical parameters such as gait velocity, stance time, and strike angle are correlated with disease severity and could become predictive parameters for recovery through future scientific evidence. However, methodological heterogeneity of studies, variations in assessment protocols, and lack of standardization of limitations reduce the generalizability of results and prevent the definition of clear clinical thresholds. Consequently, the interpretation of biomechanical parameters should be carried out in an integrated manner, in correlation with clinical and functional assessments. Future research directions should aim at the development of multimodal and standardized predictive models of biomechanical analysis, as well as the integration of modern motion monitoring technologies into clinical practice.

References

Alderink, G., & Õunpuu, S. (2025). Biomechanics of Human Motion and Its Clinical Applications: Instrumented Gait Analysis. *Bioengineering (Basel, Switzerland)*, *12*(10), 1076. https://doi.org/10.3390/bioengineering12101076.

Andriacchi, T. P., Mündermann, A., Smith, R. L., Alexander, E. J., Dyrby, C. O., & Koo, S. (2004). A framework for the in vivo pathomechanics of osteoarthritis at the knee. *Annals of biomedical engineering*, *32*(3), 447–457. https://doi.org/10.1023/b:abme.0000017541.82498.37).

Balasubramanian, C. K., Bowden, M. G., Neptune, R. R., & Kautz, S. A. (2007). Relationship between step length asymmetry and walking performance in subjects with chronic hemiparesis. *Archives of physical medicine and rehabilitation*, *88*(1), 43–49. https://doi.org/10.1016/j.apmr.2006.10.004.

Blackburn, J. T., Pietrosimone, B., Harkey, M. S., Luc, B. A., & Pamukoff, D. N. (2016). Quadriceps Function and Gait Kinetics after Anterior Cruciate Ligament Reconstruction. *Medicine and science in sports and exercise*, 48(9), 1664–1670. https://doi.org/10.1249/MSS.0000000000000963.

Barak, S., & Duncan, P. W. (2006). Issues in selecting outcome measures to assess functional recovery after stroke. *NeuroRx: the journal of the American Society for Experimental NeuroTherapeutics*, *3*(4), 505–524. https://doi.org/10.1016/j.nurx.2006.07.009.

Capin, J. J., Zeni, J. A., Jr, Forster, J. E., Cheuy, V. A., Peters, A., Hogan, C., Yang, C., Christiansen, C. L., Stevens-Lapsley, J. E., & Bade, M. J. (2025). Preoperative and Post-Rehabilitation Predictors of Gait Biomechanics Six Months After Total Knee Arthroplasty. *Journal of orthopaedic research: official publication of the Orthopaedic Research Society*, *43*(11), 1964–1972. https://doi.org/10.1002/jor.70052).

Del Din, S., Godfrey, A., Galna, B., Lord, S., & Rochester, L. (2016). Free-living gait characteristics in ageing and Parkinson's disease: impact of environment and ambulatory bout length. *Journal of neuroengineering and rehabilitation*, *13*(1), 46. https://doi.org/10.1186/s12984-016-0154-5.

Hausdorff J. M. (2009). Gait dynamics in Parkinson's disease: common and distinct behavior among stride length, gait variability, and fractal-like scaling. *Chaos (Woodbury, N.Y.)*, *19*(2), 026113. https://doi.org/10.1063/1.3147408.

Kobsar, D., Osis, S. T., Hettinga, B. A., & Ferber, R. (2015). Gait Biomechanics and Patient-Reported Function as Predictors of Response to a Hip Strengthening Exercise Intervention in Patients with Knee Osteoarthritis. *PloS one*, *10*(10), e0139923. https://doi.org/10.1371/journal.pone.0139923.

Li, S., Ng, W. H., Abujaber, S., & Shaharudin, S. (2021). Effects of resistance training on gait velocity and knee adduction moment in knee osteoarthritis patients: a systematic review and meta-analysis. *Scientific reports*, *11*(1), 16104. https://doi.org/10.1038/s41598-021-95426-4.

Lopes, A. D., Mascarinas, A., & Hespanhol, L. (2023). Are alterations in running biomechanics associated with running injuries? A systematic review with meta-analysis. *Brazilian journal of physical therapy*, *27*(4), 100538. https://doi.org/10.1016/ j.bjpt.2023.100538.

Lu Z. (2011). PubMed and beyond: a survey of web tools for searching biomedical literature. *Database : the journal of biological databases and curation*, *2011*, baq036. https://doi.org/10.1093/database/baq036.

Miyazaki, T., Wada, M., Kawahara, H., Sato, M., Baba, H., & Shimada, S. (2002). Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. *Annals of the rheumatic diseases*, *61*(7), 617–622. https://doi.org/10.1136/ard.61.7.617).

Mizner, R. L., Petterson, S. C., Stevens, J. E., Axe, M. J., & Snyder-Mackler, L. (2005). Preoperative quadriceps strength predicts functional ability one year after total knee arthroplasty. *The Journal of rheumatology*, *32*(8), 1533–1539.

Morris, M. E., Huxham, F., McGinley, J., Dodd, K., & Iansek, R. (2001). The biomechanics and motor control of gait in Parkinson disease. *Clinical biomechanics (Bristol, Avon)*, *16*(6), 459–470. https://doi.org/10.1016/s0268-0033(01)00035-3.

Neal, K., Williams, J. R., Alfayyadh, A., Capin, J. J., Khandha, A., Manal, K., Snyder-Mackler, L., & Buchanan, T. S. (2022). Knee joint biomechanics during gait improve from 3 to 6 months after anterior cruciate ligament reconstruction. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, *40*(9), 2025–2038. https://doi.org/10.1002/jor.25250.

Olney, S. J., Griffin, M. P., & McBride, I. D. (1998). Multivariate examination of data from gait analysis of persons with stroke. *Physical therapy*, *78*(8), 814–828. https://doi.org/10.1093/ptj/78.8.814.

Palmieri-Smith, R. M., & Lepley, L. K. (2015). Quadriceps Strength Asymmetry After Anterior Cruciate Ligament Reconstruction Alters Knee Joint Biomechanics and Functional Performance at Time of Return to Activity. *The American journal of sports medicine*, *43*(7), 1662–1669. https://doi.org/10.1177/0363546515578252.

Paterno, M. V., Rauh, M. J., Schmitt, L. C., Ford, K. R., & Hewett, T. E. (2014). Incidence of Second ACL Injuries 2 Years After Primary ACL Reconstruction and Return to Sport. *The American journal of sports medicine*, *42*(7), 1567–1573. https://doi.org/10.1177/0363546514530088.

Patterson, K. K., Gage, W. H., Brooks, D., Black, S. E., & McIlroy, W. E. (2010). Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization. *Gait & posture*, *31*(2), 241–246. https://doi.org/10.1016/j.gaitpost.2009.10.014.

Riera, J., Campion, M., Néri, T., Rambaud, A. J. M., & Duclos, N. C. (2025). Association between walking gait biomechanical changes after anterior cruciate ligament injury or reconstruction and the development of osteoarthritis: A systematic review. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, 10.1002/ksa.70183. Advance online publication. https://doi.org/10.1002/ksa.70183.

Riley, R. D., Hayden, J. A., Steyerberg, E. W., Moons, K. G., Abrams, K., Kyzas, P. A., Malats, N., Briggs, A., Schroter, S., Altman, D. G., Hemingway, H., & PROGRESS Group (2013). Prognosis Research Strategy (PROGRESS) 2: prognostic factor research. *PLoS medicine*, *10*(2), e1001380. https://doi.org/10.1371/journal.pmed.1001380.

Palmieri-Smith, R. M., & Lepley, L. K. (2015). Quadriceps Strength Asymmetry After Anterior Cruciate Ligament Reconstruction Alters Knee Joint Biomechanics and Functional Performance at Time of Return to Activity. *The American journal of sports medicine*, *43*(7), 1662–1669. https://doi.org/10.1177/0363546515578252.

Selves, C., Stoquart, G., & Lejeune, T. (2020). Gait rehabilitation after stroke: review of the evidence of predictors, clinical outcomes and timing for interventions. *Acta neurologica Belgica*, *120*(4), 783–790. https://doi.org/10.1007/s13760-020-01320-7.

Stergiou, N., & Decker, L. M. (2011). Human movement variability, nonlinear dynamics, and pathology: is there a connection?. *Human movement science*, *30*(5), 869–888. https://doi.org/10.1016/j.humov.2011.06.002).

Steyerberg, E. W., Moons, K. G., van der Windt, D. A., Hayden, J. A., Perel, P., Schroter, S., Riley, R. D., Hemingway, H., Altman, D. G., & PROGRESS Group (2013). Prognosis Research Strategy (PROGRESS) 3: prognostic model research. *PLoS medicine*, *10*(2), e1001381. https://doi.org/10.1371/journal.pmed.1001381).

Straub, R. K., & Powers, C. M. (2025). Biomechanical predictors of primary ACL injury: A scoping review of prospective studies. *Gait & posture*, *116*, 22–29. https://doi.org/10.1016/j.gaitpost.2024.11.013.

Youssef, H., Sabıroğlu, M., Mahmoud Abdel-Rahman, S., Hasanin, T., Manay, M., Gönül, M. N., Mancini, M., Del Din, S., & Vural, A. (2026). Can wearable sensor based measures of gait accurately reflect Parkinson's disease severity? A systematic review and meta-analysis. *Parkinsonism & related disorders*, *142*, 108108. https://doi.org/10.1016/j.parkreldis.2025.108108