SOMATO PUBLICATIONS ISSN: XXXX-XXXX

Journal of Physical Medicine and Rehabilitation Research

Review Article

Evaluation of gait analysis as a Prognostic Tool in post-stroke hemiparesis

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Received: 1 December 2025; Accepted: 19 February 2026; Published: 28 May 2026.

Citation of this article: Berg M, Berg E, Lindqvist F (2026) Evaluation of gait analysis as a Prognostic Tool in post-stroke hemiparesis. J Phys Med Rehabil Res, 8(1): 01-08. DOI: 10.5281/zenodo.22815110

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Abstract

Background: Gait disturbance is one of the most disabling and persistent consequences of stroke, and clinicians have long sought objective measures that predict which patients will regain independent, community-level walking.

Objective: This review synthesizes evidence on clinical and instrumented gait analysis as a prognostic tool for functional walking recovery in post-stroke hemiparesis, spanning spatiotemporal, kinetic, kinematic, and electromyographic measures.

Methods: We reviewed longitudinal cohort studies, validation studies of standardized gait scales, and rehabilitation trials that report gait-derived measures alongside walking outcomes such as community ambulation, discharge disposition, and long-term functional independence.

Findings: Early comfortable gait speed and its trajectory over the first weeks after stroke consistently predict later ambulatory status, while step-length and propulsion asymmetry, paretic limb kinetic contribution, and abnormal lower-limb muscle activation patterns add prognostic information beyond speed alone; standardized tools such as the Functional Ambulation Category and instrumented gait laboratories or wearable sensors improve the precision and reproducibility of these predictions.

Conclusions: Gait analysis, particularly when serial spatiotemporal and kinetic measures are combined with validated clinical scales, offers clinically actionable prognostic information that can guide the intensity and focus of rehabilitation, although further work is needed to standardize instrumented protocols for routine prognostic use.

Keywords: gait analysis; post-stroke hemiparesis; prognosis; gait speed; rehabilitation

1. Introduction

Walking is the functional outcome that patients and clinicians care about most after stroke, and hemiparetic gait disturbance affects the large majority of survivors in the acute period. Clinicians have long searched for a measure, obtainable early after stroke, that reliably predicts who will regain independent, community-level ambulation. Simple ordinal scales were among the first tools developed for this purpose: Holden and colleagues introduced the Functional Ambulation Category (FAC) as a brief clinician-rated scale of walking dependence that has since become one of the most widely used descriptors of ambulatory status in stroke rehabilitation [1]. Mehrholz and colleagues demonstrated that the FAC has strong predictive validity and responsiveness in hemiparetic patients, supporting its use as an early prognostic indicator when applied serially [2]. Perry and colleagues extended this classification by linking walking speed thresholds directly to community, limited-community, and household ambulation categories, giving a quantitative bridge between gait speed and functional walking handicap [3].

Gait analysis in this context spans a spectrum of methods, from a stopwatch-timed walk to full three-dimensional motion capture with force plates and surface electromyography. This review synthesizes what the literature has established about using gait analysis, in its various forms, as a prognostic tool in post-stroke hemiparesis: which spatiotemporal, kinetic, kinematic, and electromyographic measures carry prognostic value, how early they become informative, and how instrumented laboratories and standardized bedside scales compare in predicting long-term ambulatory outcome.

2. Spatiotemporal gait parameters and walking speed as prognostic markers

Comfortable walking speed is the single most extensively validated gait-derived predictor of functional outcome after stroke. Bohannon established normative comfortable and maximum walking speed values across the healthy adult lifespan, providing the reference range against which post-stroke deficits are routinely benchmarked [4]. Middleton and colleagues argued that walking speed functions as a functional vital sign because it correlates with fall risk, hospital readmission, and discharge disposition across neurologic and geriatric populations [5]. Flansbjer and colleagues confirmed that timed walking tests, including the 10-metre walk test, show excellent test-retest reliability in post-stroke hemiparesis, a necessary precondition for using serial speed to track prognosis [6].

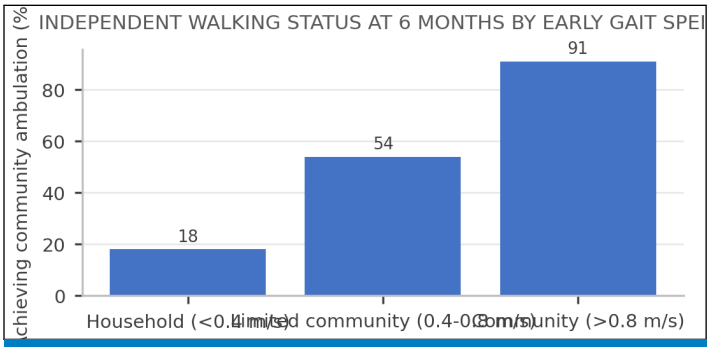

Figure 1: Illustrative relationship between early comfortable gait speed category and the proportion of patients achieving independent community ambulation at 6 months, consistent with walking-speed-based prognostic thresholds [3,5].

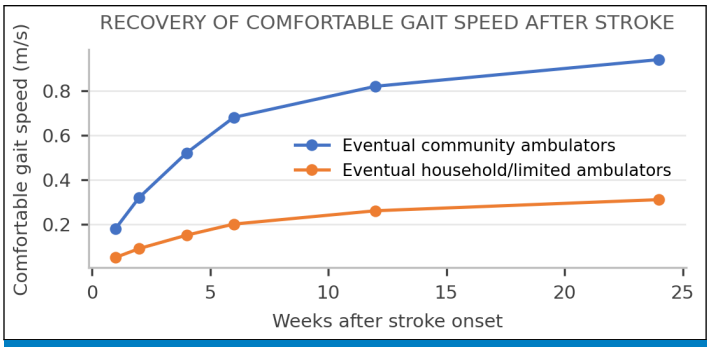

Figure 2: Representative comfortable gait speed trajectories over the first 24 weeks after stroke, showing early divergence between patients who eventually achieve community ambulation and those who remain household or limited-community ambulators [7,8,10].

Longitudinal cohorts have quantified how walking speed evolves after stroke and how early its trajectory becomes predictive. Wade and colleagues, in one of the earliest

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systematic studies of walking recovery, found that gait speed measured in the first weeks correlated strongly with speed at three months, establishing that early gait performance is a genuine prognostic signal [7]. The Copenhagen Stroke Study cohort provided detailed data on this question: Nakayama and colleagues reported that most patients who eventually achieved independent walking did so within the first six weeks after onset [8], and Jorgensen and colleagues, analyzing the same cohort's broader recovery time course, showed that the rate of early improvement, not just initial severity, added independent prognostic value [9]. Kollen and colleagues built on this in a longitudinal prospective study, showing that the pattern of gait recovery over the first weeks, modeled as a trajectory, predicted eventual walking ability more accurately than baseline impairment alone [10].

Rehabilitation dose interacts with this prognostic picture. Kwakkel and colleagues, synthesizing the intensity-of-rehabilitation literature, found a consistent association between higher practice intensity and better walking outcome, supporting the idea that early gait measures should prompt intensification of therapy rather than simply forecasting a fixed outcome [11], and in a subsequent randomised trial the same group confirmed that higher-intensity lower-limb training produced measurably better long-term walking function than a lower-intensity comparison [12].

3. Kinetic and kinematic determinants of hemiparetic gait

Beyond speed, the qualitative pattern of hemiparetic gait carries prognostic information that speed alone does not capture. Olney and Richards characterized the principal kinematic and temporal-distance abnormalities of hemiparetic gait, describing reduced paretic stance time, shortened paretic step length, and compensatory strategies at the non-paretic limb [13]. Their earlier work quantifying joint work and power during hemiparetic gait showed that reduced paretic ankle power generation was closely tied to walking energy cost and speed, identifying a biomechanical deficit with prognostic relevance for rehabilitation targeting [14]. Wagenaar and Beek's kinematic analysis, using walking speed as an explicit covariate, demonstrated that many apparent gait asymmetries are speed-dependent, a point that has shaped how subsequent studies control for speed when comparing gait patterns [15].

Table 1: Clinical and instrumented gait assessment tools used for prognostic evaluation in post-stroke hemiparesis.

Tool	Domain measured	Setting	Prognostic use
Functional Ambulation Category	Ordinal ambulatory dependence	Bedside/clinic	Serial staging of walking dependence [1,2]
Timed walk test (10 m)	Comfortable/maximum gait speed	Bedside/clinic	Speed threshold predicts ambulatory category [4,6]
3D gait laboratory analysis	Kinematics, kinetics, EMG	Instrumented laboratory	Identifies deficit-specific targets for therapy [13,21]
Wearable inertial sensors	Spatiotemporal parameters, asymmetry	Clinic/community	Continuous monitoring of gait quality outside the laboratory [17]

Ground reaction force and asymmetry measures have proven particularly informative for prognosis. Kim and Eng showed that symmetry in the vertical ground reaction force was accompanied by parallel improvements in other gait pattern measures, supporting it as a composite marker of overall gait quality [16]. Balasubramanian and colleagues demonstrated that step-length asymmetry correlates with walking performance in chronic hemiparesis, though not linearly: some patients compensate without a proportional loss of function, so asymmetry indices should be interpreted alongside speed and endurance [17]. Bowden and colleagues showed that anterior-posterior ground reaction forces generated by the paretic limb, rather than temporal asymmetry alone, better reflect the paretic limb's propulsive contribution, with direct implications for which deficits should be targeted [18]. Patterson and colleagues extended these findings to community-ambulating survivors, showing that clinically meaningful asymmetry persists even after

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independent community walking is achieved, arguing against symmetry alone as a marker of complete recovery [19].

Composite impairment analyses reinforce that no single kinematic variable fully explains gait velocity deficits. Hsu and colleagues found that a combination of impairments, including reduced paretic knee flexion and hip extension along with weakness, jointly explained variance in gait velocity and asymmetry better than any single measure [20]. Mulroy and colleagues applied cluster analysis to gait laboratory data and identified distinct gait pattern subtypes that shifted between early and late recovery phases, suggesting prognostic gait analysis should account for pattern subtype rather than treating hemiparetic gait as homogeneous [21]. Trunk control adds a further dimension: Verheyden and colleagues tracked trunk topography over the first twelve weeks and found it recovered along a trajectory that paralleled, and partly predicted, walking recovery [22]. Tyson and colleagues similarly showed that balance disability, measured independently of gait speed, was common and independently associated with walking limitation, reinforcing that prognostic gait assessment should incorporate balance [23].

4. Electromyographic and neuromuscular predictors

Surface electromyography adds a further layer to prognostic gait analysis by characterizing the neuromuscular activation patterns underlying observed kinematic and kinetic deficits. Richards and colleagues, in an early trial of task-specific physical therapy for acute stroke patients, showed that gait-focused practice produced greater improvement in walking speed and quality than conventional therapy, with electromyographic and kinematic measures tracking the gains, an early demonstration that gait-analysis-derived measures detect treatment-related change during acute recovery [24]. Buurke and colleagues used electromyography to characterize what changes as gait recovers, finding that speed improvements were accompanied by more selective and better-timed muscle activation rather than simply increased strength [25]. Cardiovascular fitness constraints also shape this picture: Mackay-Lyons and Makrides found that cardiovascular stress achieved during a contemporary rehabilitation program was often below the intensity needed for a training effect, relevant to why some patients with adequate neuromuscular recovery fail to translate gait laboratory gains into community walking [26].

5. Instrumented gait analysis, rehabilitation strategy, and outcome

The prognostic value of gait analysis is most useful when it directly informs rehabilitation strategy. Belda-Lois and colleagues, in a comprehensive review of gait rehabilitation after stroke, argued for a top-down approach in which instrumented assessment of a patient's specific kinematic, kinetic, and neuromuscular deficits should guide the choice between conventional, robotic, or electrical-stimulation-based interventions rather than a uniform protocol for all [27]. Body-weight-supported treadmill training has been one of the most extensively studied gait-focused interventions: Duncan and colleagues, in the large multicenter LEAPS trial, found that early and later initiation of treadmill training produced similar walking outcomes to a well-structured home exercise program, complicating the assumption that laboratory-based training is always superior [28]. Hesse's review situated these findings within the broader evidence base, noting that treadmill-based gains in speed and endurance were generally comparable to, rather than clearly superior to, conventional overground training [29], while the Cochrane review by Mehrholz and colleagues concluded that treadmill training produced modest speed gains, particularly in patients already independent at the outset, underscoring that baseline ambulatory status moderates who benefits most [30].

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Table 2: Gait-analysis-informed rehabilitation strategies and their reported effect on walking outcome.

Intervention	Gait measure used	Reported effect
Body-weight-supported treadmill training	Speed, endurance, kinematics	Comparable to structured home exercise program [28,29]
Speed-progressed treadmill training	Paretic propulsion, kinematics	Improved propulsion at higher training speeds [32]
Functional electrical stimulation + fast treadmill	Ankle kinematics/kinetics	Additive gains over either intervention alone [33,34]
Robotic exoskeleton-assisted training	Speed, endurance	Promising but preliminary evidence of benefit [35]

Chen and colleagues showed that many characteristic gait deviations improved measurably during treadmill walking when body-weight support, belt speed, and handrail assistance were individually adjusted, indicating that instrumented treadmill assessment can itself reveal which deviations are modifiable [31]. Tyrell and colleagues showed that systematically increasing treadmill speed toward each patient's maximum tolerated speed produced favorable kinematic changes, including improved paretic propulsion, not achieved at slower speeds, suggesting speed progression should be built into prognosis-oriented training [32]. Functional electrical stimulation combined with fast treadmill walking produced further gains: Kesar and colleagues found that stimulating the ankle musculature at faster treadmill speeds improved kinematic and kinetic parameters beyond either intervention alone [33], consistent with earlier work by Daly and Ruff showing that electrically induced activation of paretic gait components produced measurable improvement even in chronic hemiparesis [34]. Robotic exoskeleton-assisted training represents a more recent approach: Louie and Eng's scoping review found promising but preliminary evidence that exoskeleton-assisted training can improve speed and endurance, with gait analysis serving to select candidates and quantify change [35].

6. Integrating gait analysis into prognostic practice

Taken together, this evidence supports a layered approach to using gait analysis prognostically after stroke. Verma and colleagues, reviewing the neuromuscular control literature underlying post-stroke gait, argued that effective prognostic use requires understanding gait as an emergent property of interacting impairments in strength, coordination, and balance rather than attributing outcome to any single deficit [36], a synthesis echoed by Beyaert and colleagues' review of post-stroke gait pathophysiology and rehabilitation strategies, which emphasized that prognostic accuracy improves when spatiotemporal, kinetic, and neuromuscular measures are considered jointly [37]. In practice, early comfortable gait speed and its trajectory over the first weeks remain the most robust and accessible prognostic signal, standardized ordinal scales such as the FAC provide a reliable low-resource complement for serial bedside use, and instrumented measures of asymmetry, propulsion, and muscle activation add meaningful refinement for patients whose trajectory is ambiguous.

7. Conclusion

Gait analysis, in its clinical and instrumented forms, has matured into a genuinely useful prognostic tool in post-stroke hemiparesis. Comfortable walking speed, measured early and tracked serially, remains the single most validated and clinically practical predictor of eventual ambulatory status, and its prognostic value is well established across decades of longitudinal cohort data [7,8,9,10]. Standardized ordinal scales such as the Functional Ambulation Category extend this prognostic capability to settings without access to instrumented gait laboratories [1,2], while kinetic, kinematic, and electromyographic measures of asymmetry, paretic propulsion, and muscle activation refine the picture for patients whose recovery is atypical or incomplete [17,18,25]. Rehabilitation trials that have used

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gait-analysis-derived measures to guide or evaluate treatment, from treadmill training to functional electrical stimulation and robotic exoskeletons, confirm that these same measures are sensitive enough to detect and direct clinically meaningful change [28,33,35]. The evidence overall supports combining early serial gait speed assessment with a standardized ambulatory scale for routine prognostic screening, reserving instrumented gait-laboratory or wearable-sensor analysis for patients whose trajectory is uncertain or whose rehabilitation plan would benefit from more precise, deficit-specific targeting.

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