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FUNCTIONAL GAIT ANALYSIS AS AN OUTCOME TOOL FOR QUANTIFYING GAIT IMPROVEMENT IN STROKE PATIENTS (2020–2025): A NARRATIVE REVIEW

Manoj Jayakumar[1], Senthil P[2], Prathap Suganthirababu[3], Vinodhkumar Ramalingam[4], Chella Perumal Palanisamy[5*]

[1]Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai-602105, Tamil Nadu, India. mdevfranny@gmail.com, https://orcid.org/0009-0008-4722-1819
[2]VELS School of Physiotherapy, VELS Institute of Science, Technology & Advanced Studies (VISTAS), Chennai, Tamil Nadu - 600117, India. senthilp101010@gmail.com, https://orcid.org/0000-0002-0472-0043
[3]Department of Neuroscience, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai-602105, Tamil Nadu, India. prathap.scpt@saveetha.com, https://orcid.org/0000-0002-1419-266X
[4]Department of Sports Sciences, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai-602105, Tamil Nadu, India. vinodhkumar.scpt@saveetha.com, https://orcid.org/0000-0002-5269-0520
[5]Phytochemistry and Pharmacotherapy Lab, Department of Dermatology, Saveetha Medical College & Hospital (SMCH), Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai, Tamil Nadu 602105, India. perumalbioinfo@gmail.com, https://orcid.org/0000-0002-3527-3477

ABSTRACT
Stroke is a leading cause of long-term disability, with over 70% of survivors experiencing gait impairments reduced speed, asymmetrical strides, impaired balance, and increased fall risk. This narrative review synthesizes 2020-2025 evidence from major databases (PubMed, Scopus, Web of Science, Embase, CINAHL, PEDro, Cochrane) on functional gait analysis for quantifying gait improvement in adult stroke survivors, critically analyzing original research, systematic reviews, meta-analyses, and guidelines covering validated clinical tools (FGA, DGI, TUG, 10MWT, 6MWT) and digital technologies. Results show functional gait analysis has evolved into a multidimensional, highly reliable, valid, and responsive clinical outcome across acute to chronic stages. The FGA is especially valued for addressing dynamic balance with reduced ceiling effects and correlates strongly with established measures. Emerging technologies wearable inertial sensors, smartphone-based applications, machine-learning algorithms, and markerless motion capture enhance precision, ecological validity, and clinical accessibility. Integrating functional gait analysis into multidisciplinary rehab supports personalized treatment planning and objective longitudinal monitoring. In conclusion, functional gait analysis is indispensable for post-stroke recovery evaluation; combining standardized clinical assessments with digital innovations enables comprehensive walking performance assessment and therapeutic effectiveness tracking. Future research should harmonize protocols, establish universal clinically meaningful thresholds, and integrate AI with wearable sensors for continuous real-world gait monitoring and feedback.

KEYWORDS: Stroke rehabilitation; Functional gait analysis; Dynamic balance; Motion analysis; Outcome measures; Neurorehabilitation.

1. INTRODUCTION
Stroke continues to represent one of the most significant neurological disorders affecting adults worldwide and remains a major contributor to long-term disability, healthcare expenditure, and reduced quality of life. Despite substantial advances in acute stroke management, thrombolytic therapy, endovascular thrombectomy, and neurorehabilitation, persistent locomotor dysfunction remains highly prevalent among stroke survivors. Walking independence is universally regarded as one of the highest rehabilitation priorities because successful ambulation determines an individual's ability to perform activities of daily living, participate in community activities, return to work, and maintain social engagement [1].

Gait impairment following stroke results from a complex interaction of neurological deficits involving muscle weakness, spasticity, impaired motor coordination, proprioceptive dysfunction, sensory deficits, abnormal muscle synergies, impaired postural control, cognitive impairment, and cardiovascular deconditioning. These impairments collectively produce characteristic hemiparetic gait patterns, including reduced gait velocity, shorter stride length, prolonged double-support time, increased gait asymmetry, inadequate foot clearance, circumduction, hip hiking, reduced knee flexion during swing, diminished ankle dorsiflexion, and impaired propulsion. Consequently, many stroke survivors experience decreased walking efficiency, increased metabolic cost, reduced endurance, fear of falling, and limited community mobility [2].

Recovery of walking function has therefore become one of the principal goals of stroke rehabilitation. Physiotherapists, rehabilitation physicians, occupational therapists, and multidisciplinary stroke teams rely heavily on objective outcome measures to quantify improvements following interventions such as body weight-supported treadmill training, robotic gait rehabilitation, ove rground gait training, functional electrical stimulation, virtual reality-based rehabilitation, task-specific locomotor training, and conventional physiotherapy [3].

Historically, gait assessment relied primarily on laboratory-based three-dimensional motion analysis systems, force platforms, electromyography, and sophisticated biomechanical modeling. Although these technologies provide highly accurate kinematic and kinetic measurements, they remain expensive, technically demanding, time-consuming, and inaccessible in many rehabilitation settings. Their implementation often requires dedicated gait laboratories, specialized equipment, and highly trained personnel, limiting their routine use in daily clinical practice [4].

To address these limitations, functional gait analysis has emerged as an attractive clinical alternative. Rather than focusing solely on biomechanical parameters, functional gait analysis evaluates the patient's ability to safely and efficiently perform walking tasks encountered during everyday activities. These assessments incorporate dynamic balance, obstacle negotiation, directional changes, stair climbing, dual-task walking, head movements, variable walking speeds, and environmental adaptability, thereby providing a more comprehensive representation of functional mobility [5].

Among contemporary clinical assessment tools, the Functional Gait Assessment (FGA) has gained particular prominence. Developed as a modification of the Dynamic Gait Index (DGI), the FGA includes ten standardized walking tasks designed to evaluate dynamic gait stability while minimizing ceiling effects observed with earlier instruments. It has demonstrated strong reliability, validity, and responsiveness across multiple neurological populations, including individuals recovering from stroke. Recent studies further support its correlation with lower-limb motor recovery, gait speed, endurance, balance performance, and activities of daily living, reinforcing its role as a valuable outcome measure in stroke rehabilitation [6].

Simultaneously, technological innovations have transformed functional gait analysis. Wearable inertial measurement units (IMUs), pressure-sensitive insoles, smartphone-based motion analysis, markerless computer vision systems, depth cameras, and artificial intelligence algorithms now permit accurate quantification of gait characteristics outside specialized laboratories. These digital technologies enable continuous monitoring of gait performance in real-world environments, facilitate tele-rehabilitation, reduce assessment costs, and improve accessibility for clinicians and patients alike. Such developments have significantly expanded the clinical utility of functional gait analysis and have accelerated its adoption across rehabilitation settings [7].

Between 2020 and 2025, the literature has demonstrated remarkable growth in studies investigating functional gait assessment as both a primary and secondary outcome measure in randomized controlled trials, cohort studies, validation studies, and systematic reviews. These investigations have evaluated not only traditional clinical scales but also integrated sensor-based approaches capable of capturing temporal, spatial, kinematic, kinetic, and functional parameters simultaneously. Emerging evidence also highlights the growing role of machine learning and predictive analytics in identifying gait recovery trajectories, fall risk, and rehabilitation responsiveness.

Given the rapid evolution of both clinical assessment tools and digital gait technologies, a comprehensive synthesis of contemporary evidence is timely and clinically relevant. While previous reviews have examined isolated gait assessment methods or individual rehabilitation interventions, few have comprehensively evaluated functional gait analysis as an integrated outcome measure across the spectrum of stroke rehabilitation during the most recent period of technological advancement [8].

Accordingly, this narrative review aims to critically evaluate current evidence published between 2020 and 2025 regarding the application of functional gait analysis for quantifying gait improvement in stroke patients. Particular emphasis is placed on standardized clinical outcome measures, psychometric properties, wearable sensing technologies, artificial intelligence-assisted gait assessment, rehabilitation applications, current limitations, and future opportunities for precision neurorehabilitation.

2. LITERATURE SEARCH METHODOLOGY

This narrative review was conducted to comprehensively summarize contemporary evidence regarding the application of functional gait analysis as an outcome tool for quantifying gait improvement in adult stroke survivors between January 2020 and December 2025. Unlike systematic reviews that primarily focus on predefined intervention effects, the present review was designed to integrate diverse evidence related to clinical assessment methods, psychometric validation, technological innovations, rehabilitation applications, and emerging trends in functional gait evaluation.

A comprehensive literature search was performed using PubMed/MEDLINE, Scopus, Web of Science, Embase, CINAHL, PEDro, Cochrane Library, IEEE Xplore, and Google Scholar. Search terms included combinations of:

- "Stroke"
- "Hemiparetic gait"
- "Functional gait assessment"
- "Functional gait analysis"
- "Dynamic gait index"
- "Walking assessment"
- "Gait rehabilitation"
- "Wearable sensors"
- "Inertial measurement units"
- "Artificial intelligence"
- "Motion analysis"
- "Digital biomarkers"
- "Outcome measures"
- "Neurorehabilitation"

Boolean operators (AND/OR) were employed to optimize search sensitivity and specificity.

The review included:

- Randomized controlled trials

- Prospective cohort studies
- Cross-sectional studies
- Validation studies
- Reliability studies
- Clinical practice guidelines
- Systematic reviews
- Meta-analyses

published in English between 2020 and 2025 involving adult stroke survivors.

Studies were excluded if they focused exclusively on pediatric stroke, traumatic brain injury, spinal cord injury, Parkinson disease, multiple sclerosis, cerebral palsy, or animal models without direct clinical relevance to stroke rehabilitation.

The selected literature was narratively synthesized into the following thematic domains:

- Pathophysiology of gait dysfunction
- Functional gait assessment tools
- Clinical outcome measures
- Psychometric evidence
- Wearable technology
- Artificial intelligence-assisted gait analysis
- Clinical implementation
- Rehabilitation monitoring
- Future research directions

This approach enabled integration of evidence from clinical medicine, biomechanics, biomedical engineering, rehabilitation sciences, and digital health, providing a multidisciplinary perspective on functional gait analysis in stroke rehabilitation.

3. Pathophysiology of Gait Impairment Following Stroke

Walking is among the most sophisticated human motor activities, requiring coordinated interactions between cortical motor areas, basal ganglia, cerebellum, brainstem locomotor centers, spinal central pattern generators, peripheral nerves, muscles, sensory receptors, and the musculoskeletal system. Stroke disrupts these integrated neural networks, producing complex locomotor impairments that vary according to lesion location, severity, and recovery stage [9]. Approximately 70–80% of stroke survivors develop clinically significant gait abnormalities during the acute phase, while nearly one-third continue to experience persistent walking limitations years after stroke. These impairments substantially reduce independence, community participation, and health-related quality of life [10].

3.1. Neural Mechanisms Underlying Post-Stroke Gait Dysfunction

Following ischemic or hemorrhagic stroke, damage to the corticospinal tract reduces voluntary motor control of the paretic lower limb. Loss of descending motor drive contributes to impaired recruitment of ankle dorsiflexors, knee flexors, hip flexors, and intrinsic foot muscles, resulting in diminished limb advancement during the swing phase [11]. Disruption of supraspinal motor pathways also alters muscle activation timing, producing abnormal co-contraction between agonist and antagonist muscles. Consequently, movement becomes inefficient, energy expenditure increases, and walking velocity decreases [12]. Simultaneously, impaired sensory feedback from proprioceptors and cutaneous receptors compromises postural control and balance reactions. Stroke survivors often demonstrate reduced joint position sense, impaired weight transfer, delayed anticipatory postural adjustments, and diminished reactive balance responses [13].

3.2. Spasticity and Abnormal Muscle Synergies

Upper motor neuron syndrome remains one of the principal contributors to abnormal gait.

Common features include:

- Spastic plantar flexors
- Hyperactive quadriceps
- Hip extensor dominance
- Reduced selective motor control
- Flexor and extensor synergy patterns

Instead of isolated joint movements, multiple muscle groups contract simultaneously, limiting smooth locomotion.

For example:

- excessive gastrocnemius activity causes equinus gait,
- quadriceps overactivity restricts knee flexion,
- hip circumduction develops as a compensatory strategy for inadequate foot clearance.

These abnormal movement patterns increase walking instability and metabolic demand [14].

3.3. Balance Dysfunction

Balance impairment represents another major determinant of post-stroke gait disability.

Stroke affects:

- vestibular integration,
- visual dependence,
- somatosensory processing,
- anticipatory balance,
- reactive balance.

Consequently, patients demonstrate:

- increased mediolateral sway,

- prolonged double-support phase,
- cautious walking,
- reduced step length,
- fear of falling.

Dynamic balance deficits become particularly evident during:

- turning,
- obstacle negotiation,
- stair climbing,
- dual-task walking,
- uneven terrain ambulation.

These activities form the basis of modern functional gait assessments because they closely resemble everyday mobility challenges [15].

3.4. Cardiovascular and Musculoskeletal Deconditioning

Reduced physical activity following stroke leads to rapid deterioration of aerobic capacity.
Studies consistently report:

- decreased VO_2 peak,
- muscle atrophy,
- reduced lower-limb strength,
- impaired endurance,
- increased fatigability.

Consequently, many patients demonstrate slower walking speed despite neurological recovery.
This highlights why functional gait assessment should evaluate endurance and walking adaptability rather than gait speed alone [16].

4. Biomechanics of Normal and Post-Stroke Gait

Human walking consists of repetitive gait cycles involving coordinated movements of the lower extremities, pelvis, trunk, and upper limbs.
A complete gait cycle begins with heel strike of one limb and ends with the subsequent heel strike of the same limb.
The gait cycle comprises two principal phases:

- Stance phase (~60%)
- Swing phase (~40%)

During normal walking, both limbs work synergistically to ensure forward progression while minimizing energy expenditure.
Stroke profoundly alters these biomechanical characteristics [17].

4.1. Temporal Gait Changes

Temporal parameters describe timing characteristics of walking.
Stroke survivors typically demonstrate:

- reduced cadence,
- prolonged gait cycle,
- increased double-support time,
- reduced single-limb support,
- slower walking velocity.

The prolonged double-support phase reflects increased dependence on bilateral support to maintain stability [18].

4.2. Spatial Gait Alterations

Spatial parameters include:

- step length,
- stride length,
- base of support,
- foot progression angle.

Typical findings include:

- shortened paretic step,
- asymmetric stride length,
- widened walking base,
- reduced toe clearance,
- inconsistent foot placement.

These abnormalities significantly increase fall risk [19].

4.3. Kinematic Abnormalities

Joint kinematics are profoundly affected after stroke.
Common abnormalities include:

Hip

- circumduction
- hip hiking
- reduced extension

- excessive external rotation

Knee

- stiff-knee gait
- inadequate flexion
- genu recurvatum
- reduced shock absorption

Ankle

- equinus gait
- foot drop
- inadequate dorsiflexion
- reduced push-off

Collectively, these impairments reduce walking efficiency and increase compensatory trunk movements [20].

4.4. Kinetic Alterations

Ground reaction forces become asymmetrical after stroke.

Patients generate:

- reduced propulsive force,
- diminished ankle plantarflexor moment,
- decreased hip power,
- altered knee loading,
- asymmetric weight acceptance.

Reduced propulsion from the paretic limb often forces excessive reliance on the unaffected limb, further increasing gait asymmetry [21].

4.5. Functional Consequences

Biomechanical abnormalities produce clinically important limitations including:

- slower community walking,
- inability to negotiate obstacles,
- impaired stair climbing,
- reduced endurance,
- increased falls,
- limited participation,
- decreased independence.

Modern functional gait analysis (Table 1) captures many of these impairments through task-oriented assessment rather than relying exclusively on laboratory-based biomechanical measurements. Recent evidence supports the Functional Gait Assessment (FGA) as a reliable and responsive tool for evaluating dynamic walking balance in stroke, with strong relationships to balance, lower-limb motor recovery, and functional mobility (Figure 1) [22].

Table 1. Major Gait Abnormalities Following Stroke

	Reduced	Limited community ambulation
	Reduced	Slower walking
	Asymmetrical	Poor gait efficiency
	Shortened	Reduced endurance
	Increased	Balance compensation
	Reduced	Foot clearance problems
	Prolonged on unaffected side	Weight-bearing asymmetry
	Foot drop	Increased trip risk
	Stiff-knee gait	Reduced toe clearance
	Circumduction	Increased energy expenditure
	Excessive lateral lean	Postural instability
	Asymmetrical	Reduced propulsion

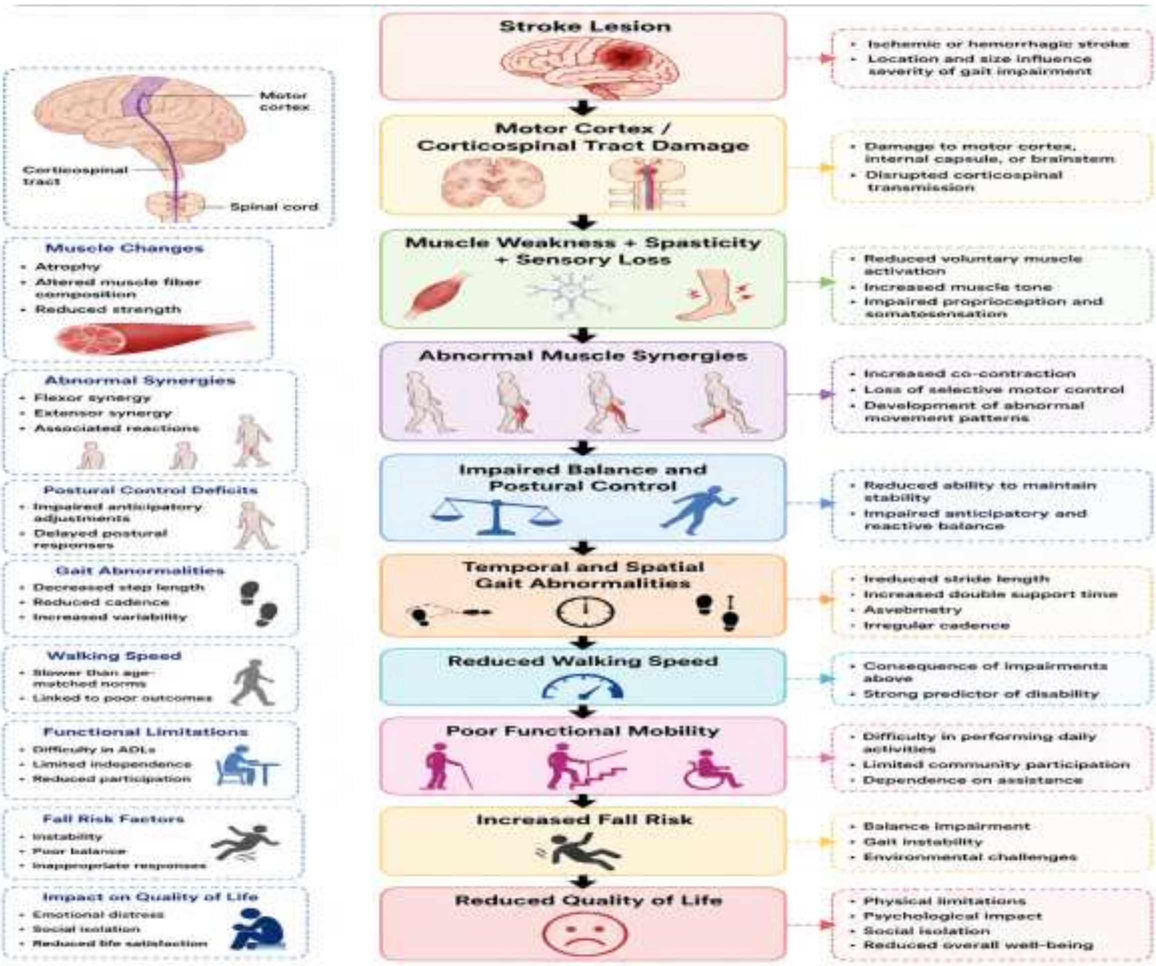

Figure 1. Mechanisms Underlying Post-Stroke Gait Dysfunction (Concept for Illustration).

5. Functional Gait Analysis: Concepts and Clinical Importance

5.1. Introduction to Functional Gait Analysis

Walking is one of the most fundamental components of human mobility and independence, requiring the coordinated interaction of multiple physiological systems, including the central and peripheral nervous systems, musculoskeletal structures, sensory feedback mechanisms, cardiovascular endurance, and cognitive processing. Following stroke, disruption of these integrated systems frequently results in impaired locomotion characterized by reduced walking speed, gait asymmetry, poor balance, impaired adaptability to environmental challenges, and increased risk of falls. Consequently, accurate evaluation of gait performance has become a cornerstone of stroke rehabilitation, serving as an essential indicator of neurological recovery, functional independence, and overall quality of life [23].

Traditionally, gait assessment relied heavily on laboratory-based biomechanical analysis using three-dimensional motion capture systems, force platforms, pressure-sensitive walkways, and electromyography. Although these techniques provide highly accurate kinematic and kinetic data, they require sophisticated infrastructure, specialized personnel, and considerable financial investment. Furthermore, laboratory assessments often evaluate walking under highly controlled conditions, which may not adequately reflect the complexities of community ambulation encountered in daily life. These limitations have prompted increasing interest in functional gait analysis, a clinically oriented approach that evaluates an individual's ability to safely and effectively perform walking tasks representative of real-world environments [24].

Functional gait analysis is defined as the systematic clinical evaluation of walking performance during functional activities that require dynamic balance, postural control, directional changes, obstacle negotiation, speed modulation, and adaptability to environmental demands. Unlike purely biomechanical assessments that focus primarily on joint angles, ground reaction forces, or muscle activation patterns, functional gait analysis emphasizes the integration of motor performance with task execution and participation-level outcomes. This approach aligns closely with the International Classification of Functioning, Disability and Health (ICF) framework, which recognizes mobility as the product of interactions between body structures, functional capacity, activity performance, participation, and environmental factors [25].

In stroke rehabilitation, functional gait analysis has evolved from a supplementary observational tool into one of the most important outcome measures for evaluating treatment effectiveness. It enables clinicians to identify movement impairments that influence everyday mobility, monitor longitudinal recovery, determine rehabilitation goals, and objectively quantify improvements following therapeutic interventions. As rehabilitation increasingly adopts patient-centered and goal-directed approaches, functional gait analysis provides clinically meaningful information that extends beyond laboratory measurements by capturing performance during tasks directly relevant to daily living [26].

5.2. Evolution of Functional Gait Analysis

The concept of gait evaluation has undergone substantial evolution over the past five decades. Early gait assessment primarily focused on descriptive observational methods in which clinicians documented visible abnormalities such as foot drop, circumduction, or reduced arm swing. Although these observations provided valuable clinical insight, they lacked standardized scoring systems and demonstrated considerable inter-rater variability [27]. The introduction of computerized gait laboratories during the 1980s and 1990s revolutionized gait research by enabling precise quantification of spatiotemporal, kinematic, and kinetic parameters. Marker-based optical motion capture systems, synchronized force plates, and surface electromyography significantly advanced the understanding of post-stroke gait biomechanics. These technologies revealed complex movement abnormalities that were not readily detectable through visual observation alone, including altered joint moments, reduced propulsive forces, impaired muscle activation timing, and compensatory movement strategies [28]. Despite their scientific value, laboratory-based systems remained impractical for routine clinical application due to high costs, technical complexity, lengthy assessment procedures, and limited accessibility. Consequently, rehabilitation specialists recognized the need for standardized clinical instruments capable of providing reliable, valid, and responsive measures of functional walking performance [29]. This led to the development of several standardized observational outcome measures, including the Functional Ambulation Category (FAC), Dynamic Gait Index (DGI), Timed Up and Go (TUG), 10-Meter Walk Test (10MWT), Six-Minute Walk Test (6MWT), and subsequently the Functional Gait Assessment (FGA). These tools shifted the emphasis from isolated biomechanical variables toward evaluation of mobility under functional conditions, incorporating tasks such as turning, obstacle negotiation, walking at different speeds, stair climbing, head movements, and dual-task performance [30]. Between 2020 and 2025, advances in wearable technologies, inertial measurement units (IMUs), pressure-sensing insoles, depth cameras, smartphone applications, and artificial intelligence algorithms have further transformed functional gait analysis. These innovations have enabled continuous monitoring of gait performance in home and community environments, reducing reliance on specialized laboratories while providing ecologically valid assessments of real-world mobility. The integration of digital health technologies has also facilitated tele-rehabilitation, remote patient monitoring, and personalized rehabilitation planning, representing a significant advancement in contemporary stroke care [31].

5.3. Fundamental Components of Functional Gait Analysis

Functional gait analysis encompasses multiple dimensions of walking performance, reflecting the complexity of human locomotion. Comprehensive assessment extends beyond gait speed to evaluate the interaction between balance, coordination, endurance, adaptability, and cognitive function [32].

5.3.1. Dynamic Balance

Dynamic balance is the ability to maintain postural stability while the body is in motion. Following stroke, impaired balance is one of the primary contributors to reduced mobility and increased fall risk. Functional gait assessments challenge dynamic balance through tasks involving changes in walking direction, turning, obstacle crossing, head movements, tandem walking, and stair negotiation. Evaluation of these activities provides valuable insight into an individual's capacity to safely navigate community environments [33].

5.3.2. Gait Adaptability

Successful community ambulation requires continuous adaptation to changing environmental conditions. Functional gait analysis therefore evaluates an individual's ability to modify walking patterns in response to external demands, including alterations in walking speed, negotiation of uneven terrain, avoidance of obstacles, and execution of multidirectional movements. Impaired gait adaptability has been associated with reduced community participation and increased dependence among stroke survivors [34].

5.3.3. Motor Coordination

Stroke frequently disrupts the temporal and spatial coordination of lower-limb movements, resulting in abnormal gait patterns characterized by asymmetrical step length, prolonged double-support time, reduced knee flexion during swing, and impaired ankle dorsiflexion. Functional gait analysis evaluates the efficiency and coordination of these movements during task-specific walking activities, enabling clinicians to identify movement deficits that may not be apparent during simple straight-line ambulation [35].

5.3.4. Walking Endurance

Walking endurance reflects the capacity to sustain locomotion over prolonged distances and is influenced by cardiovascular fitness, muscular strength, neuromuscular coordination, and metabolic efficiency. Many stroke survivors exhibit markedly reduced endurance despite improvements in short-distance walking speed. Functional gait analysis therefore incorporates endurance measures such as the Six-Minute Walk Test to assess functional capacity and community mobility [36].

5.3.5. Dual-Task Performance

Walking in daily life rarely occurs in isolation. Individuals frequently perform simultaneous cognitive or motor tasks while ambulating, such as conversing, carrying objects, or navigating crowded environments. Stroke-related impairments in attention and executive function may compromise dual-task walking, increasing instability and fall risk. Contemporary functional gait assessments increasingly incorporate dual-task paradigms to better reflect real-world mobility demands and identify individuals requiring targeted cognitive-motor rehabilitation [37].

5.4. Clinical Importance of Functional Gait Analysis in Stroke Rehabilitation

Functional gait analysis has become indispensable in contemporary stroke rehabilitation because it provides objective, standardized, and clinically meaningful measures of locomotor performance. Accurate gait assessment is essential throughout the rehabilitation continuum, from the acute phase of hospitalization to long-term community reintegration. During the acute stage, functional gait analysis assists clinicians in establishing baseline mobility, determining rehabilitation goals, and identifying patients at increased risk of falls. Early assessment also facilitates individualized

treatment planning by identifying impairments requiring targeted intervention, such as balance deficits, foot drop, or impaired weight transfer [38].
In the subacute phase, repeated functional gait assessments enable objective monitoring of neurological recovery and treatment responsiveness. Improvements in dynamic balance, gait speed, endurance, and walking adaptability provide measurable indicators of rehabilitation progress and guide progression of therapeutic exercises. Functional outcome measures are particularly valuable in evaluating the effectiveness of interventions such as body weight-supported treadmill training, robotic-assisted gait therapy, functional electrical stimulation, virtual reality-based rehabilitation, task-specific overground training, and intensive physiotherapy. For individuals with chronic stroke, functional gait analysis plays an important role in long-term management by identifying persistent mobility limitations, evaluating compensatory movement strategies, and monitoring age-related changes in functional performance. Objective assessment facilitates ongoing optimization of rehabilitation programs and supports decisions regarding assistive devices, orthotic prescription, community mobility training, and fall prevention strategies [39].
From a research perspective, standardized functional gait measures have become essential outcome variables in randomized controlled trials and longitudinal cohort studies investigating stroke rehabilitation. Their widespread adoption has enhanced comparability between studies, improved evidence synthesis, and contributed to the development of evidence-based clinical practice guidelines. Furthermore, regulatory agencies and funding organizations increasingly emphasize the use of validated patient-centered outcome measures, reinforcing the importance of functional gait analysis in contemporary rehabilitation research [40].

5.5. Functional Gait Analysis Within the International Classification of Functioning (ICF)

The World Health Organization's International Classification of Functioning, Disability and Health (ICF) provides (Table 2) a comprehensive framework for understanding disability by integrating impairments, activity limitations, participation restrictions, environmental influences, and personal factors. Functional gait analysis aligns closely with this framework because it evaluates walking not only as a biomechanical process but also as a functional activity that determines an individual's ability to participate in society [41].
Within the ICF model, impairments such as muscle weakness, spasticity, impaired proprioception, and reduced motor control influence activity-level outcomes including walking speed, balance, stair climbing, and obstacle negotiation. These activity limitations subsequently affect participation domains such as employment, social interaction, recreational activities, and independent living. Functional gait assessment therefore serves as a bridge between physiological recovery and meaningful participation outcomes, enabling clinicians to evaluate rehabilitation success from both biomedical and patient-centered perspectives [42].
The increasing integration of ICF principles into stroke rehabilitation underscores the importance of multidimensional outcome measures that capture functional performance within real-world contexts. Functional gait analysis fulfills this requirement by combining standardized clinical observation with quantitative assessment of mobility-related activities, thereby providing comprehensive information to support individualized rehabilitation planning [43].

Table 2. Core Components Evaluated During Functional Gait Analysis

	Stability during walking, turning, head movements	Predicts fall risk
	Speed changes, obstacle negotiation, stair climbing	Reflects community mobility
	Cadence, step length, stride symmetry, gait speed	Indicates locomotor efficiency
	Limb coordination, foot clearance, weight transfer	Identifies neuromuscular deficits
	Sustained ambulation over time or distance	Measures functional capacity
	Walking while performing cognitive or motor tasks	Evaluates cognitive-motor integration
	Community ambulation, assistive device use	Guides rehabilitation planning
	Turning, obstacle avoidance, recovery from perturbations	Supports fall-prevention strategies

Key Message: Functional gait analysis has evolved from a subjective observational technique into a multidimensional, evidence-based outcome measure that integrates motor control, balance, adaptability, endurance, and participation-level mobility. Its increasing incorporation into stroke rehabilitation reflects a shift toward patient-centered assessment and precision neurorehabilitation, providing clinicians with clinically meaningful metrics for monitoring recovery and optimizing individualized therapeutic interventions.

6. Functional Gait Assessment (FGA): Development, Administration, Scoring, and Clinical Applications in Stroke Rehabilitation

6.1. Historical Development of the Functional Gait Assessment

The Functional Gait Assessment (FGA) was developed as an enhanced version of the Dynamic Gait Index (DGI) to overcome several psychometric limitations identified in neurological populations. Although the DGI had been widely adopted for assessing gait and balance, clinicians observed substantial ceiling effects among higher-functioning individuals recovering from stroke and other neurological disorders. These ceiling effects reduced its sensitivity to detect subtle improvements during rehabilitation and limited its usefulness for monitoring patients with mild or moderate mobility impairments [44].

To address these shortcomings, the FGA retained seven tasks from the original DGI while incorporating additional, more challenging activities that better reflected the demands of community ambulation. The revised instrument consists of 10 functional walking tasks that assess an individual's ability to maintain gait stability under varying environmental and task-specific conditions. These tasks evaluate essential aspects of locomotor control, including gait adaptability, dynamic balance, speed modulation, obstacle negotiation, narrow-base walking, visual-vestibular integration, and postural control [45].

Since its introduction, the FGA has undergone extensive validation across multiple neurological conditions, including stroke, Parkinson disease, vestibular disorders, multiple sclerosis, traumatic brain injury, and older adults at risk of falls. Between 2020 and 2025, the FGA has become one of the most frequently used clinical outcome measures in stroke rehabilitation trials because of its excellent psychometric performance, ease of administration, and ability to capture clinically meaningful changes in walking function [46].

6.2. Conceptual Basis of the FGA

The FGA is grounded in the principle that successful walking extends beyond forward locomotion on a level surface. Community mobility requires continuous adaptation to changing environmental demands, including turning, obstacle avoidance, stair negotiation, head movements, changes in walking speed, and maintenance of balance while multitasking [47].

Accordingly, the FGA evaluates gait as a multidimensional construct encompassing:

- Dynamic postural stability
- Anticipatory and reactive balance control
- Sensorimotor integration
- Walking adaptability
- Lower-limb coordination
- Vestibular contributions to locomotion
- Functional mobility under real-world conditions

Unlike laboratory-based gait analysis, which primarily quantifies biomechanical variables such as joint angles or ground reaction forces, the FGA emphasizes functional performance during activities representative of everyday mobility. This patient-centered perspective aligns closely with the International Classification of Functioning, Disability and Health (ICF), in which walking is considered an activity influenced by impairments, environmental factors, and participation demands [48].

6.3. Administration of the Functional Gait Assessment

The FGA is designed for use by physiotherapists, rehabilitation physicians, occupational therapists, and other trained healthcare professionals. The assessment typically requires 10–15 minutes to complete and can be performed in most outpatient clinics, inpatient rehabilitation units, and community settings without specialized laboratory equipment [49].

Equipment Required

- A straight walkway (approximately 6–8 m)
- Stopwatch
- Two obstacles of different heights
- Staircase with handrail
- Marked pathway for tandem walking
- Standardized instruction sheet
- Appropriate footwear and gait aid (if routinely used)

Patients perform each task under standardized instructions while the examiner observes movement quality, balance, coordination, and safety. Rest periods may be provided if fatigue develops, particularly in individuals with reduced cardiovascular endurance [50].

6.4. Components of the Functional Gait Assessment

The FGA consists of 10 standardized tasks, each designed to challenge specific aspects of functional mobility.

Task 1. Gait on a Level Surface

The individual walks at a comfortable pace over a designated distance. This task evaluates baseline walking speed, step symmetry, postural alignment, and overall gait quality.

Task 2. Change in Gait Speed

Participants alternately increase and decrease their walking speed upon verbal instruction without compromising stability. Successful performance reflects motor adaptability and anticipatory control.

Task 3. Gait with Horizontal Head Turns

Walking while repeatedly turning the head left and right challenges vestibulo-ocular integration and dynamic postural control. Stroke survivors often demonstrate reduced gait stability during this task because of impaired sensory integration.

Task 4. Gait with Vertical Head Turns
This task requires walking while looking upward and downward. Vertical head movements alter vestibular input and challenge balance control during locomotion.
Task 5. Gait with Pivot Turn
The participant walks forward before executing a rapid 180° pivot turn. This task evaluates turning ability, dynamic balance, coordination, and postural stability.
Task 6. Step Over Obstacle
Individuals walk while stepping over an obstacle without interrupting forward progression. Performance depends upon lower-limb coordination, anticipatory motor planning, foot clearance, and balance.
Task 7. Gait with Narrow Base of Support
Patients walk heel-to-toe along a straight line, substantially reducing the base of support. This task challenges mediolateral stability and dynamic balance.
Task 8. Gait with Eyes Closed
Walking without visual input evaluates reliance on proprioceptive and vestibular systems. Many stroke survivors demonstrate increased instability under these conditions.
Task 9. Ambulating Backward
Backward walking requires different neuromuscular control strategies than forward gait and is particularly sensitive to balance deficits.
Task 10. Stair Negotiation
Participants ascend and descend stairs using their customary strategy. Stair climbing represents one of the most demanding functional mobility tasks encountered in everyday life and provides valuable information regarding strength, coordination, endurance, and confidence [51].

6.5. Scoring System

Each task is scored on a 4-point ordinal scale (0–3):

	Normal performance without observable gait deviation
	Mild impairment with minor gait deviations
	Moderate impairment requiring supervision or demonstrating substantial gait abnormalities
	Severe impairment or inability to safely complete the task

The maximum total score is 30 points.
Higher scores indicate superior functional gait performance.
Lower scores indicate increasing gait dysfunction and greater fall risk.
The scoring system emphasizes movement quality rather than task completion alone, allowing clinicians to detect subtle improvements during rehabilitation [52].

6.6. Interpretation of Total Scores

Although interpretation should always consider the clinical context, several general principles guide clinical decision-making.
High Scores (27–30)

- Independent community ambulation
- Good dynamic balance
- Low fall risk
- Minimal functional limitation

Moderate Scores (20–26)

- Mild-to-moderate gait impairment
- Difficulty negotiating complex environments
- Reduced walking confidence
- Possible requirement for targeted balance training

Low Scores (<20)

- Significant gait instability
- Increased dependence
- High fall risk
- Need for comprehensive rehabilitation and mobility assistance

Repeated assessment enables clinicians to quantify functional improvements over time and evaluate intervention effectiveness [53].

6.7. Clinical Applications Across Stroke Recovery

Acute Stroke

In acute rehabilitation, the FGA assists clinicians in establishing baseline functional mobility, identifying early balance deficits, and determining the level of supervision required during ambulation. Because acute stroke survivors often exhibit rapid neurological changes, repeated FGA assessments provide objective information regarding early recovery and guide progression of rehabilitation intensity [54, 55].

Subacute Stroke

The subacute phase represents the period of greatest neuroplastic potential. During this stage, the FGA is particularly valuable for monitoring improvements following interventions such as body weight-supported treadmill training, robotic-assisted gait therapy, functional electrical stimulation, overground gait training, and virtual reality-based rehabilitation. Incremental increases in FGA scores reflect enhanced dynamic balance, gait adaptability, and community mobility [56, 57].

Chronic Stroke

Many individuals continue to experience persistent gait limitations months or years after stroke. In chronic rehabilitation, the FGA identifies residual deficits that may interfere with community participation, evaluates compensatory movement strategies, and supports decisions regarding assistive devices, orthotic management, fall-prevention programs, and long-term exercise prescription [58, 59].

6.8. Clinical Advantages of the Functional Gait Assessment

The growing popularity of the FGA reflects several practical and scientific advantages:

- Comprehensive evaluation of dynamic gait.
- Minimal equipment requirements.
- Rapid administration.
- Excellent feasibility in clinical practice.
- Strong inter-rater and intra-rater reliability.
- High responsiveness to rehabilitation-induced changes.
- Reduced ceiling effects compared with the Dynamic Gait Index.
- Applicable across acute, subacute, and chronic stroke populations.
- Suitable for outpatient, inpatient, community, and tele-rehabilitation settings.
- Easy integration into multidisciplinary rehabilitation programs.

Importantly, the FGA complements rather than replaces laboratory-based gait analysis. While instrumented systems provide precise biomechanical measurements, the FGA offers a standardized assessment of functional walking performance that is directly relevant to everyday mobility and rehabilitation outcomes [60, 61].

Table 3. Summary of the Ten Functional Gait Assessment Tasks

	Basic locomotion	Baseline walking ability
	Motor adaptability	Community ambulation
	Vestibular integration	Dynamic balance
	Sensorimotor control	Postural stability
	Turning ability	Fall-risk assessment
	Foot clearance	Obstacle negotiation
	Mediolateral balance	Dynamic stability
	Proprioceptive control	Sensory integration
	Coordination	Advanced mobility
	Functional independence	Community participation

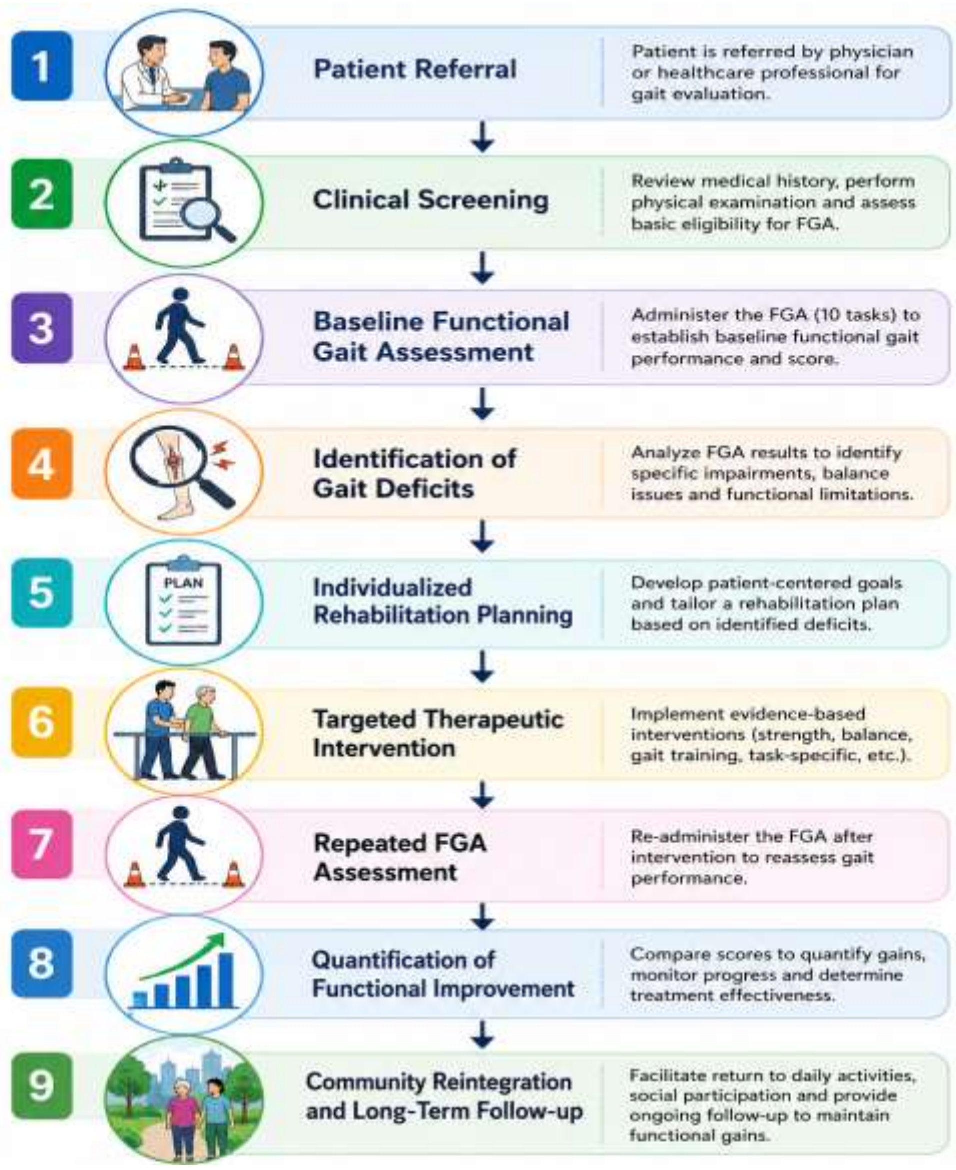

Figure 2. Clinical Workflow for Functional Gait Assessment

7. CONCLUSION

Functional gait analysis has become an indispensable outcome tool for evaluating gait recovery and functional mobility in stroke rehabilitation. By integrating assessments of dynamic balance, gait adaptability, postural control, and community ambulation, it provides a more comprehensive evaluation than conventional measures based solely on gait speed or endurance. Recent advances between 2020 and 2025, including the Functional Gait Assessment (FGA), wearable sensors, and artificial intelligence-assisted gait analysis, have further enhanced the accuracy, sensitivity, and clinical applicability of gait evaluation. Functional gait analysis enables clinicians to objectively monitor rehabilitation progress, personalize therapeutic interventions, predict fall risk, and facilitate evidence-based decision-making across acute, subacute, and chronic stroke care. Future research should focus on standardized assessment protocols, multicenter validation studies, and integration of digital technologies to support continuous, real-world monitoring. Overall, functional gait analysis represents a robust, patient-centered outcome measure that is pivotal for optimizing stroke rehabilitation and improving long-term functional independence and quality of life.

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