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Electromyographic and kinematic assessment of locomotor function in patients with ischemic stroke (case report)

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Abstract

Objective: Gait disorders in post-stroke patients are caused by factors such as the severity of motor paralysis, sensory impairment, spasticity, instability, and gait strategy. Severe motor paralysis and spasticity lead to abnormal muscle activity patterns that affect the kinematics of the lower limbs during walking. Sensory impairment and loss of balance lead to impaired motor coordination of the lower limbs, stride length and balance. This report presents a system for electromyographic and kinematic gait assessment in patients one year after stroke. **Materials and methods:** The 10-Meter Walk Test (10MWT) and a portable electromyographic system for the objective measurement of kinematics and muscle activity (FREE EMG and G-Walk sensor, BTS Co., Italy) were used. **Results:** Increased stride length on the affected side, slightly longer stance phases, and decreased walking speed and cadence were revealed. Stride time, the duration of the single stance phase in both lower limbs and double stance time were increased, with the deficit being more pronounced on the left side. Increased obliquity in the gait cycle of the affected side often indicates pelvic 'hiking' — a compensation for insufficient dorsiflexion and/or limited knee flexion during the swing phase. **Discussion:** According to the authors, hemiplegic gait after stroke comprises deviations and compensatory movements dictated by residual functions. Therefore, each patient should undergo examination to identify and document their unique gait pattern. **Conclusion:** Early diagnosis, regular functional assessments, and targeted rehabilitation are essential for improving gait and independent performance of activities of daily living in patients.

Keywords: Electromyography (EMG), kinematic assessment, locomotor function, post-stroke gait

1. Introduction

Human locomotor function is a complex, automated motor process coordinated by the interaction between multiple systems - sensory, motor and vestibular [1]. Locomotor impairments are frequently seen in stroke patients and can manifest to varying degrees depending on the location and severity of the brain damage [2]. They are most often the result of central paresis/paralysis, sensory disturbances, and impaired coordination. After a stroke, 50% of patients are initially unable to walk, 12% can walk with assistance, and 37% can walk independently. At the end of 11 weeks of rehabilitation after a stroke, 18% of patients are still unable to walk, 11% can walk with assistance, and 50% can walk independently [3]. Gait disorders in post-stroke patients are caused by factors such as the severity of motor paralysis, sensory impairment, spasticity, instability, and gait strategy. For instance, severe motor paralysis and spasticity cause abnormal muscle activity patterns, which affect lower limb kinematics during gait. Sensory impairment and loss of balance lead to impaired lower-limb motor coordination, stride length, and balance. Gait strategies, such as the ratio of cadence to gait speed, alter limb kinematics and compensate for gait disorders by decreasing gait efficiency [4]. These factors result in a pattern of joint motion of the

paretic leg during gait that differs from that of healthy individuals. Specifically, this altered motion often manifests as an extension thrust or stiff knee gait pattern. Such abnormal gait patterns are associated with functional impairments, such as spasticity. Unlike joint kinematics, which captures the movement characteristics of individual joints, limb kinematics considers the movement characteristics of the entire lower limb. This allows us to understand the coordination and control of multiple segments and evaluate more global movements [5]. While the individual control of each joint allows for greater degrees of freedom, limb kinematics controls the lower limb's motion during gait with fewer degrees of freedom [6]. These laws of motion are expressed by limb angle and length and provide the basis for human gait kinematics. The motion of the hip and knee joints can be approximated from limb kinematics. However, it is difficult to derive the motion of the ankle joint from limb kinematics. Ankle motion can be estimated from limb angle during the stance phase; however, neither limb angle nor length reflects ankle motion during the swing phase. Clinically, it is significant to note that limb kinematics contributes more than joint kinematics to the recovery of gait speed in post-stroke patients. Post-stroke patients often develop an asymmetrical gait with impaired rhythm, reduced push-off, and compensatory strategies such as pelvic hiking [7]. Instrumental analysis using kinematic and electromyographic systems allows objective monitoring of these changes [8]. It is extremely important to identify the clinical characteristics primarily associated with walking after stroke in order to develop effective gait training programs [9]. Effective rehabilitation strategies should be based on the complex pathokinesiological analysis and pathophysiology of gait disorders in patients after stroke. The aim of the report is to consider an individual gait analysis in a patient after ischemic stroke based on modern equipment for electromyographic and kinematic assessment of locomotor function.

2. Methods

The study was conducted at South-west University "Neofit Rilski" in Blagoevgrad on individuals after suffering a ischemic stroke. The current analysis was restricted to study participants with NIHSS 0–5 at baseline and a final diagnosis of an ischaemic stroke. Patients were referred by a neurologist, were informed about the study design, and signed informed consent statements. For the purpose of this report, we present the case of a 58-year-old man 1 year after an ischemic stroke, who had a Brunnstrom Stages of Motor Recovery score of 4 (decreased spasticity). In the case under consideration, the presence of hemiparesis was observed, with no impairment of information and cognitive functions (e.g. memory, attention, thinking and perception) that would make it impossible to establish verbal-logical contact.

2.1. Materials and methods

The study used a 10-meter walk test (10MWT) and a portable electromyographic system (FREE EMG and G-Walk sensor, BTS Co., Italy) to objectively measure kinematic and muscle activity (Figure 1). Each study participant determined their own walking speed in meters per second (m/s) for the distance covered in 10 meters while walking barefoot. BTS FREE EMG electrodes were placed bilaterally on the tibialis anterior and gastrocnemius medialis muscles. A G-sensor was placed at the S1 level of the sacrum to assess pelvic movements and tilts (Figure 1).

A **B**

Fig. 1. The equipment used to assess the electromyographic and kinematic characteristics of gait A) G-Walk sensor and B) Bluetooth electrodes of FREE EMG of BTS Co. Italy

This equipment allows for the assessment of muscle activity and the analysis of movements specific to each part of the body. Quantitative values determine the patient's functional state. It can record and analyze any movement, dysfunction, residual potential, and established compensation strategies. Bluetooth electrodes allow us to acquire electromyographic signals, providing an immediate view of how the reference muscles behave in relation to the performed movement. This allows us to prevent and monitor the condition.

Fig. 2. Positioning of the G-Walk sensor in the area of S1 (os sacrum) and the FREE EMG electrodes on the m.tibialis anterior and m.gastrocnemius medialis of the examined person.

2.2. Measured and analyzed gait parameters

Pelvic kinematics (PK) assesses pelvic movement in inclination, elevation, depression, and rotation, i.e., the analysis of angular variations in the frontal, sagittal, and transverse planes. These data allow us to assess the position of the subjects' pelvises and their movements during the gait cycle. We can also link excessive movements with loss of equilibrium due to disturbances in balance, center of gravity, etc.
The global symmetry index (GSI) evaluates whether the right and left limbs perform the gait cycle symmetrically with respect to stance and swing phase duration. A GSI result between 75 and 100 is indicative of a high degree of symmetry, meaning the stance and swing phases for both the right and left limbs fall within their respective normal ranges.
The symmetry index (SI) is the percentage difference in the stance and swing phases between the right and left limbs, respectively. An ideal score of 0% is achieved when the right and left stance and swing phases have the same values. Normative values are SI <3.6.
The gait cycle quality index (GCQI) evaluates a subject's ability to perform balanced gait cycles on the right and left. An ideal GCQI score of 100 is achieved when the stance and swing phases represent 60% and 40% of the gait cycle, respectively.
Temporal parameters (TP) include the stance and swing phases, as well as the single and first double stance phases, expressed as a percentage of the gait cycle. Muscle activation timing (EMG, mV) shows which phase of the gait cycle the studied muscles are active in.
Electromyographic (EMG) Bluetooth measurement of the electrical activity produced by muscles (m. tibialis anterior - TA and m. gastrocnemius medialis- GM). It involves recording electrical signals using electrodes on the skin (surface EMG) to analyze muscle function during the left and right gait cycle.

3. Results

A clinical case was examined involving a 58-year-old patient with a one-year history of the disease, marked weakness, and paresis on the left side. Table 1 presents gait phase indicators in post-stroke

patient. The results revealed reduced stride length, increased stride length on the affected side, slightly longer stance phases, and decreased walking speed and cadence. Stride time, the duration of the single stance phase in both lower limbs, and the time for double stance are increased, with the deficit being more pronounced on the left side. Additionally, there is less stance time and more swing time on the affected side, as well as asymmetries in spatial and temporal factors. The patient walks with a cadence of 85.3 steps/min (decrease relative to the norm ~114) and prolonged stride time (1.45 s left, 1.42 s right). The stance phase is 63.9% left vs. 50.6% right, and the swing phase is 36.1% left vs. 49.4% right. The symmetry index is 13.3% (normal <3.6%), and the global index is 0%. The combination of extended left stance, extended right swing, decreased GCQI, and high SI is consistent with a post-stroke gait pattern dominated by reduced left "push-off" (weak contribution of plantar flexors in terminal stance), probable difficulties in dorsiflexion and/or knee flexion during swing (compensations such as hiking/circumduction), and a stability strategy with increased double support in the right cycle.

Table 1
Gait phases, symmetry indices and gait cycle time parameters for left and right legs in patient with ischemic stroke compared to normative values

Temporal Gate Parameters	**Right**	**Left**	**Normal values**
Stance Phase (% Gait Cycle)	63.9 ± 7.6	50.6 ± 4.8	59 ± 2
Swing Phase (% Gait Cycle)	36.1 ± 7.6	49.4 ± 4.8	40 ± 3.6
Single Support Phase (% Gait Cycle)	48.9 ± 10	34.8 ± 3.2	38.9 ± 2.6
1st Double Support Phase (% Gait Cycle)	4.7 ± 2.8	11.2 ± 3.6	10.3 ± 3.1
Stride Time (s)	1.45 ± .09	1.42 ± .23	1.1 ± .09
Stance Time (s)	0.93 ± .13	0.72 ± .14	0.65 ± .07
Swing Time (s)	0.52 ± .11	0.7 ± .13	0.44 ± .05
Cadence (steps/min)	85.3 ± 7.9		114 ± 4.2
Global Simmetry Index (%)	67.9		75 < GSI < 100
Simmetry Index (%)	13.3		SI < 3.6
Gait Cycle Quality Index	84.4	79.2	90 - 100

As illustrated in the following graphs, there is a tendency to deviate from normal values in the examined individual, especially with regard to the right half during the gait cycle (Fig. 3). The first bar of the graph represents the movement of the pelvis during the right gait cycle, while the second bar of the graph represents the movement of the pelvis during the left gait cycle. Pelvic kinematic graphs allow for the evaluation of pelvic movement in the frontal, sagittal, and transversal planes. The red lines represent pelvic movement during the left cycle. The green lines represent pelvic movement during the right cycle. Graphs of pelvic obliquity, tilt, and rotation show deviation from the normal range during parts of the gait cycle (visual assessment). These specific kinematic signals indicate that the pelvis actively contributes to compensating for insufficient leg weakness during push-off phase. Increased obliquity in the gait cycle of the affected side often indicates pelvic "hiking"—a compensation for insufficient dorsiflexion and limited knee flexion during the swing phase. Reduced pelvic rotation is associated with a shortened stride length (the assessment is relative to normal "gray" areas).

The results of the electromyographic assessment of the ankle joint antagonists show the specificity of muscle activation during the gait cycle. In our study, we analyzed the m. tibialis anterior (TA) and the m. gastrocnemius medialis (GM) to see how these two muscles (agonist and antagonist) work during walking. At the beginning of the gait cycle, there is activation of the m. tibialis anterior, which works eccentrically to control the drop of the foot. During the single-support phase, when the foot is fully planted on the support, the TA must be turned off because the GM takes over the action, which initially works eccentrically to control the rolling of the tibia forward on the foot, and immediately after that it must work concentrically to develop the driving force necessary to lift the foot off the ground and therefore the limb into swing. During the swing phase, the GMs no longer have a reason to work and the m. The TA takes over again, the function of which is necessary to dorsiflex the ankle and allow the limb to swing, preventing the ball of the foot from touching the ground. The EMG signal graphs shown below reveal in which phases of the gait cycle the activation and deactivation of each muscle studied occur.

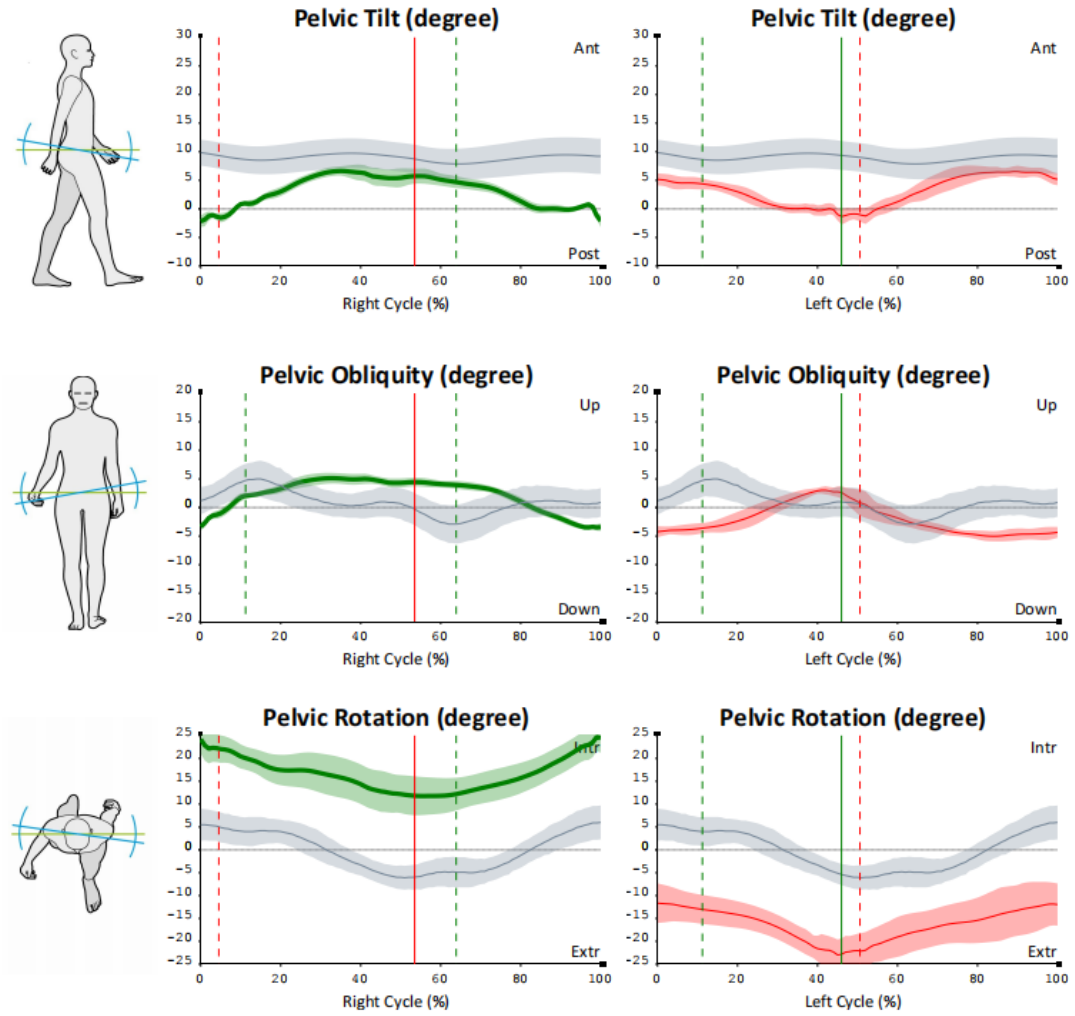

Fig.3. Kinematic characteristics of pelvic movements: in green is during the right gait cycle, in red is during the left gait cycle, and in gray is the normative values.

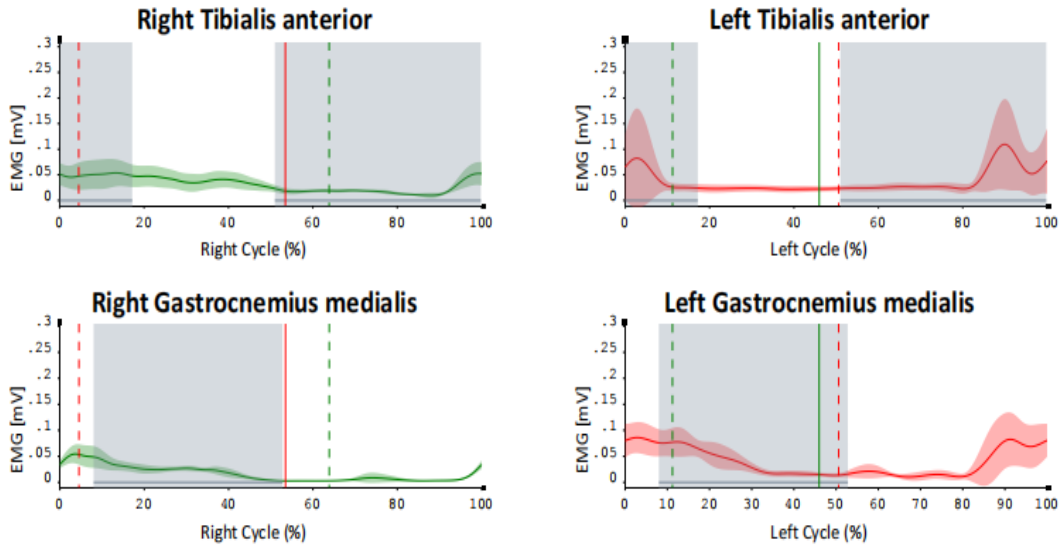

Fig. 4. Electromyographic assessment of muscle activity of m. tibialis anterior and m. gastrocnemius medialis during the left and right gait cycle.

The show in which phases of the gait cycle the activation and deactivation of each muscle studied occur. The gray (darker) bars identify areas in which the muscle should be active (normal activation). If the muscles are well coordinated, they should exhibit a peak of activation in the gray (darker) area and be approximately flat outside it (Fig. 4).

Fig. 4 shows better activation of GM and weak activity of m. tibialis anterior, especially in the left leg, which may lead to a risk of falling during the swing phase on the right and single support on the left. Also, during some phases of the gait cycle, the data for the left leg show co-contraction of the agonist-antagonist muscles, suggesting increased muscle stabilization, most likely a sign of spasticity. The left TA shows reduced amplitude, likely delayed activation during swing. The left GM has a reduced peak in end stance, with a tendency for continued activity in the early swing, while the right leg muscles show indicators in the gray line close to the norms presented by the device software.

4. Discussion

Normal gait is generally symmetrical in both space and time, with interlimb differences in vertical force and temporal parameters measuring less than 6% [1, 10]. In contrast, hemiparetic gait is characterized by asymmetry, poor selective motor control, delayed and impaired balance responses, and reduced loading of the paretic limb. Smooth, symmetrical forward body movement is impaired with large variations in gait patterns associated with the degree of recovery. Additionally, well-controlled limb-to-limb coordination is replaced by massed limb movement patterns (synergies) on the paretic side. These synergies require compensatory adjustments of the pelvis and the non-paretic side [11]. Awad et al. have shown experimentally that hip-hiking and circumduction are often behavioral adaptations (compensations)—not always directly driven by asthenic changes—and that interventions that restore anatomical height and activity time (e.g., through FES or knee/ankle mobility training) can reduce these movements. Increased obliquity in the patient is most likely a compensatory response that is amenable to targeted treatment [12]. Reduced pelvic rotation in the transverse plane is associated with a shorter stride length and an impaired ability to transfer energy from the pelvis to the lower limb during the push-off phase of walking. From a clinical perspective, this helps to explain why the patient's stride length is shortened and their push-off is reduced — part of the energy chain is 'lost' at the pelvic level when transverse rotation is reduced. This is consistent with more recent classifications that consider pelvic excursion amplitude to be a key factor in the functional outcomes of chronic post-stroke patients [6,7,13]. After stroke, increased coactivation between GM/TA is often observed, meaning that the plantar and dorsiflexors are activated simultaneously or with excessive overlap – this increases ankle “stiffness” and reduces swing and push-off efficiency [14]. A study of collective muscle synergies showed that, in post-stroke gait, the time of plantar flexor (GM) activity increases, even during the swing phase when it should be at rest in healthy people. This leads to 'holding back' and slowing down [15]. Therapists often focus primarily on improving dorsiflexion to prevent falls and injuries [16]. However, this does not consider the overall kinematic movement of the lower extremities, and the focus should also be directed towards analyzing the compensatory functions of adjacent joints and muscle groups. In patients with insufficient dorsiflexion and/or insufficient knee flexion impulse in swing, adequate foot clearance and effective push-off in terminal stance are lacking. As a result, frontal-planar compensations occur—most commonly pelvic “hiking” (increased obliquity) and/or circumduction—which increase the vertical position of the pelvic girdle and facilitate the passage of the paretic leg through the swing phase. This logic is well described in the classic reviews of hemiparetic gait [10,11]. In addition, rehabilitation should have components for symmetry, rhythm, and balance — since muscle deficits manifest themselves precisely in the integration of the limb into the function of gait. The gait velocity of individuals with post-stroke gait impairment ranges from approximately 0.18 to 1.03 metres per second. In contrast, the gait velocity of healthy, age-matched adults is 1.4 m/s [7]. Reduced walking speed and compensatory pelvic movements (such as hiking, increased obliquity and vaulting of the contralateral leg) increase the mechanical and metabolic cost of walking. These movements are often associated with reduced independence and increased fatigue. Reducing these compensations is important in therapeutic planning, as it leads to improved walking distance and speed, as well as a reduced risk of falls [17]. The combined analysis of pelvic kinematics and EMG profile shows that the pelvis functions as a “replacement motor” – through

elevation (obliquity) and rotational restriction, it compensates for the lack of strength and control in the ankle joint. This is consistent with the descriptions of Awad et al. (2017) and Komaris et al. (2025), according to which pelvic compensations are primarily behavioral adaptations that arise in response to peripheral weakness and impaired muscle timing [12, 15]. A post-stroke gait analysis of a hemiparetic patient reveals an interdependence between muscle weakness, impaired coordination and compensatory pelvic movements. Reduced functional activity in the left TA and GM causes asymmetry, a higher energy cost and lower walking efficiency. Targeted rehabilitation should aim to restore synchrony between the dorsiflexors and plantar flexors, while reducing pelvic compensations. This will lead to improved gait symmetry and functional independence.

5. Conclusion

Locomotor disorders following a stroke are serious, progressive disabilities that affect all aspects of patients' lives, not just motor problems. The study showed that the hemiparetic gait pattern after stroke results from a combination of deviations and compensatory movements dictated by residual function. Gait analysis of hemiparetic patients reveals an interdependence between muscle weakness, impaired coordination and compensatory pelvic movements. For this reason, each patient should undergo an examination to identify and document their unique temporal-spatial gait pattern. Quantitative gait analysis is the recommended method for understanding the complex, multifactorial nature of gait dysfunction in hemiparetic patients. It facilitates the identification of deviations from normal gait in individual phases. Innovative analytical systems enable personalised interventions to be designed to measure recovery of a similar gait pattern after stroke, using temporospatial, kinematic and kinetic indicators to identify specific deviations and compensations. This enables clinicians to design more objective and effective, patient-specific interventions. Early diagnosis, regular functional assessments (including electromyography and kinematic assessments) and targeted rehabilitation are essential for improving gait and independent performance in activities of daily living.

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Limitation of the study

The protocol provides high-quality temporal parameters and graphs of pelvic kinematics but lacks quantitative ROM values (in degrees) and full temporal normalization of EMG onsets/offsets. For a more rigorous causal relationship between reduced TA/GM and specific pelvic compensation, 3D motion capture and synchronized, normalized EMG analysis with calculated onsets/offsets and co-contraction coefficients (CCI) are recommended. This will allow for more detailed follow-up in future interventions.

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