MODULE 2: BIOMECHANICS IN STROKE REHABILITATION

Session 4: BIOMECHANICS AND ITS ROLE IN THERAPEUTIC DECISION-MAKING

Index

1. LEARNING OBJECTIVES

The main objectives of this session are:

- To describe the usefulness and main applications of biomechanical assessment in the field of rehabilitation, with special emphasis on neurorehabilitation.
- To analyse the state of the art and the existing scientific evidence in relation to the role of biomechanics and instrumental techniques in the decision-making process and the therapeutic management of patients with neurological pathologies, with special attention to patients with stroke.

At the conclusion of the session, the student should be able to recognise the applicability of biomechanical studies using instrumental techniques and to justify it based on existing scientific evidence in order to use these tools in clinical practice to help decision-making in the rehabilitation treatment of the neurological patient.

2. APPLICABILITY OF BIOMECHANICAL ASSESSMENT IN THE NEUROREHABILITATION FIELD

2.1. Functional assessment in rehabilitation

Within the rehabilitation field, functional assessment is of vital importance both to determine the functional prognosis of the disabled patient and to plan the treatment and measure the results of a determined therapeutic action. In general terms, the main objective of rehabilitation programmes is to achieve the highest level of recovery and to improve and maintain function in order to provide the best quality of life and as much independence as possible for the disabled patient, whatever the cause.

As explained in chapter 3.3 (E.Viosca Herrero) of the *Manual of Rehabilitation and Physical Medicine*, the term "functional assessment" refers to the process through which the data about a specific function are measured, collected and assessed. A function is considered to be "what people do and how they do it" (walking, handling objects, etc.), tasks that allow individuals to adapt to the environment by performing activities of daily living (ADLs). Given the importance of functional assessment in the rehabilitation field, it is logical to think that the development and progress of functional assessment methods is a key element in the development and progress of rehabilitation itself.

Because of the potential severity of neurological deficits in stroke, it is even more important than in other rehabilitation areas to accurately assess the patients function and, therefore, their disability. As discussed in session 1 of module 1, a complete neurological examination generally includes an exhaustive assessment of the patient's superior functions, motor function, reflexes and sensitivity, as well as specifically assessing fundamental functions such as sitting, standing, manipulating, and especially gait and balance, which were more thoroughly described in previous sessions.

Regarding the methodology, the most commonly used instruments traditionally include functional assessment scales to assess a specific segment (shoulder, knee, hip) or a specific function (gait scales, balance scales, etc.), and global scales, which consider the individual holistically and assess disability generically. Some of the recommendations for assessing deficits and function in patients after stroke according to classical methods (manual tests and clinical scales) included in the *Stroke Rehabilitation Clinical Practice Guidelines* 2016 of the American Heart Association/American Stroke Association are shown below:

Construct/Measure	Comments	Approximate Time to Administer, min
Impairment		
Paresis/strength		
Motricity Index	Consists of strength testing via manual muscle testing at 3 key UE segments and 3 key LE segments; yields a score from 0–100 indicating strength of each limb	<5 for UEs; <5 for LEs
Muscle strength	Via manual muscle testing, graded on a 0–5 scale or handheld dynamometry	<5
Grip, pinch dynamometry	Grip and pinch dynamometers are available in most rehabilitation clinics and hospitals; normative data are available for comparison	<5
Tone		
Modified Ashworth scale	Quantifies spasticity on a scale measuring resistance to passive movement from 0–4, with higher numbers indicating greater severity; can assess at all joints or only a few	10
Sensorimotor impairment measures		
Fugl-Meyer	Quantifies sensorimotor impairment of the UE (0–66 points) and LE (0–34 points) on separate subscales; items are rated on ability to move out of abnormal synergies	25
Chedoke McMaster Stroke Assessment, impairment inventory	Quantifies impairments in 6 dimensions of shoulder pain, postural control, arm, hand, leg, and foot, each on a 7-point scale, with higher scores equalling less impairment	45
Activity		
UE function		
Action Research Arm Test	Criteria based with 19 items; scores are from 0–57, with normal=57; allows observation of multiple grasps, grips, and pinches	10
Box and Block Test	Score is the number of blocks moved in 1 min; higher scores equal better performance; normative data are available for comparison	<5
Chedoke Arm and Hand Activity Index	Criterion based with functional items requiring bilateral UE movement; available in 7-, 8-, 9-, and 13-item versions	25
Wolf Motor Function Test	Time- and criterion-based scores on 15 items; contains some isolated joint movements and some functional tasks	15

Construct/Measure	Comments	Approximate Time to Administer, min
Balance		
Berg Balance Scale	Criterion-based assessment of static and dynamic balance; widely used in multiple settings	15
Functional Reach Test	A single-item test that measures how far one can reach in standing; normative data are available for comparison	<5
Mobility		
Walking speed†	Brief and widely used; categories based on speed are: <0.4 m/s=household ambulation 0.4–0.8 m/s=limited community ambulation >0.8 m/s=community ambulation; normative data available for comparison	<5
Timed Up and Go	Quantifies more than straight walking, including sit/stand and a turn; scored by time to complete; criterion values available for comparison	<5
6-Min walk test	Quantifies walking endurance; normative and criterion values for community ambulation distances available	<10
Functional ambulation category	Classification made after observation or self-report of walking ability; 6-point scale with higher equals better walking ability; this tool allows assessment of walking ability in people who are not independent ambulators	<5
Observational gait analysis	Commonly used in many clinics to plan treatment programs; several standardized formats are available; appropriate to use in conjunction with one of the above more quantifiable measures	5
Participation		
Self-reported impairments, limitations, and restrictions		
Stroke Impact Scale: Strength, Mobility, ADL, and Hand Function subscales	These 4 subscales measure different aspects of physical performance; people rate their perceived ability to do different items; each subscale ranges from 0–100, with higher scores indicating better abilities	5 per subscale
Motor Activity Log	14 or 28 questions about how the affected UE is used in daily life; scores range from 0–5, with 5 equal to similar to before the stroke	20
Activities-specific Balance Confidence Scale	16 questions in which people with stroke rate their balance confidence during routine activities; scores range from 0–100, with higher scores indicating more confidence	20

Figure 1 Table of recommended measures in stroke patients. From *Guidelines for Adult Stroke Rehabilitation and Recovery: A Guideline for Healthcare Professionals* of the American Heart Association/American Stroke Association. Downloaded from http://stroke.ahajournals.org/

It should be noted that, according to the recommendations of the Spanish Society of Rehabilitation and Physical Medicine (SERMEF), in order to evaluate the results of a rehabilitation programme in a patient with stroke, it is necessary to differentiate between deficit in a function, limitation in an activity or participation restrictions, following the general framework of the International Classification of Functioning Disability and Health (ICF).

As seen in session 1 of this module, besides the methods and scales explained, recent technological advances have created solutions with various levels of complexity and usability that allow us to assess deficits in different quantities of movement or force, as well as to perform a global assessment of functions such as gait or balance. These new methods, which are increasingly perfect, offer a series of advantages over classical scales, manual tests and visual analysis, as explained in session 1. In this way, we know that instrumental techniques, once validated and tested for reliability, can provide greater accuracy, objectivity and sensitivity to change when physical examination and clinical scales are not enough. In addition, these techniques give comprehensive and complex information related to basic functions such as gait, balance or manipulation.

2.2 Usefulness of biomechanical assessment in stroke rehabilitation

In general, from the clinical point of view, instrumental analysis in stroke is mainly useful to assist in the diagnosis, to help to determine the main cause of a specific disorder and the severity of such disorder or injury, to select between different therapeutic options, and to predict and assess the results of a specific intervention.

More specifically, it should be noted that the neurorehabilitation field in which biomechanical analysis has proved to be most useful is balance study, and prominently gait study.

In the case of balance, the techniques for studying postural control (such as posturography, which measures the centre of pressure, as seen in session 3 of this module) can provide information and data about the functional disorder of this activity and about the degree of compensation achieved by the central nervous system. Although it does not give a precise nosological or topographic diagnosis, it makes it possible to define the treatment (either medical or rehabilitative) based on the deficits detected. From the rehabilitation perspective, this technique is interesting for many reasons. On the one hand, it makes it possible to diagnose the function and progress in balance disorders and postural instability, in this case, of neurological origin. On the other hand, it allows us to design an individualised treatment according to the deficiencies and dysfunctions of each subject, to retrain postural control using visual feedback techniques, and to monitor clinical progress.

Regarding gait analysis, although the visual analysis of this function is usually performed by musculoskeletal system professionals, it is often unsystematic, and usually provides only a general impression of the patient's walking ability. A thorough analysis of gait requires a systematic approach, preferably by means of objective measurement techniques. This type of objective and comprehensive study could help clinical decision-making in various stages, as proposed in chapter 5 of *Gait Analysis, An introduction* (Michael W. Whittel, 1991):

- Hypothesis formulation. Search for the cause or causes of the abnormality or disorder observed, which involves a thorough review of all the assessment data. In this sense, it is important to know that a patient's gait pattern is **not completely the result of the pathology, but rather a combination of the original problem and the patient's compensation ability**. It is therefore imperative to understand which deviations from normality should be treated and which should not because they are compensating for the original pathology and therefore improving function and final gait efficiency.
- Hypothesis testing. There are several ways to test the hypothesis about the cause of the main disorder and/or the factors that need to be addressed to improve gait pattern and efficacy. Gait can be studied using different methods (combining kinematic 3D information with dynamic information and surface electromyography, for example) or a new study can be performed after modifying a specific aspect (for example, by paralysing a muscle with local anaesthesia or placing an orthosis) and then analysing the changes.

Some specific examples of gait disorders and their possible cause, as well as the disorders that would confirm such cause in a comprehensive study of gait, are included below:

Disorder observed	Possible causes	Diagnostic, biomechanical and neuromuscular evidence
Initial plantigrade stance	A) Hyperactivity of plantar flexors at the end of the swing phase B) Stiffness structured at ankle level C) Shortening of step length	A) Excessive muscle activity (EMG) in plantar flexors at the end of the swing phase B) Limitation of the total range of motion of basal ankle and during the gait cycle C) See next section*
Shortening of step length*	A) Weak pre-swing toe-off B) Weakness in hip flexors at final toe-off and initial swing C) Excessive deceleration of lower limb at terminal swing D) Hyperactivity of contralateral hip extensors during stance phase	A) Ankle flexor moment/power generation/EMG activity of plantar flexors below normal at take-off B) Hip flexor moment/power/EMG activity of hip flexors below normal at terminal stance (pre-swing) and initial swing C) Muscle activity of knee flexors (EMG)/flexor moment/power absorption above normal at terminal swing D) EMG muscle hyperactivity of contralateral hip extensors
Stiff knee in flexion during stance phase	Extensor hyperactivity in the initial and mid stance of hip and ankle support, with a reduction in extensor activity in the concomitant knee	EMG hyperactivity/increase in the hip extensors and plantar flexors moment at initial and mid stance
Trendelemburg gait	A) Weakness in the abductors of the hip B) Hyperactivity in the adductor muscles of the hip	A) Muscle activity (EMG) below normal in hip abductors (gluteus medius and minimus, tensor fasciae latae) B) Muscle activity (EMG) above normal in hip adductors (longus,magnus, brevis y gracilis)

Table 1. Example from Michael Whittel. *Gait Analysis, an introduction*. British Library Cataloguing in Publication Data, 1991 ISBN 0 75060045 4

As Baker R. et al. explained in their paper from 2016, the dynamic analysis and the analysis of muscle activity during gait allow us to make an accurate and individualised therapeutic decision in relation to where a specific focal treatment of the lower limb should be applied. This involves choosing a treatment with an orthosis, selecting the muscles to be injected with botulinum toxin, nerve blocks or orthopaedic surgery for tendon transfers, lengthening, or correction of bone misalignment. For example, in cases of equinovarus foot of neurological origin (common in acquired brain damage), the clinical examination, along with kinematic, dynamic and EMG analysis can help to find the cause of the deformity (hyperactivation of plantar flexors during swing or stance, hypoactivation of dorsiflexors in the swing phase, stiff knee, knee flexion, or hip flexion and adduction, among other causes). Detecting the true cause of this type of pattern may be particularly relevant to decide whether or not to inject botulinum toxin in the plantar flexors, since an inadequate inactivation of these muscles could worsen gait speed and step length.

As previously seen in this section, balance and gait are the functions in which there is the most evidence and experience on the usefulness of biomechanical analysis; however, instrumental techniques offer great potential usefulness for measuring other functions and segments in stroke patients. For example, the next section will show some authors who are studying the advantages of using this type of objective analysis to determine variables in upper limb movement.

3. SCIENTIFIC EVIDENCE ON THE ROLE OF BIOMECHANICHAL ASSESSMENT IN THE MANAGEMENT OF STROKE PATIENTS

In order to give a rigorous answer to the usefulness of instrumental techniques and new technologies in the decision-making process, it is necessary to know the existing scientific literature about this subject. To this end, a literature review was performed focused on documents and articles that analyse the usefulness of biomechanical analysis techniques in stroke rehabilitation. This session includes some of those that are considered to be the most interesting ones.

3.1 Clinical guidelines

The most outstanding guidelines are the ***Guidelines for Adult Stroke Rehabilitation and Recovery*** of the **American Heart Association/Stroke Association 2016.**

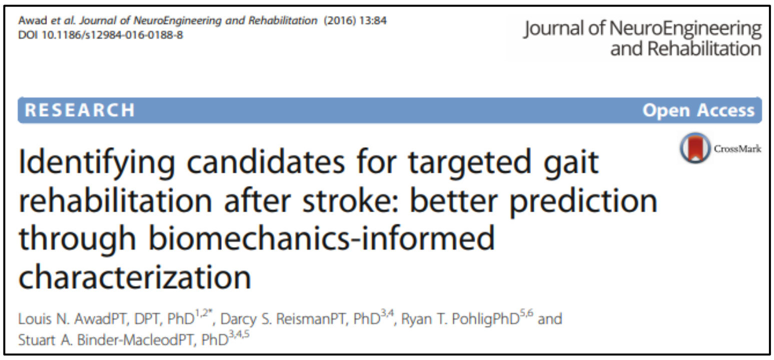
These guidelines refer to the need for a regulated and periodic assessment of the patient functions, as well as to the usefulness of new technologies in such assessment and in the rehabilitation treatment of the stroke patient.

Area	Observations	Class of recommendation	Level of evidence
Assessment of motor deficits	The assessment of motor deficits, upper limb activity, balance and general mobility using standardised objective tools is useful in patients with post-stroke sequelae.	IIb	C
	The use of **technology** as an **objective measurement method** to assess the individual's activity and participation after stroke is considered useful. Patient monitoring in real environments is emphasised.	IIb	C
Risk of falling	The risk of falling of the stroke patient should be assessed at least once a year using an **appropriate instrument**.	IIa	B
Balance and gait	Stroke patients should be assessed in relation to balance and risk of falling.	I	C
	The treatment of ataxia should consider training in task-oriented postural control.	IIb	C
	The **standardised and objective measurement** of **balance** and **gait speed** can be considered when planning the rehabilitation treatment in the subacute phase, as well as in family safety recommendations.	IIb	B
Mobility and Virtual Reality	Treatment using **Virtual Reality** can help **gait** improvement.	IIb	B
	It is reasonable to consider a treatment with **Virtual Reality** for **upper limb** rehabilitation after stroke.	IIa	B

Table 2. Examples from the *Guidelines for Adult Stroke Rehabilitation and Recovery* of the American Heart Association/Stroke Association 2016. For more information about the meaning of the recommendation classes and levels of evidence, watch the video associated with this session.

3.2 Instrumented functional assessment and its use to enhance the rehabilitation process

Patient functional assessment is perhaps the field in which there is the most evidence of the usefulness of various instrumental techniques. This is especially obvious in the functional analysis of gait after stroke, although it is not the only function that has been studied from the biomechanical perspective. In relation to gait, it should be noted that, although speed is one of the most significant parameters, many authors underline the need to determine other complementary variables depending on the objectives:


Awad *et al. Journal of NeuroEngineering and Rehabilitation* (2016) 13:84
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Journal of NeuroEngineering and Rehabilitation

RESEARCH — Open Access

Identifying candidates for targeted gait rehabilitation after stroke: better prediction through biomechanics-informed characterization

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Awad LN et al. 2016

Previous hypothesis. Although gait speed is a recognised parameter because of its clinical significance and relationship with the measurement and prediction of gait quality, ambulation in the community, functional prognosis and quality of life, there are multiple mechanisms underlying the changes in this parameter, including symmetry and compensating strategies. With this in mind, it is not clear whether the speed of basal gait is sufficient to predict the improvements resulting from therapeutic interventions, especially those intended to improve a particular aspect or deficit. The authors suggest that a deeper knowledge of gait biomechanics and the factors underlying gait efficacy would help to identify the candidates for a specific type of motor training, as well as to assess the results of such treatment.

Objective of the study. The aim is to determine if other parameters different from gait speed—such as the ability to generate propulsion during gait with the forces of the paretic limb (in a dynamic study)—are related to the final improvement of gait efficacy and speed after a specific therapeutic intervention focused on improving the propulsive force of such limb. Similarly, whether this parameter can differentiate which patients are candidates for this type of treatment should also be determined.

Method. A sample of 26 subjects with post-stroke hemiparesis (at least 6 months after the event, able to walk without technical aids for 6 minutes) were assessed after performing a training programme based on the specific improvement of the propulsive forces in the paretic limb, by combining fast gait with functional electrostimulation of the leg muscles ("FastFest programme"). Gait was assessed in relation to temporal parameters (mainly speed) and dynamic parameters (propulsive forces in the paretic limb) before the intervention, after the intervention, and 6 months later.

Results and conclusions. The measurement of the spontaneous and maximum speed of basal gait was poor to predict the improvements occurred after treatment in terms of speed. However, the measurement of the interaction of the propulsive force with the basal speeds determined, through statistical regression models, that the slower patients with greater propulsive force in the paretic limb responded better to the treatment than faster patients in the basal measurement in isolation.

Finally, the authors of the study suggest that the characterisation of subjects based on both speed and the generated reaction forces (in this case, propulsion) is a much better marker to predict the functional improvement of gait, as well as to assess the appropriateness of a specific rehabilitative treatment, in this case, the “FastFES” programme.

Analysis of Impairments Influencing Gait Velocity and Asymmetry of Hemiplegic Patients After Mild to Moderate Stroke

An-Lun Hsu, MS, PT, Pei-Fang Tang, PhD, PT, Mei-Hwa Jan, MS, PT

Hsu AL et al. 2003

Previous hypothesis. In stroke patients, gait is usually characterised by slow speed and asymmetry in various spatiotemporal parameters. In order to allow patients to improve their gait quality, based on the improvement of such items, it is necessary to identify the most important underlying factors that cause the aforementioned disorders. Although the importance of factors such as strength, motor control and spasticity, balance, and sensory and visual deficits has been considered, there is controversy about how and to what extent each of these factors contributes to the worsening of gait speed and asymmetry.

Objectives. To study the association of various factors with gait quality in patients with stroke sequelae, and to identify the most important deficits that determine gait speed and asymmetry.

Method. Twenty-six subjects with mild to moderate spastic hemiparesis after stroke (independent ambulators with no technical aids) were assessed in terms of isokinetic strength in hip flexors, knee extensors and ankle plantar flexors (using the Cybex 6000 dynamometry system), motor and sensory function (using the Fulg-Meyer assessment), and plantar flexor spasticity (with the modified Ashworth scale). In addition, a gait assessment was performed, taking into account speed and spatiotemporal parameters.

Results and conclusion. The statistical analysis revealed that the most important independent determinant of gait was the total isokinetic work at the level of the hip flexors and the knee extensors. The most significant determinant of asymmetry in the spatiotemporal parameters was spasticity at the level of the plantar flexors.

The authors conclude that gait speed and asymmetry are affected in different ways by the various deficits studied in patients with stroke. Thus, any therapeutic intervention intended to improve gait speed should consider the improvement in the strength of the hip flexors and knee extensors, whereas those interventions intended to improve symmetry should consider the treatment of spasticity mainly in the plantar flexors of the affected limb. In short, it is necessary to know the aspect or gait disorder on which we must work and its underlying cause in order to design a specific and efficient treatment in each case.

Davies RJ et al. 2016

JMIR REHABILITATION AND ASSISTIVE TECHNOLOGIES Davies et al

Original Paper

A Personalized Self-Management Rehabilitation System for Stroke Survivors: A Quantitative Gait Analysis Using a Smart Insole

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Previous hypothesis. Given the current prevalence and health costs associated with stroke, it is necessary to promote initiatives related to long-term care, monitored and self-managed by the chronic patient. In this respect, the use of new technologies makes it possible to monitor progress in real patient contexts and to promote self-care through motivation strategies and biofeedback provided by these systems.

Objective. To assess the impact of a system for assisted telerehabilitation and for monitoring biomechanical parameters during gait through a sensorised insole (image on the right).

Figure 2. Instrumented insole. Image from the article by Davies RJ et al., 2016

Method. Five patients with post-stroke sequelae (independent ambulators) participated in the intervention for a period of 2 months. The software integrated in the system monitored progress and motivation through a tablet and a smartphone, connected with the software via WiFi. The clinician could see the data stored using the appropriate software.

Users were encouraged to walk a distance and a duration chosen by them on a regular basis. In addition, the system included a set exercises for the upper and lower limbs that could also be chosen by the patients themselves.

Results and conclusions. Compared to the beginning of the programme, 4 of the 5 participants showed an improvement in the initial stance pattern of the affected limb. All of them showed a significant increase in gait speed. Regarding the symmetry of the spatiotemporal parameters, 4 of the 5 participants showed a worsening of 8.5%, which the authors associate with learning dual tasks and compensation strategies, "sacrificing" the symmetry of certain parameters for a better initial stance pattern, thus improving overall gait efficacy.

Johansson GM et al 2017.

Johansson et al. Journal of NeuroEngineering and Rehabilitation (2017) 14:11
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RESEARCH Open Access

The added value of kinematic evaluation of the timed finger-to-nose test in persons post-stroke

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Previous hypothesis. The finger-nose test is a validated gesture for measuring upper limb coordination in patients with stroke. It is included in the Fulg-Meyer assessment. Although the result is fundamentally assessed with respect to how long it takes the patient to perform the movement, a kinematic analysis could thoroughly characterise the coordination of the upper limb by measuring motor control and movement quality.

Erasmus+

Additionally, it is necessary to fully understand the construct and real measuring properties of common reaching gestures used in clinical tests.

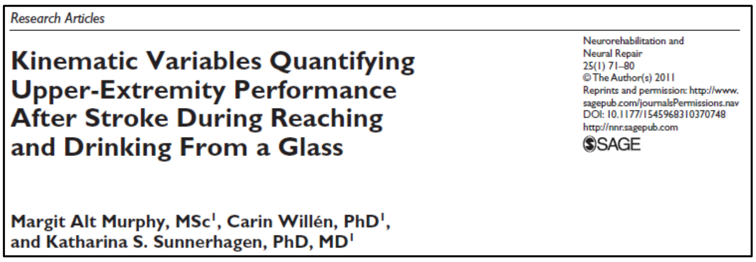
Objective. To characterise the "finger to nose" gesture in people with stroke in terms of kinematic parameters, to find significant variables that help differentiate between different levels of upper limb functionality after stroke, and to validate this test in the determination of coordination.

Method. The "finger-nose" activity was assessed in 33 patients after stroke, with mild to moderate sequelae at upper limb level (score of 50-62 or 32-49 in Fulg-Meyer) and in a control group of 41 healthy subjects. The total time to perform the movement and several kinematic variables of the hand, elbow, shoulder, scapula and trunk were calculated. The analysis focused on the approaching or reaching phase of the finger to the nose. A subgroup analysis was performed according to the performance time and stroke severity.

Results and conclusions. The total time to perform the gesture is significantly higher in the group of stroke patients than in the healthy control group. Another 6 variables of the kinematic analysis showed significant differences between both groups. In addition, at similar speeds, the group of stroke patients performed worse in relation to the variables related to movement precision and there was excessive mobilization at the scapula and trunk level in comparison with the healthy ones. The finger-nose reaching time and the elbow flexion during the gesture were the most related and differentiating variables among the different degrees of stroke severity.

It should be noted that there is an important relation between the amount of elbow flexor action and the amount of shoulder flexor action during the gesture in stroke patients with respect to the tendency to flexor synergy. In addition, no direct correlation was found between the time it takes the patient to perform the gesture and the precision variables, since, in many cases, an increase in speed involves a decrease in these variables. Therefore, the time it takes to perform the gesture cannot be considered in isolation as the variable that distinguishes between mild and moderate cases of upper limb involvement in stroke.

The authors suggest that the execution time of the finger-to-nose reaching gesture can distinguish between mild and severe deficits of the upper limb. However, the kinematic analysis of the construct validity of this gesture highlights differences in the movement quality during the movement (precision, smoothness) that is not perceived by the isolated measurement of time, and which can be important to assess the real quality of the movement and the needs of each patient when planning a specific rehabilitation.


Research Articles

Kinematic Variables Quantifying Upper-Extremity Performance After Stroke During Reaching and Drinking From a Glass

Neurorehabilitation and Neural Repair
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DOI: 10.1177/1545968310370748
http://nnr.sagepub.com
SAGE

Margit Alt Murphy, MSc[1], Carin Willén, PhD[1], and Katharina S. Sunnerhagen, PhD, MD[1]

Murphy MA et al 2015

Previous hypothesis. After a stroke, 80% of the patients show some kind of deficit at upper limb level, which involves limitation in terms of activity and participation. These deficits are classically estimated based on scales such as the Fulg-Meyer. However, these methods may not be sensitive enough to small changes, therefore, it is necessary to have more precise and objective methods. The kinematic analysis of movement can provide information about the components and strategies of movement through parameters such as speed and acceleration, or the linear and angular displacements of each segment. In this way, this type of analysis can provide information on the motor control of the upper limb in reaching and gripping activities.

Objective. To identify kinematic variables that accurately quantify the motor function of the upper limb in order to thoroughly assess the results of a therapeutic intervention and the needs and progress of the patient with regard to upper limb disability. In this case, this objective will be accomplished by analysing a common reaching and gripping activity such as taking a glass of water and drinking.

Method. Nineteen stroke patients and nineteen healthy control patients were included in the study. The activity assessed was reaching a glass placed on a table in front of the patient, lift it to their mouth, take a sip of water, and put it back in its place. A kinematic analysis was performed according to the variables of speed, movement strategy and smoothness (number of movement units, mainly), time taken to perform the gesture, interarticular coordination and compensatory movements.

Results and conclusions. Most of the kinematic parameters analysed showed significant differences between the patients and the control group. The number of movement units (related to smoothness), the total time of the gesture, and the maximum peak of angular velocity of the elbow were the parameters that best differentiated patients from healthy subjects, as well as patients with mild from moderate .

At joint level, it is worth highlighting the existence of greater shoulder abduction during the "drinking" phase and a smaller maximum extension of the elbow in the glass reaching phase in patients with stroke versus healthy subjects (maximum elbow extension was also lower in patients with moderate involvement compared to those with mild involvement). At trunk level, the anterior displacement calculated during the gesture was greater in patients with stroke. With regard to interarticular coordination, patients with stroke showed greater difficulty performing a coordinated movement of elbow and shoulder simultaneously, with differences between patients with mild and moderate involvement.

The authors of the study conclude that the kinematic study of the gesture described allows us to identify a series of variables related to movement that can be taken as an objective measurement of the upper limb function in people with stroke sequelae. The differences found in the analysis, which cannot often be measured in a visual analysis or with scales, provide us with information about the needs and the progress of the patient. For example, when designing the treatment, it will be necessary, among other aspects, to treat both the mobility in the abduction axis of the shoulder and the extension of the elbow, as well as the coordination between both segments, and focus on one of those objectives during the therapy depending on the needs detected for each patient.

The following summary includes other articles of interest in which the authors performed a functional assessment of the stroke patient using instrumental techniques to characterise the specific deficits and thus improve the global management of the rehabilitation patient:

Article	Objective of the study and main results
Jonsdottir J. et al. 2009. Functional resources to increase gait speed in people with stroke: Strategies adopted compared to healthy controls.	The objective of this study was to identify the mechanisms and strategies used by stroke patients to increase gait speed. To this end, a kinematic and dynamic biomechanical study of gait was performed on 39 patients with post-stroke sequelae at 2 speeds (comfortable and maximum). Generally, stroke patients walked at a lower speed, with higher cadence and shorter stride length. The results indicate that, in order to increase gait speed, patients with hemiparesis draw on different functional resources that varied from individual to individual (positive/negative work and power at ankle and hip level, stride length or cadence). Thus, gait analysis at different gait speeds should be adopted to develop individualised programmes that will improve gait pattern and consequently the patient quality of life.
Perry J et al 1995. Classification of Walking Handicap in the Stroke Population.	The aim of this study was to improve the accuracy of functional prognosis from the acute phase in stroke patients, as well as to establish relationships between deficit, disability and activity limitations. To do this, a total of 148 patients with stroke sequelae were assessed in relation to functional gait capacity using the modified Hoffer Functional Ambulation scale, spatiotemporal gait parameters (speed, support pattern, stride length, cadence), global mobility through a 19-item questionnaire (walking ability questionnaire), muscle strength using manual tests, voluntary motor control, and proprioception. The authors found that the parameters of voluntary motor control and extension strength at knee level were better related than the rest with respect to disability and differentiated household from community ambulators. In addition, the velocity gait parameter improved the functional prediction.
Hall A.L. et al 201. Biomechanical variables related to walking performance 6-months following post-stroke rehabilitation.	The aim of this study was to identify the biomechanical variables associated with the improvement of gait speed at free cadence after completing a training programme on treadmill with partial body weight support in patients with stroke sequelae. Experimental kinematic and kinetic data were recorded from 18 hemiparetic patients after completing a 12-week locomotor training programme on treadmill with a 6-month follow-up study. The study found that most subjects improved or retained their self-selected speed gait after treatment from post-training to the follow-up session. Moreover, step length symmetry and the number of steps in daily activity were positively related to walking speed improvements. The authors conclude that the motor control deficits that lead to persistent step length asymmetry and low daily step activity

	at the end of rehabilitation are associated with poorer outcomes six months after the completion of the programme.
Yang S. et al 2013 Estimation of spatio-temporal parameters for post-stroke hemiparetic gait using inertial sensors.	The authors intend to develop an inertial sensor system for assessing post-stroke gait through parameters such as walking speed and spatiotemporal gait symmetry. Two inertial sensors were attached in the midpoint of each leg to measure the accelerations and angular velocity during gaitin 13 subjects with post-stroke hemiparesis. The results show that, despite the abnormalities in hemiparetic gait, the angular velocity of most subjects (12 out of 13) was similar to that of healthy individuals, which made it possible to estimate the walking speed and to detect gait events based on the pendulum model. The results of a standard 10-meter walk test showed that the IMU-based method has excellent coherence with the stopwatch method classically used in the clinical setting. However, the segmentation of gait events failed when the angular velocity significantly deviated from the profile of the healthy groups (1 subject). The authors conclude that, with further development and simultaneous validations, the sensor-based inertial system may eventually become a useful tool to continuously monitor the spatiotemporal parameters of gait in a real environment with stroke patients.
Mah CD et al 1999 Quantitative Kinematics of Gait Patterns During the Recovery Period After Stroke	The purpose of this study was to assess the potential of a new quantitative kinematic analysis based on the analysis of major components in order to document the gait function and progress in patients with a neurological injury. To this end, a gait study was performed on 16 hemiparetic patients with preserved ambulation ability one year after the stroke. Gait speed and stride length were analysed, among other spatiotemporal parameters. Seven patients showed a 50% increase in the self-selected gait speed from the first to the last test. The analysis of the kinematic pattern suggested that different mechanisms were used to generate changes in gait speed at different speed levels. The authors conclude that there is a significant fraction of stroke population for whom the analysis of the kinematic gait pattern can provide information different from that provided only by speed, stride length, and cadence. In addition, kinematic analysis can provide information on the mechanisms of pathological gait, which can be very useful when establishing the objectives of a rehabilitation programme.

3.3 Examples of specific uses

As seen in the previous section, multiple authors try to improve the diagnostic process by performing an objective instrumented analysis of functions, such as gait (fundamentally) or object manipulation in daily activities. These authors try to make an assessment from a global perspective based on the function studied in order to assess or monitor the status of stroke patients.

There are also authors who describe the usefulness of instrumental analysis techniques in making therapeutic decisions with specific objectives. For example, to select an orthosis to treat equinovarus foot, the surgical technique for neurological equinovarus foot, or to specifically detect patients with risk of falling.

The article from 2003 "*Three dimensional gait analysis and controlling spastic foot on stroke patients"* by Caillet F et al., performs a kinematic study of gait in the 3 planes in order to specifically measure the effects of an orthosis compared with the selective neurotomy of the tibial nerve (internal popliteal sciatic) in the treatment of foot spasticity in stroke patients who are able to walk, and who show plantar flexors spasticity and some degree of equinovarus foot. For this purpose, after the physical examination of the strength and spasticity of the lower limb, a biomechanical gait analysis was performed on two groups of patients. In a group of 10 patients, gait was analysed barefoot and with a Saitn Genis type orthosis (see figure 3), whereas in another group of 9 patients, gait was studied barefoot before and 6 months after the selective tibial neurotomy. The results of the study showed that in the first group average ankle spasticity was 2.5 on the Ashworth scale, gait with orthosis was more efficient in terms of speed, and equinus disappeared in the swing phase. Additionally, in the stance phase, the typical recurvatum of these patients was also controlled by the orthosis, anterior pelvic tilt decreased, and hip extension increased. Moreover, these changes were related to reduced discomfort during gait. In the second group (neurotomy group), 6 months after the neurotomy, the spasticity decreased from 3.4 to 0, gait speed increased, and ankle dorsiflexion improved in the mid stance phase, which helped the tibia progression and corrected the recurvatum of some patients during the stance phase. The authors conclude that 3D gait analysis is a useful tool for the functional assessment of this activity, which can specify the degree of correction provided by an orthesis or by tibial neurotomy, as well as the impact on the upper segments.

The article from 2002 by Fuller DA et al., *Impact of Instrumental Gait Analysis on Surgical Planning: Treatment of Spastic Equinovarus Deformity of the Foot and Ankle* intends to identify the specific degree of contribution of instrumented gait analysis to the decision about the surgical technique to treat ankle deformity and foot equinovarus in patients with acquired brain damage (including patients with stroke sequelae). For this purpose, two surgeons were asked to independently assess 36 patients with this deformity and to design a detailed surgical plan, before and after a comprehensive gait assessment including 3D kinematic analysis and surface electromyography (EMG). The authors of the study found that the planning of the surgical techniques (lengthening, transfer, release, no surgery) changed up to 64% after the biomechanical gait analysis. Besides, the instrumented analysis also increased the agreement between both surgeons about the surgery planning. It should be also noted that the deformity was corrected in all cases. The authors highlight the fact that the equinovarus deformity of neurological origin can be caused by various forces, and that no surgical technique is the most appropriate to solve it. Therefore, a thorough understanding of the deformity causes is important, including an approach to muscle activity through an EMG study, in order to choose the best treatment and obtain the best possible results.

The study from 2013 by Baetens T et al., *Gait analysis with cognitive-motor dual tasks to distinguish fallers from non-fallers among rehabilitating stroke patients*, intends to assess the level of risk of falling in 32 stroke patients using gait analysis through spatiotemporal parameters, with and without combined dual task. In the dual task, the evaluator asked the patient to repeat or name a series of items such as animals or subtractions in threes. After the gait study, a follow-up of the falls, which the patients wrote down in a "diary of falls", was performed. The results showed a correlation between a shorter stride length and a shorter step length in the healthy side during gait with dual task in relation to a greater risk of falling. These findings can help differentiate those patients who need a more specific and powerful intervention to prevent falls from those who do not need it.

3.4 Biomechanical assessment and therapeutic decision-making in the clinical field

Before finishing the session, it is worth pointing out that, as Wren TAL et al. mention in their systemic review from 2011, there is strong evidence in favour of the use of instrumental techniques, specifically in the gait analysis of neurological patients, in terms of reliability, validity and diagnostic accuracy, and because they help to improve the diagnosis and planning of rehabilitation treatment. In addition, evidence shows the efficiency of using these instrumental techniques at higher levels, such as the final functional results of the patients and the cost-effectiveness of their use. However, most of the cases in this review describe successful cases of paediatric patients with infantile cerebral palsy, where instrumental techniques are more explored. But, as we have seen in previous sections, there is great evidence in favour of the use of instrumental techniques in the context of stroke patient rehabilitation.

In fact, the article by Ferrain M et al. from 2015, *Does gait analysis change clinical decision-making in post-stroke patients? Results from a pragmatic prospective observational study*, deals specifically with this issue. The authors performed a prospective study by evaluating the changes in the treatment plan before and after a gait analysis, as well as certainty in the decision-making of the professional in both scenarios from 0 to 10 points. To do this, a sample of 49 patients with post-stroke sequelae was first examined by professionals from the Unit of Gait Analysis using clinical scales (Timed up and Go, 10-meter Walking Test, Barthel's index, Ashworth scale for spasticity, muscle strength according to the Medical Research Council Scale, and range of motion at hip, knee and ankle level), and using visual analysis of gait. Based on these early findings, the clinical evaluator established a specific therapeutic plan that included physiotherapy and/or treatment with botulinum toxin and/or orthosis and/or surgery. Next, an instrumented gait analysis was performed, including a complete kinematic analysis, dynamic analysis, and EMG of the main muscle groups of both lower limbs. After this analysis, the clinician re-established a specific therapeutic plan. The results of the study showed that the therapeutic plan was modified in up to 71% after the instrumented analysis and that the certainty of the professional in the decision-making significantly increased both for those who changed the plan and for those who did not. The authors conclude that the use of instrumented functional analysis as a tool to improve rehabilitation management in stroke should be promoted, especially in decisions related to the type of surgical treatment, the performance and location of infiltrations with botulinum toxin, or the use of a specific type of orthosis.

Despite all the scientific evidence, we cannot ignore the fact that, in many cases, the instrumented biomechanical analysis performed in laboratories is far from the usual clinical practice and has been relegated to the research level. This could be due to the time required to perform this type of tests in some cases, or the complexity and cost of the instruments. As Mulder T et al. mention in their article from 1998 *Clinical gait analysis in a rehabilitation context: some controversial issues*, another reason could be that there is often a gap between the real functional disability (which is mainly addressed within the rehabilitation context) and the specific deficit determined, on which these instrumental techniques sometimes focus. In addition, the interaction with external factors that affect functions such as gait or balance in real life is often not considered: performing other simultaneous activities, continuous visual and auditory stimuli, etc. Taking into account these factors, the future of biomechanical analysis adapted to the clinical setting may involve low cost and low complexity technologies that provide easily interpretable data and information on the real functionality and disability of the patient. Furthermore, the measurement should simulate the real conditions under which a function is performed in real life by implementing dual tasks or carrying out the measurement in a real or a virtual environment that simulates the real one.

5. KEY IDEAS

- Functional assessment is a necessary tool in the rehabilitation field focused on therapeutic planning and decision-making as well as monitoring the progress of the patient in the rehabilitation context.
- In patients with stroke sequelae, it is necessary to perform a comprehensive assessment of their needs, motor and sensory disabilities and deficits, as well as their higher functions.
- In the study of functions such as gait and balance, as well as in the assessment of mobility and/or strength deficits in stroke patients, instrumental techniques provide a series of advantages over classical methods (visual analysis, scales, etc.) such as objectivity, precision and greater sensitivity of change.
- Scientific evidence supports the use of instrumental techniques as a complement to assess patients with stroke sequelae and to help to make therapeutic decisions.
- The existing literature regarding biomechanical analysis in the context of stroke is fundamentally focused on its use and usefulness in gait assessment; however, many authors propose the use of instrumental techniques to measure other segments and/or functions, like those of the upper limb.

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