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Gait Pattern in Stroke Patients and Gait Rehabilitation: a systematic literature review

By

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Outline

1. Summary

After a stroke, patients usually struggle with physical deficits that have a direct impact on their quality of life. Strokes cause a lot of mortality and morbidity in the population. The challenges exist particularly for strokes survivors. Such an event in a person's life often brings not only physical but also mental health issues. Good motivation is crucial in the process of rehabilitation to achieve good results.

Therefore, it should be essential to ensure accurate patient care to offer individual patients specific procedures. It is important to be able to reintegrate people into their surroundings as well. In that instance, recovery of motor deficits or deficits during walking should be provided. A precise analysis of motor deficits is essential, which can be obtained in detail using different assessment methods. This also determines the further course of therapy options or effects of different therapy options on individual stroke patients. A basic understanding of normal gait physiology in humans should play a role for every participating therapist. This is particularly useful to be able to evaluate pathological gait patterns and to recommend appropriate therapy options.

Furthermore, precise gait analyses should be carried out to record different gait parameters. The different problems of patients are often very specific.

Gait rehabilitation can utilize many different strategies today. It is helpful to ensure a basic need for different therapy options that positively influence different factors such as gait cycle, stride length, step width, cadence, endurance, balance, motor deficits, step length, mobility, etc.

Guidelines often give an approximate idea of what a therapy plan can look like. In addition, to classic physical therapy, therapies such as proprioceptive neuromuscular facilitation, different motor learning techniques and context- or task-specific training can be used. Functional electrical stimulation has been used for stroke patients for many years and has proven its effectiveness. Basic training of the complex gait cycle through treadmill training is a crucial step in gait rehabilitation. In the next few years development of new methods may find their way into gait rehabilitation.

2. Abbreviations:

PNF = Proprioceptive neuromuscular facilitation

AFO = Ankle-foot orthosis

3. Introduction

A stroke is the most common cause of neurological deficits. Through vascular damage of the central nervous system acute, focal neurological symptoms appear. (2) According to the American Heart Association/The American Stroke Association a stroke is defined as an acute phase with neurological dysfunction that persists for more than 24 hours (3).

Strokes can be roughly divided into two main categories. Ischemic and hemorrhagic stroke.In terms of frequency, ischemic strokes are the most common cause at 87% of all strokes. The causes of ischemic strokes are diverse, in particular atherosclerosis of the small blood vessel and cardio embolisms result in strokes. Another root cause can be athero-thromboembolism (2). Whereas hemorrhagic stroke only accounts for 13% (1). Hemorrhagic strokes include intracerebral and subarachnoid hemorrhages. These can be further categorized based on their location into deep, cerebellar and lobar. Each category has its own main causative mechanism behind it. Deep bleeding is mainly caused by arteriosclerosis, whereas lobar bleeding is typically caused by cerebral amyloid angiopathy or arteriolosclerosis (2).

An ischemic stroke results in irreversible damage to brain tissue through insufficient blood supply (3). The blood supply is interrupted by either a thrombus/embolus or through arteriosclerosis (1). A focal region is usually affected. A few minutes without blood supply can lead to cell death in the tissue, resulting in necrotic damage. Surrounding tissue is not necessarily affected by necrosis and therefore has the possibility to recover and regain function. (3) The molecular mechanisms behind ischemic strokes include oxidative stress, inflammation and excitotoxicity. (1) To reduce deficits, it is crucial to promote regeneration and facilitate neuronal protection. (39) The primary reason behind subarachnoid hemorrhages are ruptured aneurysms. This causes blood to leak from the vascular pathway into the subarachnoid space. Resulting in increased intracranial pressure, which leads to displacement of brain parenchyma, followed by damage to the tissue (3). The cause behind those events is typically hypertension. Risk factors can be typically divided into modifiable and non-modifiable. Non modifiable risk factors include age, gender, race and genetic factors. Modifiable risk factors include the following: Hypertension, diabetes mellites, dyslipidemia, atrial fibrillation, smoking/alcohol, bad diet habits and obesity. (1) Hypertension seems to be the most important modifiable risk factor in stroke patients. (2)

Strokes are a major health system problem, and their prevalence is increasing, particularly in western countries. (2) This results in massive expenses, especially for patient care after a stroke. Many patients suffer permanent disabilities (6), which can be extensive, depending on the location of the infarction. Many patients have motor deficits after a stroke (approx. 80%). Of these 80%, 25% of patients remain with significant motor impairments upon discharge from hospital and are therefore dependent on rehabilitation and assistance. (12) These deficits may be a direct result of three mechanisms. 1) loss of neurons due to hypoxia is the main cause of neuronal injury. 2) The production of reactive oxygen species. Oxidative stress has shown direct influence on neuronal damage. 3) Lastly the inflammation of the tissues leads to additional damage after a stroke event. (39) The disruption of integrity of the neuronal pathways leading ultimately to impairments in motor function and thus make the necessity to make the best possible recovery with gait rehabilitation. Gait rehabilitation aims to improve those disabilities.

4. Literature search strategy:

Literature search strategy was done with the defined keywords. The articles were searched with the help of PubMed. Search was performed with “AND” and “OR”. Only articles were analyzed and included, which were written in Englisch. Only articles were used, where free and full text is available. A total of 150 abstracts were analyzed and 80 articles were evaluated. The articles were then analyzed to see if they were relevant for the topic of the thesis. This thesis is intended to address the current status of stroke gait rehabilitation, its efficacy and potential cornerstones for improvements.

4.1. Inclusion/exclusion criteria

Inclusion criteria:	Exclusion criteria:
- Articles written in english - Free available - Full text available - Stroke Patients	- Neurodegenerative disease - Children as patient group - Studies, which didn’t correlate with topic - Used animal models

4.2 Keywords:

stroke, gate analysis, gait patterns and stroke, gait assessment, stroke rehabilitation, gait rehabilitation, gait rehabilitation and stroke, effectiveness and gait rehabilitation, gait rehabilitation and future, neuroanatomy

5. Gait Pattern

5.1. Normal human gait cycle

In order to be able to recognize pathological gait patterns, it is crucial to understand the normal human gait cycle. A better understanding of the individual processes during walking can be gained to more easily identify deviations from normal walking. This also supports the therapist in carrying out different assessments and analysis and afterwards evaluating them. Furthermore, it is easier to draw conclusions about whether different therapies have a positive effect on a re-establishing normal gait pattern. Gait patterns show on a broad spectrum and depends on individual limitations. The following will take a closer look at the normal gait pattern physiology.

The normal gait pattern in humans should be as follows. The gait cycle consists of a total of two phases. 1) Stance phase, which makes up approximately 60% of the cycle. The remaining 40% makes up the 2) swing phase.

You start by placing your foot on one side of the floor, and you are in a short phase of "double support", which means that both feet are in contact with the floor for a short time. This is followed by the single support phase, in which the contralateral leg is lifted from the ground and initially swung forward. The movement ends in the terminal phase where the swinging leg touches the ground and then the next phase of "double support" begins again. (5)

The change from static standing to dynamic running is the first challenge, as balance is particularly stressed in these initial phases until you get a smooth movement. Initially it begins with a reduction in muscle activation of the m. gastrocnemius and m. soleus with a simultaneous activation of the contralateral m. tibialis. Two other factors play an important role, 1) the center of mass and 2) center of pressure. (10)

It should be mentioned that the center of pressure moves backwards during the initial movement, towards the swinging limb in order to move the center of mass forward. This happens in the direction of the leg, which is statically on the ground. After that there is no force on the swinging limb and the center of pressure is directed towards the limb, which is on the ground. This in its entirety allows the center of mass to move stable forward. (10)

Dynamic walking is typically explained using two theories. On the one hand, the "six determinants of gait" theory and the inverted pendulum swing theory.

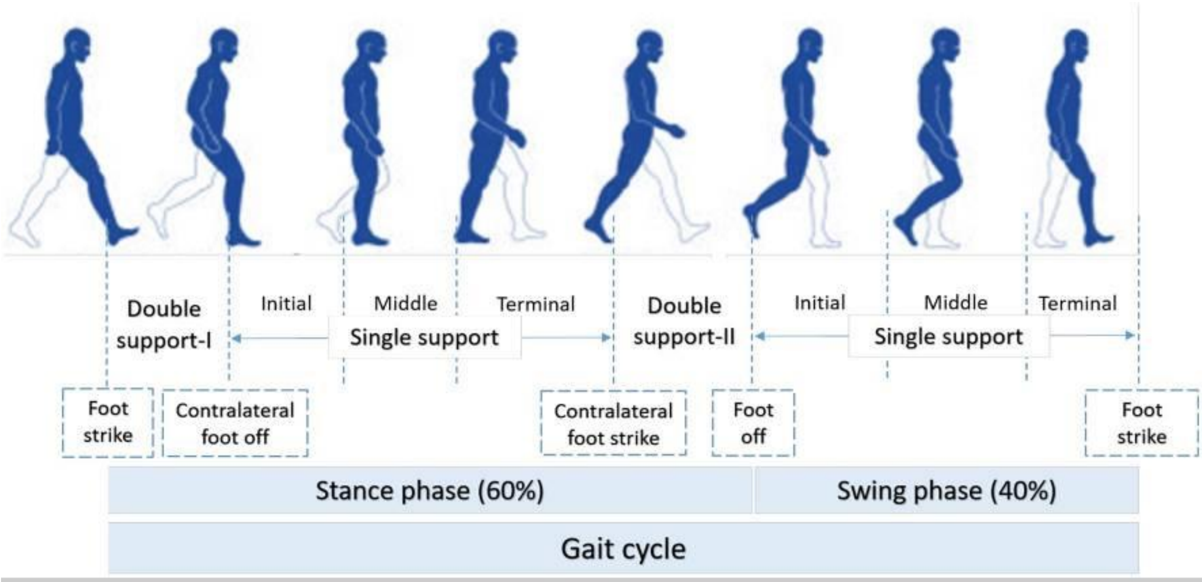

Figure 1: (Reference (8)) Assessment Methods of Post-stroke Gait: A Scoping Review of Technology-Driven Approaches to Gait Characterization and Analysis

6. Dynamic gait principles - "six determinants of gait" theory/inverted pendulum swing theory:

The six determinants of gait theory was recognized as a standard for a long time. It involves six different kinematic properties, which are linked to two additional hypotheses. (11) Kinematic properties consist of the pelvic rotation (transverse plane), pelvic tilt (coronal plane), knee flexion in the stance phase, foot+knee movement and hip adduction. (12)

In summary, the first hypothesis implies that the movement sequence is associated with the lowest possible energy expenditure, and the second hypothesis is that these six determinants keep the movement of the center of gravity as stable as possible. However, studies found that these six determinants have little influence on the center of mass displacement, and in some cases even quite the opposite. The individual kinematics can even increase the center of mass displacement. (11)

In addition, Arthur D. Kuo et. Al. (11) mentions that an intentional reduction in the center of mass displacement results in an increase in energy consumption. For example, the center of mass displacement decreases when smaller steps are taken. However, it was shown, that taking smaller steps significantly increases energy consumption, although the center of mass displacement is significantly reduced. This leads to the conclusion that the six determinants theory cannot explain some of the aspects precisely. (11)

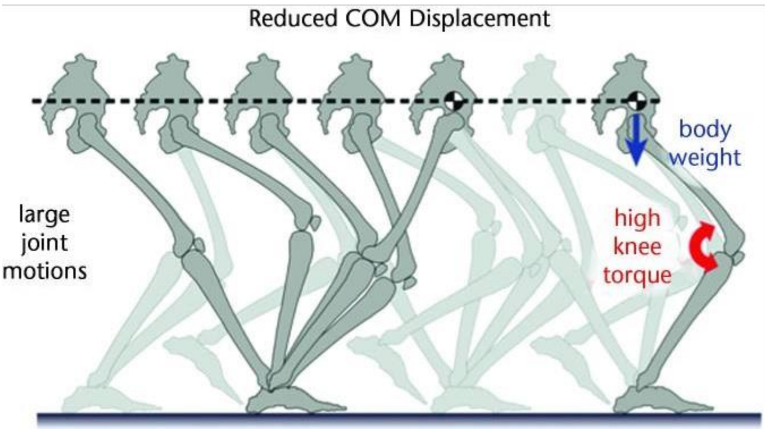

Figure 2: (Reference (11)) Dynamic Principles of Gait and Their Clinical Implications

The probably better model that has wider acceptance today is the inverted pendulum stance model. This can be best described by two phases, the phase in which the foot (on the floor) serves as an inverted pendulum. This keeps the center of mass movement relatively stable on one level and hardly allows any vertical changes. The standing leg swings over the joint, which physically requires little energy effort (inverted pendulum stance leg). The other phase describes the contralateral leg, which lifts off the ground and brings it forward through a “swing” movement. This is particularly effective when taking long, quick steps. (11)

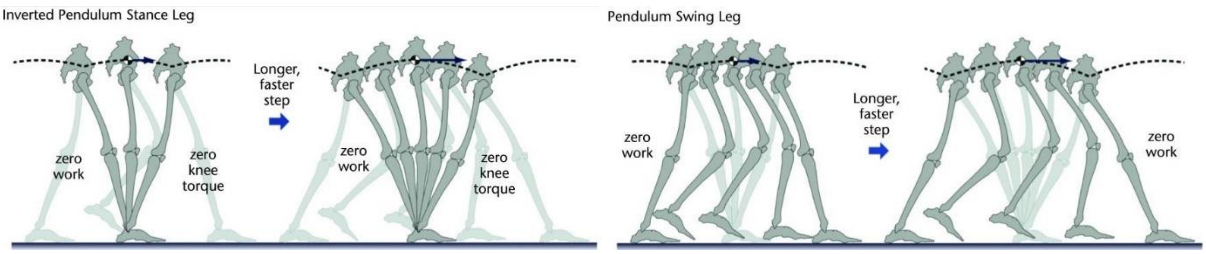

Figure 3: (Reference (11)) Dynamic Principles of Gait and Their Clinical Implications

The running process should use as little energy as possible; our musculoskeletal system is designed to be quite efficient. A disruption in this system, such as a stroke, can double the energy requirements. (8)

However, it is not possible for everyone to maintain optimal gait, as pathological processes such as strokes can cause deficits in motor performance. These make everyday life more difficult and limit individuals' performance on daily tasks. The transition from efficient locomotion to pathological gait requires a precise approach and a fundamental understanding of the underlying causes and their results in gait pattern.

7. Gait pattern in stroke patients:

A pathological gait is manifested by asymmetry when walking. (12) The problems in spastic gait mainly occur due to spasticity and paresis of the lower limb. The normal gait cycle changes to where the stance phase one the healthy leg is significantly shortened, and the affected leg is significantly longer in its swing phase with additional rotation through the hip joint ("circumductory gait"). (12) Strokes in the corticospinal and dorsal reticulospinal tract can lead to spastic gait. Spastic gait is characterized by asymmetrical gait patterns due to increased muscle tone and decreased strength, resulting in reduced walking velocity and cadence, and an increase in stride time. In addition, there is an increase in the paretic swing time and possibly an extended time in the nonparetic stance phase. There is also a reduction in range of motion in the knee and ankle joints. (51)

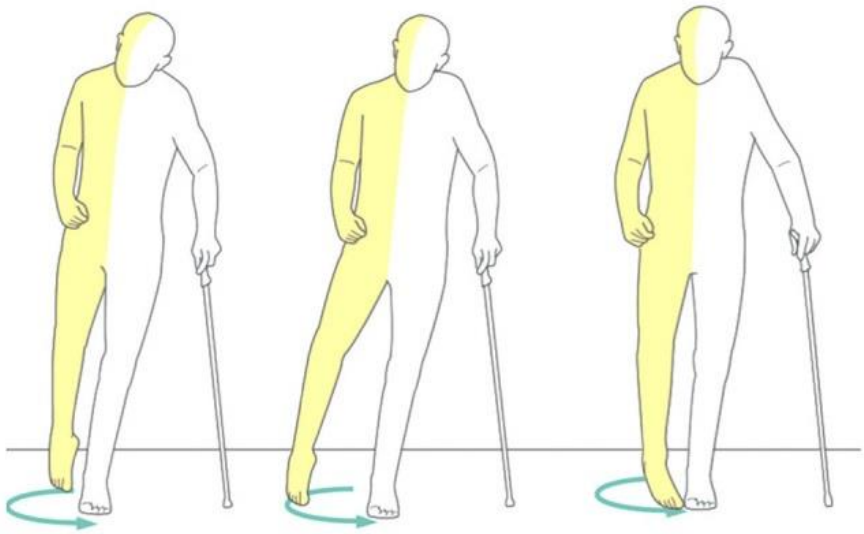

Figure 4: (Reference (8)) Assessment Methods of Post-stroke Gait: A Scoping Review of Technology-Driven Approaches to Gait Characterization and Analysis

A stroke in the cerebellum or cerebellar pathway can also lead to specific gait patterns. Ataxic gait often occurs with cerebellar damage and is often referred to as "drunken gait". Typical characteristics of this are an increased step width, a reduced range of motion in the ankle joint and increased gait variability. (51) Step length seems to be not regular, as well as leg movement. Initiation of gait can be seen typically as normal, and patients often try to stabilize their stance by bending their hip. (52) The increased step width can be attributed to a compensatory mechanism to compensate for the imbalance with a wider step. Additional strategies include increasing joint muscle coactivation to better control the center of mass movement and compensate for hypotonia. Some patients might bend their upper body further forward because the inconsistency makes them want to fall forward rather than backward.

Decreased joint coordination manifests itself through abnormal intra-limb joint and upper/lower body segments coupling. (51)

Steppage gait is typically manifested by a foot drop, decreasing the ability to lift the foot of the ground. This creates compensatory mechanism by increasing flexion in the knee and hip joint. Two factors can be determined in the steppage gait. On the one hand, the foot drop by decrease in muscle strength of the dorsal flexors or by decrease in muscle strength of the dorsal flexor muscles in combination with plantar flexor muscle strength decrease to prevent falling over. Steppage gait results in reduced gait speed, but due to the compensation mechanisms of patients, the step length often remains within normal ranges. (51) For patients suffering from steppage gait, it's typically not possible for them to stand on the heels and are also unable to toe walk. (52)

Gait impairment is influenced by a variety of factors. (12) It can have heterogenous and complex features. (49) On one hand, due to the damage to the motor cortex and possibly the cerebrospinal tract can also be affected. This leads to an expression of negative upper motor neuron signs. (12) Upper motor neuron signs can be divided into two categories. While with negative signs the loss of motor function occurs. (14) This leads ultimately to hemiparesis, muscle weakness on the affected side.

The other factor affecting gait is the loss of supraspinal inhibition, ultimately leading to an increase in activity in the reticulospinal and vestibulospinal tract. This results in positive upper motor neuron signs (12), such as “hyperreflexia, propagation of reflexes, clonus, spasticity, flexor and extensor contraction, synkinesia and spastic dystonia”. (14)

Trailing limb angle plays an essential role in walking. It describes the position of the entire lower limb extremity. (40) It influences the strength of the propulsion force from the ground and is linked to reduced gait speed. Other factors including co-contraction of the shank muscles are increasing while being in the stance phase and balance reduction through trunk instability were also notable. (16)

Spasticity in the ankle can often be observed after a stroke. This can lead to a wide variety of deformities, with equinovarus being one of the most common. Equinovarus deformities resulting in a shift of force towards the knee leading to a hyperextension of the knee while being in the stance phase. (41)

In the case of a stroke, the problems are not limited to one cause. Patients with motor deficits have particular problems with reduced walking speed, shorter steps and an impaired automatism, while walking itself. (16) Relevant measures should be walking speed, cadence, base width and step length. (52) In addition, instabilities often arise, especially in trunk. (16)

Changes in gait can also be divided into two categories. 1) primary and 2) secondary deviations.

Primary deviations occur due to the defect in the physiology and are directly related to it. Secondary deviations occur as a result of the primary deviation/lesion and are related to the physics resulting from the primary deviation. (8) Deficits appear throughout, especially due to “poor muscle strength/tone, mobility, perception, motor control, sensation and balance”. (8)

A study was carried out in which the gait characteristics were tested at different walking speeds. For this purpose, 130 patients with hemiparesis after a stroke even were sorted out. There was also a control group in which it was ensured that they were approximately the same age (+-2 years) and approximately the same height (+-5cm) and the walking speed was adjusted to (+-0,5 km/h).

The inclusion criteria were defined as age range between 20-69 years, as well as unilateral hemiparesis and only individuals who had suffered a stroke. In total there were (n=130) in the control group and (n=130) in the stoke patient group. The respective individuals were then divided into a running speed category with their matched partner (0,5-1,4 km/h; 1,5-2,4 km/h; 2,5-3,4 km/h; 3,5-4,4 km/h; 4,5-5,5 km/h). The 10-meter walk test was used to find out the walking speed. In addition, force plates were used, and the movement was recorded in 3D with a motion camera system. 12 markers were connected on both sides of the body (shoulder, pelvis, hip, knee, ankle and the 5th metatarsal head”). After a short period of getting used to the treadmill, data was collected for 20 seconds and the step length, stance, swing and double stance time were determined. (15) Regarding walking speed there was significant difference in gait speed in stroke patients' group with longer step- and stride length (0,5-1,5 km/h) and lower cadence (0,5-2,4km/h), indicating changes in spatiotemporal pattern for stroke patients at different treadmill speeds. (15)

Bianca Callegari et al. (7) investigated how delays in physical therapy treatment affect gait patterns. For this purpose, (n=40) patients were included, (n=15) suffered an ischemic stroke, the other (n=25) had a history of hemorrhagic stroke. All patients had deficits in motor cortex and/or subcortical areas, but to be included, they had to be able to walk 10 meters without additional support. In addition, parameters such as “age, gender, height, weight, time of last stroke and time since last physiotherapy session were gathered.

Some assessments were used, such as the stroke impact score, timed up and go test, berg balance score and Brunnstrom score. All patients were tested both before and after the start of physiotherapy. To avoid fluctuations, a single therapist was used. The physiotherapy was carried out by using a standard protocol. The results showed no significant differences in all groups on the stroke impact scale. In addition, patients with ischemic strokes showed improvement in the timed up and go test after physiotherapy. This was not the case for the patient group with hemorrhagic strokes.

In the gait assessment there were no changes in the gait cycle either between the groups nor before or after physiotherapy. The stance phase and swing phase were the same in all groups both before and after physiotherapy. There was also improvement in the amplitude of the electromyogram during the stance phase after physiotherapy, although the effect was only limited to patients with an ischemic stroke. Muscle activation was higher in patients with ischemic stroker after physiotherapy.

In summary, one can say that a higher effect can be expected in patients with an ischemic stroke. Furthermore, it has been shown that ischemic strokes are more common and seem to produce fewer neurological deficits. This could be because the affected areas are usually larger when caused by a hemorrhagic stroke. There were improvements in the timed up and go test and changes in muscle activity, especially in the posterior muscle groups (m. Biceps femoris, m. semitendinosus, m, gastrocnemius). (7)

An accurate assessment of the gait pattern should be carried out to provide an individual plan for rehabilitation. To evaluate the initial condition and extent of the motor deficits in detail, different assessment methods help provide useful data. This data can be used to engage different treatment plans for the patient and each possible therapy option available. Another point in which gait assessment is important is to follow-up on rehabilitation therapies that have been implemented. With the following assessment methods it's possible to collect starting parameters and create an overview of the progression through regular controls.

8. Assessment of gait pattern/gait analysis:

Therefore, precise clinical observation of patients is necessary and carrying out a gait analysis is crucial. Reliable methods are necessary to make a gate analysis. (47)

You should focus on two essential parameters, both the ability to walk, but also how the individual patient walks. It is important to examine how high the capacities of the individual patient are, easily done by different tests.

Only to mention an example that can be used: the 6-minute walk test. (8) Was originally developed for diseases of the cardiovascular and respiratory system. However, the test is also becoming more and more popular with patients after a stroke even, because 1) it is easy to carry out and 2) it allows you to make a good statement about the patients' physical resilience. (9) Other possible procedures include the motor assessment scale and the functional ambulation category and are also useful. (8)

A detailed analysis of the gait should be performed for every patient post-stroke. This is the only way to ensure that appropriate rehabilitation can take place for each individual. Initial gait analysis is typically done by visual observation during a physical examination. (8) It is heavily dependent on the experience of the physician. (50) Motion capture technology is also often used in clinical applications to carry out a detailed gait analysis. (48)

Different tests and tools also help to better assess certain expressions of a stroke. In particular, the application of the Fugl-Meyer assessment can be utilized. The assessment is often used in patients with hemiparesis and evaluates both motor/joint function as well as balance and sensation. It should also be noted that there is no consensus as to when patients with stroke anamnesis should receive detailed analysis of the individuals gait. (8)

However, it must be noted that visual observation and the use of certain assessment strategies often do not provide exact information about how certain parameters affect the patient, since walking is a complex system. For example, patients can have the same point scala in an assessment but have completely different gait patterns. It is important to evaluate everything in its entirety and, if possible, collect as much data as possible. (8)

As already mentioned, there are a variety of different assessment methods. Another test that is standard is the 10-meter walk test. (30) The test is very easy to carry out and can provide good indications of progress of the therapies used. It’s a simple motor task where 10 meters should be walked as fast as possible. Meanwhile, time is measured. (31).

Another helpful tool can be the functional gait assessment, in which 0 to 3 points can be achieved on each task. (33) You get 0 points if you cannot carry out the task and 3 points if it's very easy for the patient. The following 10 categories are evaluated: 1) flat ground walking 2) changing gait speed 3) walking with horizontal and 4) vertical head turns 5) walking with a pivot turn 6) stepping over an obstacle 7) heel-to-toe walking 8) walking without visual input 9) walking backwards 10) walking up and downstairs. (32)

The Berg balance scale is used to test balance through 14 different tasks patients have to do. A maximum of 4 points can be collected for each task. 14 Taks multiplied by 4 points results in a maximum of 56 points. Zero points are awarded if the task cannot be completed. It's an excellent tool to assess balance in stroke patients. (34)

After a detailed gait analysis has been carried out and the gait patterns and deficits have been assessed, an insight into the specific requirements can be obtained. The gait assessment serves as the basis for the individual development of a therapy plan and thus forms a cornerstone of gait rehabilitation.

9. Gait rehabilitation:

Rehabilitation for stroke patients should play an essential role. On one hand, to reintegrate them into their normal daily lives with as much functionality and independence as possible and on the other hand, it is about giving the patient part of his own freedom back. In addition, it plays a major role in successful rehabilitation that patients remain motivated and ensure the highest level of compliance.

The approach is typically physical therapy, often a combination of different methods, with each of these methods having its advantages and disadvantages. Conventional rehabilitation usually focuses on the physical level (bottom-up principle) in order to drive neuroplasticity by influencing the neural system. Although neuroplasticity is still not fully understood. In the following chapter, different methods will be discussed and their properties will be explained. Afterwards, other techniques and possibilities for the future will be presented.

(The European stroke organization has published guidelines for interventions for motor deficits. These are intended to give an approximate picture of what rehabilitation after strokes might look like. First of all, time is very important, it is best to mobilize patients within the first 24 hours, if possible.

Furthermore, it may be important that patients who have mild deficits should be discharged from the hospital as early as possible and should have the best possible rehabilitation from home. The frequency of rehabilitation applied plays an essential role, Patients should have as many sessions of therapy as possible. Another important point is to maximize mobility, particularly to include exercises that bring functional improvement as well as movements that are frequently used. The following section will summarize some specific therapies.

It's crucial to improve muscle weakness, which can be done through progressive resistance training. Stroke rehabilitation should always include balance training. In order to improve walking, patients should repeat this frequently; task and goal-oriented training are ideal for this.

Additionally, muscle training can help maximize aerobic fitness. (28) Although it has been shown that muscle training does not have a direct positive effect on walking patterns, it does increase the force with which patients can move forward. Also, strength training of the muscles has no influence on walking speed but can increase bone strength, preventing osteoporosis. (43)

Since repetition is often a key point in rehabilitation, treadmill training should take place with or without bodyweight support or walking exercises in combination with conventional rehabilitation. (28)

Robot-assisted movement training could also be used, but this should be combined with other conventional therapies. (28) An ankle foot orthosis may be an option for some patients to achieve more stability while walking. Functional electrical stimulation should be complementary to other rehabilitation options. (28)

Neurophysiological applications generally attempt to strengthen correct movement sequences. An example of this would be the Bobath concept. (17).

A studied that compared the effectiveness of the Bobath concept with other neurophysiological techniques, such as forced use therapy, or motor relearning therapy, showed that the Bobath concept is often inferior to other protocols and often has no additional benefits. Especially in regard to improvement of motor activity, gait, spasticity and daily life there is inconclusive evidence. (18)

Another option for treating motor deficits is proprioception neuromuscular facilitation. Basically exercises are performed to facilitate active and passive muscle movement. This can be explained by four theoretic mechanisms:

1) Autogenic inhibition is a mechanism in which a stretched or contracted muscle shows reduced excitability. So, when under physical force, the Golgi tendon organ sends a signal to an inhibitory interneuron. The signal is then passed through an alpha motor neuron, which leads to a reduction in excitability through reduced motor drive.

2) It is also about reciprocal inhibition, during a voluntary movement, when the muscle is used. This ensures that opposing muscles or muscle groups don’t work against each other.

3) Stress relaxation is a phenomenon in the musculotendinous units when they are constantly under stress. PNF tries to increase stress by stretching the tensile, which leads to muscle fiber elongation. Stress relaxation is a protective mechanism to prevent muscle tearing.

4) The Gate control theory proposes that when the muscle is moved further beyond its range of motion, the golgi tendon organs are activated to prevent injury.

PNF is rarely used for strokes. To further investigate, a randomized clinical trial was carried out on this topic, to determine if pelvic PNF techniques improve balance and gait patterns in chronic stroke patients. It consisted of two groups. 1) group A was dedicated to a task-oriented lower-limb exercise in combination with pelvic proprioceptive neuromuscular facilitation. 2) group B did isolated task- oriented lower-limb exercise. Various parameters were collected to evaluate the study.

The Berg balance scale, stride length, cadence, gait velocity and with help of a PALM device possible pelvis issues, were included. The parameters were measured both at the start of the study and afterwards and showed that PNF therapy in combination with task-oriented exercise has better effect on chronic stroke patients' balance, gait parameters and also on the pelvic asymmetry than task-oriented lower-limb exercise alone. (20)

Barlinn et al. (21) also suggested that physical therapy based on proprioceptive neuromuscular facilitation could have a positive effect on chronic stroke patients' gait speed and balance, but also on positive effects on trunk control. (21)

In addition to the neurophysiological techniques, there are also motor learning techniques, which require active participation of the patient. The underlying principles are based on two different concepts, 1) context-specific training and 2) task-specific training. Theses can be individually adapted to the patient. The primary aim is to do exercises that improve learning motor strategies, usually specific motor tasks, which are returned with feedback. (17)

Task specific training is a common method for stroke patients to regain functional abilities and focuses more on the repetition of tasks that can be used or are frequently involved in the patient's personal life. (24) The exercises are very functional und adapted to your individual needs. Several studies indicated that task-specific training reduced the spasticity in m. gastrocnemius und m. soleus, resulting in better gait patterns after strokes. (22) It is possible that task-specific training can also increase physical activity in stroke patients, which has positive influence on their daily life as well as preventing possible future stroke events. (23) You can divide task specific training into two different categories. The first category includes treadmill training with or without body-support for a high number of repetitions. The second category contains exercises for specific processes like getting up, climbing stairs, etc. Theoretically, you could also use over-ground walking as an alternative, as the movement sequence is a little more natural compared to treadmill training. Here, the ideal solution might be the combination of treadmill training with a mix of task-specific training. (43) and also, to mention, core/trunk stability probably also plays a role in good balance and mobility. It has also been shown that trunk stability training can improve both factors.

Functional electrical stimulation is a method that has been used for strokes for several decades. Muscles are stimulated with an electrical signal to trigger action potentials. This causes muscle contraction. (17) This is particularly used in foot drop after stroke, where it has been shown that spasticity was reduced, motor function improved and ultimately walking speed could also be recovered. (26)

Iosa et. Al investigated on implantable functional electrical stimulation and its effect on gait performance proposed promising results regarding walking speed, spatiotemporal gait and endurance. The gait stability was also improved with implantable FES. There were also significant differences in joint kinematics. (27)

Another essential rehabilitation method is treadmill walking. The advantage is that treadmill training, both with and without body weight support, can ensure a high number of repetitions. This method is a task-specific therapy in which a full gait cycle is repeated. An alternative to this is the over-ground- walking therapy, however it seems to be inferior to the use of a treadmill because significantly smaller repetition can be achieved. However, there were significant differences between groups of dependent and independent walking patients. Apparently, patients who can initially walk independently benefit from treadmill training and can thereby improve their walking velocity. Patients who were initially dependent when walking had no significant influence on their walking speed using treadmill training. There are also significant differences between independent and dependent walkers and improvement in walking endurance. Only patients who were initially able to walk independently benefited from treadmill training and were able to improve walking endurance. (28)

There may be evidence that high intensity speed-based treadmill training may be effective in increasing walking speed in chronic stroke patients. (29)

Ankle foot orthoses are often used in gait rehabilitation for stroke victims. They work by stabilizing the ankle laterally, improving the stance phase. In addition, toe clearance can be improved, possibly through the reduction in circumduction movement and hip hiking. The main mechanism behind this is to aid in dorsiflexion of the ankle, which limits the time of forefoot contact. So overall a reduction in compensatory mechanisms and a reduction in abnormal gait patterns, especially in patients with hemiparetic gait patterns. (42)

There is still a lack of consent on how to maximize stroke rehabilitation effect. Furthermore, there are responders in stroke patients which respond very well to gait rehabilitation, but there are also non-responders for whom the improvement compared to the responders is very low. (46)

In addition to the usual therapy options that are now widely used in rehabilitation after a stroke, there are other methods, the effectiveness of which, however, has yet to be clearly proven. Some studies show promising results that could open new possible applications used for gait rehabilitation in stroke patients.

9.1 Other Interventions:

In the last section other possible therapy options will be reviewed that are still less used in stroke rehabilitation.

Spencer et al. (45) analyzed the evidence on how biofeedback affects gait training. In summary, biofeedback training is about giving the user a haptic stimulus for specific processes. This stimulus can be visual, auditory or tactile. Examples that can be given here are the force that is used to push yourself away from the ground with your foot. If the force was sufficient, the patient receives biofeedback in the form of the stimulus. Feedback targets are spatio-temporal parameters like step length, kinematic parameters, like joint angles and position and kinetic like the ankle moment. However, so far this has only been ambiguous evidence, with the need to carry out studies with larger populations in order to collect particular parameters such as feedback target, mode and dosage, in differently affected stroke patients. (45)

Today's world offers a variety of different technologies. Virtual reality-based training could be an interesting way to better rehabilitate stroke victims. Virtual reality is basically an artificial environment with which people can be in direct contact and navigate through. These can be combined for example with treadmills or bicycles. There might be promising results that indicate that virtual reality could have a positive impact on gait rehabilitation. (35) Nevertheless, a lot needs to be done in this research field to be able to give a good assessment of how much virtual reality can support conventional therapy options. (36)

A trial looked at whether cerebellar stimulation can have a positive effect on improving balance and gait. Theta-burst stimulation (CRB-iTBS) was used in combination with physiotherapy, showing promising results in motor recovery in patients after ischemic, hemiparetic stroke. (37)

In times of digitalization and the fact that basically everyone has a smartphone, it might make sense to use this as a resource. Patients could improve their gait rehabilitation through their mobile devices, doing rehabilitation more from home. (38)

10. Conclusion

In summary, it can be said that strokes and their possible consequences for patients still play an essential role for the healthcare system and rehabilitation. The significant impact on patients' motor skills is still a major problem. It is essential to understand the basics of normal huma gait physiology. In addition, different theories such as the "six determinants of gait" theory or the inverted pendulum model can be reviewed for a better understanding. This makes it easier to recognize deviations from normal gait patterns and to determine pathological deviations. Different locations of a stroke result in different gait patterns. Cerebellar damage results in ataxic gait patterns, often referred to as "drunken gait", with a typical increase in step width, a reduced range of motion in the ankle and increased gait variability. (51/52) Damage to the corticospinal/reticulospinal tract leads to a spastic gait pattern, which is manifested by an increase in muscle tone and decreased strength. This is associated with an asymmetrical gait pattern and reduced walking velocity and cadence and an increased stride time.

Steppage gait usually manifests by foot drop. This leads to the use of compensatory mechanisms such as increased flexion in the hip and knee joint.

Nevertheless, gait patterns often manifest themselves differently in patients and instabilities of the trunk can often be found. (16) In order to develop a good and customized plan for each patient, it should be essential to use different analysis and assessments methods to identify specific deficits in gait. The fundamental parts of gait rehabilitation should therefore be physiotherapy, gait training, balance training and, for some patients, ankle-foot orthosis to improve stabilization. Although it has been shown that muscle training has no direct influence on gait patterns and walking speed, targeted muscle training can prevent osteoporosis through bone strengthening. It can also increase the force of the forward movement. (43), making it a helpful factor.

The Bobath concept is still often used for stroke patients, but its effectiveness has been found to be lower than compared to other techniques like forced use therapy or motor releasing therapy. There was also no improvement in motor activity, gait and spasticity. Perhaps further studies should examine the Bobath concept and its effectiveness in stroke patients as evidence was inconclusive. (18)

Another method that could be used is proprioceptive neuromuscular facilitation. However, this is not yet used often in stroke patients, but it has been shown that PNF has a positive effect on gait speed and balance in chronic stroke patients and better trunk control can also be achieved. PNF should be used in combination with physiotherapy, where patients showed improvements in gait parameters and pelvic assembly, more than physiotherapy alone. (20)

Task specific training is commonly used and showed, that it can reduce spasticity in muscles. (22) It is fundamentally important to focus on tasks whose application is useful in his/her everyday life. Task-specific training should be used for every stroke patient.

Treadmill training should also play an essential role in gait rehabilitation and should be offered to every patient. It was shown that in patient groups (initially able to walk independently) walking velocity and walking endurance has been increased. The treadmill also offers a high number of repetitions. There is also evidence that high intensity treadmill training has a positive effect on walking speed in chronic stroke patients. This type of training can be done with or without body-support, depending on the patients' abilities. (28)

For some patients an AFO may be useful. It has been shown that it can reduce forefoot time and compensatory mechanisms like hip hiking and circumduction movements. AFOs are particularly helpful in patients with hemiparetic gait patterns. (42)

Functional electrical stimulation has long been used in gait rehabilitation. An important are of application is foot drop. Functional electrical stimulation showed to reduce spasticity and improve motor function resulting in increased walking speed. (17) Implantable functional electrical stimulation showed promising improvements in walking speed, spatiotemporal gait and endurance, but requires further investigation. (27)

Other methods, such as biofeedback, are used, but according to (45) there is only ambiguous evidence. There is still a need for further studies on this topic, especially with larger study groups.

In summary, one can say that gait rehabilitation for stroke patients consists of physiotherapy as the main factor, with task- specific training and muscle strengthening training. Gait training with treadmills should play a role in any rehabilitation program if it is suitable for the patient. In addition, an important factor seems to be balance, which can make balance exercises a helpful tool. If necessary and indicated, ankle-foot orthoses can be used to provide additional stability. However, there is still a great need for new protocols and techniques that provide better and more comprehensive recovery.

11. Warranty

PLEDGE

Of Vilnius University student submitting a thesis

Tobias Fabian Nitschko

Faculty: Faculty of Medicine

Study programme: Medicine

Thesis topic: Gait Pattern in Stroke Patients and Gait Rehabilitation

Thesis type: systematic literature review

I pledge that my thesis has been prepared in good faith and independently and that there has been no contribution by other individuals to this thesis. I have not made any illegal payments related to this thesis. Quotes from other sources used in this thesis, directly or indirectly, are indicated in the list of references.

I, Tobias Fabian Nitschko confirm

I declare that this thesis has been uploaded to the Vilnius University Study Information System.

09/05/2024

(name/surname) (signature) (date)

12. Attachments

Fig. 1: (Reference (8)) Assessment Methods of Post-stroke Gait: A Scoping Review of Technology-Driven Approaches to Gait Characterization and Analysis

Fig.2: (Reference (11)) Dynamic Principles of Gait and Their Clinical Implications

Fig.3: (Reference (11)) Dynamic Principles of Gait and Their Clinical Implications

Fig.4: (Reference (8)) Assessment Methods of Post-stroke Gait: A Scoping Review of Technology-Driven Approaches to Gait Characterization and Analysis

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