Narrative Review

Gait Disturbances in Patients With Stroke

Birol Balaban, MD, Fatih Tok, MD

Poststroke hemiplegic gait is a mixture of deviations and compensatory motion dictated by residual functions, and thus each patient must be examined and his/her unique gait pattern identified and documented. Quantitative 3-dimensional gait analysis is the best way to understand the complex multifactorial gait dysfunction in hemiparetic patients. The goals of the present work are to (1) review the temporospatial, kinematic, kinetic, and electromyographic deviations from normal gait that commonly occur after stroke and are of clinical significance, along with the most likely causes of these deviations, and (2) differentiate the departures from normal gait parameters that arise as a direct consequence of poststroke motor problems and those that arise as learned or adaptive compensations for poststroke motor problems.

PM R 2014;6:635-642

INTRODUCTION

Upper motor neuron syndrome caused by stroke results in a constellation of sensorimotor impairments including muscle weakness, impaired selective motor control, spasticity, and proprioceptive deficits that interfere with normal gait [1-5]. Gait recovery is a major objective in the rehabilitation of patients who experience stroke. A wide range of walking ability is present in patients after stroke that is dependent upon the severity of sensorimotor impairment. After stroke, 50% of patients initially are unable to walk, 12% can walk with assistance, and 37% can walk independently. At the end of 11 weeks of stroke rehabilitation, 18% of patients still are unable to walk, 11% can walk with assistance, and 50% can walk independently [6].

Patients who have experienced a stroke and have functional ambulation exhibit gait patterns that differ from those observed in healthy persons and are associated with an increased risk of falling. Marked variation in gait patterns among patients who have experienced a stroke also has been noted. To characterize the nature and degree of walking dysfunction in patients who have had a stroke, the profile of poststroke gait has been studied using numerous techniques, including temporospatial gait parameters, oxygen consumption measures, electromyography (EMG), kinematics, and kinetics [7,8]. Although hemiplegic gait has been investigated during research for the development of methods for gait analysis and rehabilitation, the cause and effect relationship between impairment caused by stroke and poststroke gait pattern has yet to be fully understood [9,10].

Accordingly, the goals of the present work were to (1) review the temporospatial, kinematic, kinetic, and EMG deviations from normal gait that commonly occur after stroke, are of clinical significance, and are the most likely causes of these deviations, and (2) differentiate the departures from normal gait parameters that arise as a direct consequence of poststroke motor problems and those that arise as learned or adaptive compensations for poststroke motor problems.

ASYMMETRY IN HEMIPLEGIC GAIT

Normal gait tends to be symmetrical, both spatially and temporally, with interlimb differences in vertical force and temporal parameters measuring <6% [11,12]. In contrast, hemiparetic gait is characterized by asymmetry, with poor selective motor control, delayed and disrupted equilibrium reactions, and reduced weight bearing on the paretic limb;

B.B. Gulhane Military Medical Academy, Department of Physical Medicine & Rehabilitation, Ankara, Turkey. Address correspondence to: B.B.; e-mail: balabanbirol@yahoo.com
Disclosure: nothing to disclose

F.T. İskenderun Military Hospital, Physical Medicine & Rehabilitation Clinic, İskenderun, Hatay, Turkey
Disclosure: nothing to disclose

Submitted for publication April 19, 2013; accepted December 12, 2013.

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smooth and symmetrical forward progression of the body is impaired, with wide variation in gait patterns related to the degree of recovery [13]. Furthermore, well-controlled intralimb and interlimb coordination is replaced by mass limb movement patterns (synergies) on the paretic side that require compensatory adjustments of the pelvis and nonparetic side [14].

Temporospatial parameters are the gait variables most commonly analyzed for symmetry; however, occasionally, kinetic and kinematic parameters also are used. Temporal symmetry calculations typically use swing time, stance time, or an intralimb ratio of swing to stance time, whereas spatial symmetry calculations use step length. Temporal asymmetry in hemiplegic gait is commonly described quantitatively as a prolonged paretic swing time and/or a prolonged nonparetic stance time compared with the contralateral limb [9,12]. In contrast, the pattern of spatial or step-length asymmetry is less consistent. Because patients who have had a stroke constitute a heterogeneous group, some may exhibit longer paretic step length, whereas others exhibit longer nonparetic step length [15]. The severity of the stroke, as well as the location and type, and the associated complications, such as limited joint range of motion and trunk control, determine to a large extent the level of dysfunction. Hence patients who eventually regain some form of walking ability vary greatly in gait symmetry.

Limiting the degree of asymmetry in poststroke gait is a common aim of rehabilitation; however, in contrast, some investigators suggest that gait asymmetry should not be changed, particularly in the chronic stage. According to this point of view, gait asymmetry is a positive adaptation to neurologic deficits associated with stroke that provides patients with a certain level of gait function. It has been posited that aiming for biomechanical symmetry in a body system that is in a stable state (ie, chronic stroke) is less justifiable because it is unlikely to result in optimal performance [16].

TEMPORAL FEATURES OF HEMIPLEGIC GAIT

Various temporal (time-dependent) and spatial (distance-dependent) parameters have been defined to quantify human gait. For example, step length is the linear distance between 2 consecutive points of contact with the ground by the right and left feet, whereas stride length is the linear distance between 2 consecutive points of contact with the ground by the same foot. Similarly, stance time is the duration that the foot is in contact with the ground during the gait cycle, and swing time is the duration that the foot is not in contact with the ground during the gait cycle [17]. Velocity is associated with both temporal and spatial gait data.

One of the characteristic temporal features of hemiplegic gait is reduced walking velocity [18]. Preferred paced walking values in patients in the chronic phase after a stroke were reported to range from 0.10 m s^{-1} [4] to 0.76 m s^{-1} [19]. Less frequently measured is the maximum walking speed in patients who have had a stroke, which in patients in the chronic phase ranged from 0.76 m s^{-1} [20] to 1.09 m s^{-1} [19]. The wide variation in reported values is likely the result of multiple factors, including differences in measurement techniques and equipment, the degree of assistance allowed during measurement (eg, walking aids, orthoses, and external support), and the severity and chronicity of the stroke [21].

Temporal gait asymmetry has been observed in 55.5% of a group of poststroke hemiplegic patients, whereas spatial asymmetry was less prevalent, affecting 33.3% of the same group [11]. The values of symmetry are difficult to compare across studies because of differences in the equations used to calculate symmetry and in the gait parameters analyzed; however, in studies in which investigators used a simple ratio, reported values for swing-time asymmetry (paretic swing time/nonparetic swing time) ranged from 1.23 [22] to 1.61 [23], and the authors of one study reported a mean step-length symmetry (paretic step-length time/nonparetic step length) ratio of 0.92 [11].

As a clinical measure, velocity is an indicator of overall gait performance, and not surprisingly, it has been associated with many other temporospatial gait parameters, including cadence, stride length, double support duration, paretic and nonparetic stance duration, and stride period [23]. The temporal features of hemiplegic gait are characterized by increased stride time and reduced cadence [6,23,24]. Alterations in stance-phase and swing-phase periods also have been noted in hemiplegic patients, with increased stance periods being observed in both lower limbs, relative to healthy participants [25]. With the hemiplegic limb, less time is spent in stance and more time is spent in swing [26]; as a result, the unaffected lower extremity exhibits a prolonged period of stance and a reduced period of swing [6]. An increase in double support periods also has been reported, along with a tendency for an increase in double support time on the unaffected lower extremity [23]. Reports on the amount of time hemiplegic patients spend in single-limb support on each leg are inconsistent. When single-limb support is calculated as a percentage of the walking cycle, there is a reduction in the portion of the cycle spent in single limb support. On the unaffected limb, an increase in the time spent in single limb support, as a percentage of the gait cycle, was reported to be equivalent to that in healthy control subjects [27]. As a result of these bilateral differences, hemiplegic patients exhibit marked asymmetry in many of the distance and temporal parameters of walking [6].

To summarize, gait velocity is reduced in patients who have had a stroke, although wide variation exists in the preferred velocity adopted by such patients. Decreased velocity is likely the result of multiple factors, including poor motor recovery, impaired balance, and decreased muscle strength, and has a significant negative effect on a person's level of independence [28,29]. A sample temporospatial analysis of a hemiplegic patient is shown in Table 1. All the

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