Gait Function Across the Lifespan in People with Spastic Cerebral Palsy: Part I – Literature Review

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Body structure and function in gait, gait activity, and participation are areas of abundant research in habilitation and rehabilitation. Within the diagnosis of cerebral palsy (CP), there are descriptions of specific findings, especially concerning body system impairments in children, but there is no cohesive big picture of gait across the lifespan. There are occasionally opinions of how intervention could proceed to affect positive changes from these studies.

Historically, gait research was limited to studies of children with CP and did not include adults. In two systematic reviews on the status of function and gait training for adults with CP that searched back to 1970, no research studies prior to 1995 were cited.[1,2] Fortunately, there are now a few studies that address some aspects of gait and its changes across the lifespan in people with CP. Almost all are confined to people with spastic CP who function at Gross Motor Functional Classification System Levels (GMFCS) I-III.

This article will summarize the available literature on gait and its changes across time in people with spastic CP. Intervention ideas will then be presented from the author's clinical experience.

Gait Across the Lifespan

There is abundant literature on normal (typical, functional) gait in children and adults dating back hundreds of years prior to computerized analysis that has proliferated since the advent of computerized methodology.[3] Gait studies have looked at the kinematics and kinetics of phases of the gait cycle; development of gait in children developing typically; gait in adults; postural control in gait, including trunk muscle activity; and specific activity or participation functions.[4-12] Textbooks have been written about typical and pathological gait[13] and gait in children with cerebral palsy.[14] The literature can be easily accessed by physical therapists and physical therapist assistants.

Gait Function Across the Lifespan in People with Cerebral Palsy

There is little information in the peer-reviewed literature about how gait develops and changes over the years in people with CP. Studies of young children with CP look to predictors of walking ability based on other gross motor skills,[15] prevalence of gait abnormalities,[16] and gait patterns in spastic hemiplegia and diplegia[17] to predict future gait function. A 2002 study[18] looked longitudinally at gait in children ages 4-12, describing the natural progression of gait changes in terms of impairments and gait patterns, but this was a comparative study, not a prospective or retrospective study.

Research on functional gait in adolescents and adults with CP emerged after 2005. These adults had spastic hemiplegic or diplegic types of CP with few exceptions and most were functioning at Levels I-III of the GMFCS. Emphasis on observed or self-reported deterioration of gait and other function predominates the literature on adults with CP who were ambulatory as children.

Walking in Adults and Adolescents with Cerebral Palsy: The Research Literature

This section summarizes peer-reviewed literature regarding gait and related activities in adolescents and adults with cerebral palsy. Studies that investigate impairments related to gait are limited. Most studies of muscle morphology, force production, strength, and range of motion in adults and children with CP tied to the activity of gait have been done at the ankle joint. It may be the easiest joint to study. Geertsen et al.[19] studied the ankle in 24 adults ranging from ages 18-57 at GMFCS Levels I-II, finding increased passive stiffness at the joint, reduced force production and rate of force production in the dorsi- and plantar flexors, and decreased push-off velocity of the plantar flexors in walking.

Gait analysis and changes in gait activity with ageing are more common in the literature than studies of body system impairments. Several studies found that crouch gait increased with age in people with spastic diplegia[20,21] and asymmetry increased in hemiplegia.[20] The most common emphasis in research about adults with CP who were ambulatory as children (most are GMFCS levels I-III) is that gait deteriorates, with some beginning as early as in their 20s, and most by age 40.[1,22-28] Gillet et al.[25] found that 50-61% of the variance in gait performance was due to loss of plantar flexor strength.

Several studies looked at activity and participation. In a study by Morgan et al.,[29] 15 of 17 participants with hemiplegia or diplegia were too slow in community level walking to be safe (e.g. crossing the street at a light). Walking speeds for school function has also been studied in elementary school children.[7]

The earliest study about adults with CP and gait I found was in 2007.[24] This retrospective study found that 7550 children starting at age 10 and 5721 adults (GMFCS levels I-IV) starting at age 25 had only a 23% decline in function 15 years later if they climbed stairs without a rail. For those who ambulated with difficulty, 33% improved their gait and 11% declined from ages 10-25. Seventy-six percent of adults who walked and climbed stairs at age 25 retained those abilities from ages 25-40.

Questionnaires about activity and participation also appear in the literature about adults with CP. Young adults less than age 32 report deteriorating function (gait and other functions) with different causes cited depending on GMFCS level of function.[23] Van Gorp et al's[26] prospective study found with the Life Habits questionnaire that after 13 years, there was increasing difficulty with function by the mid-20s, although those reporting at levels III-IV increased functional skills until age 23.

Andersson and Mattsson[27] designed their own questionnaire for 221 adults. They found that 84% lived on their own. However, although almost all adults with hemiplegia they studied could walk, only about half were employed. Adults with diplegia often reported deteriorating gait between ages 15-34, although nine with diplegia and eleven with hemiplegia stated that their abilities increased due to regular physical training.

Intervention for adults with CP is occasionally mentioned and advocated for in broad terms. Booth's systematic review[2] reports effectiveness of functional gait training in children and young adults with CP.

Walking in Children with Spastic Cerebral Palsy: The Research Literature

Far greater is the literature about gait in children with CP. Instrumented gait analysis of children developing typically and of children with CP dates back to Sutherland's,[30-32] Perry's,[13] and others' works beginning in the mid-1970s.[3] Studies have proliferated since then, and most of the studies cited here are from 2010 and later due to the sheer number of research studies available.

Of interest is that virtually all of the gait analysis is with children with spasticity, usually hemiplegia and diplegia at GMFCS levels I-III. Yes, these are the majority of children who can walk with or without assistive devices, but there are children with dystonia, athetosis, and ataxia who walk too. The research literature is void of studies of these children.

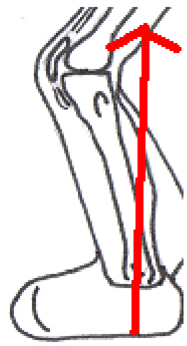
Body System Impairments Related to Gait

Gait analysis findings include lower extremity (LE) kinetics (forces that produce changes) and kinematics (motion without references to the causing forces); musculoskeletal specifics regarding range of motion, strength, stiffness, and alignment; and neurological impairments such as spasticity and loss of motor control.

Most impairment-based studies focus on the ankle joint. For children who toe walk, excessive co-activity of the tibialis anterior and gastrocnemius-soleus, loss of selective control, and spasticity are often findings, tested either with maximal voluntary contractions or through computerized gait analysis.[33-38] In addition, there are reported muscle morphology changes of reduced muscles volume and cross-sectional area, increased subcutaneous fat, and decreased muscle fascicle lengths seen with *in vivo* ultrasound.[37-41]Younger children with diplegia and children with hemiplegia are the most common toe walkers.[16,17,42] Rethefsen et al.[16] state that intervention to correct equinus and in-toeing should be done with caution, as the result can be progressive crouch gait.

The swing leg with a foot drop and stiff, extended knee is able to clear the floor with early heel rise of the stance leg. Other ways to compensate are to excessively flex the hip and knee of that LE or circumduct that LE.

Crouch gait is common, especially in diplegia. Crouching is a stable position when control and strength are lacking, increasing the child's ability to move safely in all directions. However, there is considerable muscular effort of the quadriceps femoris needed to sustain this pattern of walking,[43-45] increased mechanical stress especially on the ankle and knee joints[43] and increased metabolic energy needed dues to the need of the hip and knee extensors to increase their activity to stay upright.[45,46]

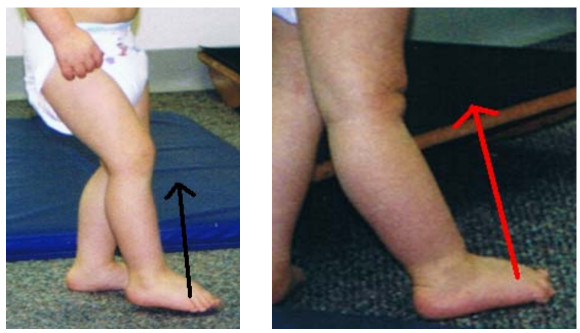


In crouch gait, the patella is usually elevated and the knee joint bears weight throughout the stance phase of gait in flexion.

Gage[14] reports that crouch develops as the gastrocnemius-soleus complex (plantar flexors) fails to restrain the tibia from moving excessively over the fixed foot from mid-stance to late stance, requiring the vasti muscles to attempt to maintain upright at the knee joint. Ries and Schwartz[45] report that when the vasti attempt the job of vertical lift that the plantar flexors are responsible for, they also move the center of mass backwards instead of forward. Steele et al.[44] reported the same findings.

Some children with hemiplegia or diplegia show knee hyperextension during the mid-stance phase of gait. Research shows that the primary impairment is lack of dorsiflexion range.[47] Lack of range prevents the body from moving forward across a stable, flat foot during stance. A similar result with subtalar fusions occurs.[48] Subtalar fusions decrease the flexibility of the ankle and foot in all three cardinal planes.

Typical gait with ground reaction force through the knee joint.



Ground reaction force of knee extension occurs when the foot enters stance phase in plantar flexion. Now the leg is loaded with the body's center of mass (COM) behind the heel, and the ground reaction force is a strong extensor force.[17,49]

Gait with excessive hip internal rotation may be compensatory to restore the abduction moment arm of the gluteus medius in children with excessive femoral anteversion and valgus deformity.[50,51]

There are more recent studies of trunk impairments during gait in children with spastic CP. Increased trunk movement is seen in children with hemiplegia and diplegia[52-54] during gait. This movement may be excessive in the thoracic or lumbar spine and is often compensatory for the lower extremity (LE) impairments that cause altered gait mechanics. However, not all impairments of trunk posture and movement are the result of dysfunctional LE impairments – they can be primary impairments as well.[55]

The lumbar spine lateral bending with Trendelenburg and Duchenne gait patterns may have implications for lower spine health as these children become adults.[53] Crouch gait, however, does not stress the lumbar spine.[54] I had difficulty understanding how the thoracic spine increased its movement in children with CP during gait, But Attias et al.[52] explains that the markers used to measure thoracic movement were placed at C7 and T10, recording movement of this section of the spine as a whole, then. My question would be *where* in the thoracic spine is the excessive movement. My clinical observations are that the thoracic spine does not rotate in gait in children with CP, but that there is often excessive movement, usually in the frontal plane, of the lower thoracic segments.

Gait Analysis

Toe walking increases vertical displacement and decreases forward movement during gait.[53] This increases the energy expenditure of gait. But crouch gait is far more energy costly, as the vasti must be responsible for vertical lift (insufficient, however) instead of the plantar flexors with the center of mass moving backward, and toe walkers can become crouch walkers[17] as they gain weight and lose relative plantar flexor strength and power.[45] The energy cost of crouch walking is like that of ascending stairs all day long.[45] Muscle fatigue of the hip and knee extensors occurs in crouch. Children with crouch gait performing the 6-minute Walk Test increase the degree of crouching by the end of six minutes of continuous walking.[43,57]

Activity and Participation

One study of children with hemiplegia or diplegia at GMFCS Levels II-III found that sit-to-stand strength was predictive of the ability to take three or more independent steps by age one.[15] Older children with spastic diplegia, ages 7-12 at GMFCS levels I-II, performed sit-to-stand activity too.[58] The researchers in this study looked at alignment and control, not predictive value of this skill. The children in their study performed the skill more slowly than peers without disability, had less efficient starting alignment, increased hip and knee flexion when standing, and decreased dorsiflexion range. Excessive coactivity at the knee joint was also found. These results are likely to be well-known to therapists; however, documentation in experimental research studies helps us justify our intervention strategies for functional outcomes.

Bar-Haim et al.[59] looked at stair-climbing skills for sensitivity for functional test development, finding that 51 children with diplegia at Levels II-III performed differently from each other in energy cost, and differently than children without CP.

Two studies[60,61] gathered information about impairments in running with children with CP, looking at GMFCS levels I-II. Both found decreased power generation from the plantar flexors for propulsion. Spasticity, body mass index, and postural control impairments also influenced running ability or prevented the child from achieving running.

Intervention

There were studies with children (some included teens and young adults) about the effects if intervention. These included open chain exercises and free weights,[62-65] functional electrical stimulation,[66-68] treadmill training[2, 69] and walking backwards.[70] Many of these studies showed some positive results at the impairment level or in efficiency of gait, although the results were mixed. Since each study used different testing, statistical analyses, and outcome measures, there is no clear direction for clinicians for best practice.

Summary of Literature Review and Clinical Interpretation

The remainder of this article is my interpretation of research findings and guidance, followed by intervention strategies that I have found useful.

Although gait is probably the most studied activity in physical therapy, there is much information still missing from the big picture of walking and its changes in people with CP across the lifespan who do walk at least part of their lives. The following list summarizes some of this missing information.

- Studies show that many ambulatory children with CP lose gait function in early to mid-adulthood. Why? Can larger retrospective analyses help find those answers? Can prospective studies follow children now, recording function and body impairments and their changes over time, surgeries and medical interventions, and environmental changes to give a clearer picture? This information would assist therapists immensely in selecting target functional skills and impairments to focus on early in a child's life to minimize impairments and loss of function. Conversely, in adults who do not lose ambulatory function or who lose function minimally, what factors contribute to their success?
- The most focused impairment-related findings point to loss of plantar flexion strength, power, and control or its lack of development as probable contributions to loss of ambulation. Some researchers caution against being too aggressive in

focusing on toe walking and gastrocnemius-soleus extensibility.[16,48] Furthermore, loss of plantar flexion appears to be a huge factor in the progression of toe walking to crouch gait seen in many children with diplegia, who toe walk as young children, then progressively crouch as they are older, bigger, and heavier. Crouch walking is energy costly and hard on joints, especially the knees. Eventually, crouch walking becomes too energy costly and painful for many teens and young adults, and walking may be abandoned. Interestingly, children and adults with hemiplegia who toe walk (usually asymmetrically) often do not lose ambulation skills completely. It is much more energy-efficient and less destructive to joint function than crouch gait.

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