Gait analysis in a clinical musculoskeletal setting

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Clinical examination of gait in relation to injury is a common occurrence in physiotherapy, podiatric, orthopaedic and general musculoskeletal clinics. The vast majority of these assessments are conducted by practitioners without immediate access to gait analysis equipment. Methodology remains vague and varied, with no systematic or standardised process available to observe adult patients' gait. Often with only a small clinical space, plinth and short walkway we are expected to take a history and then diagnose not only the current injury, but also the aetiological factors linking to this injury. A simple inversion sprain may be straightforward, but a lateral ankle pain after three miles walking with no history of trauma is less so.

This article introduces normal and abnormal foot function in gait, highlighting areas that may be more valid for assessment. It appears that further research and development of gait analysis methodology is required.

LEARNING OUTCOMES

1. Understand the principle of normal foot function and walking gait.
2. Understand the effect of abnormal foot function on walking gait.
3. Initiate clinical assessment of walking gait in relation to normal and abnormal foot function.

Background

Gait analysis is often undertaken as part of the physical examination of patients with musculoskeletal related lower limb and lower back symptomology (Baker 2007). It is also used as a tool in more general musculoskeletal (MSK) assessment in broad ranges of patient samples, including rheumatology and paediatrics (Beattie *et al* 2008; Beattie *et al* 2012; Foster & Jandial 2013). It can be generally defined as the evaluation of the manner or style of walking, usually done by observing the individual walking naturally in a straight line (Miller-Keane & O'Toole 2003). Magee (2013) states that analysis of gait takes "a great deal of time, practice, and technical skill combined with standardisation for the clinician to develop the necessary skills".

Richards and Levine (2012) assert that the purpose of gait analysis is to be used to make detailed diagnoses and to plan optimal treatment. Historically, it is proposed that when used in conjunction with patient history and general physical examination, it will aid in diagnosis of musculoskeletal pain, and predict successful treatment of related pathologies (Harris & Wertsch 1994; Whittle 1996, 2002). Understanding the basic principles of normal gait provides a foundation for understanding pathological and compensatory gait deficits (Curran & Dananberg 2005). Some authors state that gait analysis is not only a powerful investigative tool, but even comparable to an x-ray or blood test (Sweeting & Mock 2007).

Correct clinical diagnosis and optimal patient treatment is the prime aim for all clinicians. Most previous work highlights the importance of instrumented gait analysis, which is not available for the vast majority of clinicians working in general MSK clinics. Dr Jacqueline Perry was one of the first to document in detail the benefits of gait analysis (Perry 1992), stating that instrumented gait analysis provides information not detectable by the human eye, and assists in determining the correlation of multiple factors. Wren *et al* (2011), in a thorough literature review, concluded the influence of gait analysis on treatment planning and outcomes is generally positive. However, the analysis, methodology and training of examiners was varied and not linked specifically to their conclusion. They stated visual gait analysis to be less efficacious than that using computerised technology, but only two papers were available for this supposition to be made, both of which were specific sample groups, either children with cerebral palsy or amputees (Saleh & Murdoch 1985; Chang *et al* 2006). These assessments were looking for specific markers which determined surgical approaches, and therefore not valid to other sample populations or treatment options.

> "THE MAJORITY OF LOWER LIMB MUSCULOSKELETAL CASES ARE ASSESSED AND TREATED IN NORMAL OUTPATIENT ENVIRONMENTS, RATHER THAN TECHNOLOGICALLY EQUIPPED GAIT ANALYSIS CLINICS"

Although opinion and limited publications appear to find that instrumented or computerised gait analysis is more beneficial than visual, this has yet to be determined within the general symptomatic MSK sample. With improved methodology and awareness of limitations, it may be possible for the majority of clinicians who do not have access to gait analysis equipment to perform a valid and reliable gait assessment without the need for further instrumentation and expense.

Assessing walking gait

Normal walking gait requires the foot to work as a pivot, to allow us to place our lower limb out in front of us, and move it to a relative position behind us while progressing over the top of it (Perry & Burnfield 2010a). The following presents normal and abnormal gait relating to the foot, the lower limb, the lower back and pelvis and the upper limb.

Assessment criteria draws on available research for normalcy, and the authors' clinical experience on which parameters can be most accurately observed. A systemic lack of research in clinically observing these areas is fully acknowledged by the authors. It may be fair to assume that most clinicians have limited access to video gait analysis or further computerised assessment equipment in their clinics or hospital departments. The vast majority of lower limb MSK symptomology, such as plantar fasciitis or anterior knee pain syndrome, is assessed and treated in normal outpatient environments rather than more technologically equipped gait analysis clinics.

The aim of this article is to supply clinical gait analysis information to clinicians of all experience and background. The practitioner can use the outcomes from assessment not only to help in initial clinical decision making, but also in review situations to assess treatment outcomes by repeating the analysis.

HOW TO ASSESS GAIT

A set walkway of adequate length allowing frontal and sagittal plane analysis of the subject is mandatory. The average length of walkway suggested is six metres, with viewing distance from the subject recommended at two metres away in the sagittal plane. To aid in reliability, it is advised that the clinician assess gait in the same position for all assessments. This may mean sitting or standing at set locations within the assessment area.

SUBJECT SET-UP

Subjects need to be attired in a way that will allow free visual analysis of the upper and lower quadrants. Ideally, the same type of attire should be worn for each assessment where the same subject requires multiple assessments at different appointments.

Assessment can be conducted with the patient shod in valid footwear. If changing footwear is not part of their treatment, the same footwear should be worn at each assessment.

Normal and abnormal gait

1. The digits

Normal: There are three rockers of the foot which permit it to function as a successful pivot when walking: the heel, the ankle and the digits (Perry & Burnfield 2010a). Acting as the third rocker, dorsiflexion of the digits allows the foot to pivot correctly and the lower limb to obtain normal hip extension. In addition, enough weight needs to pass medially through the foot to dorsiflex the hallux, and wind the windlass at heel lift. The windlass mechanism is initiated as the hallux is dorsiflexed, when tightening the plantar fascia occurs due to the insertion of the fascia being moved further from the origin. This increased tension in the medial and central bands of the plantar fascia compresses the joints above and maintains midfoot stability through the propulsive phase of gait (Harradine & Bevan 2009).

Abnormal: Limitation of first metatarsophalangeal joint (MTPJ) dorsiflexion will prevent the windlass mechanism from occurring, resulting in a mid-tarsus unable to resist the bending moment applied as the heel is pulled off the floor (Harradine & Bevan 2009). The lowering of the arch at heel lift is analogous to subtalar joint (STJ) pronation, rather than the required supination at this time. For the windlass to function effectively, dorsiflexion of the hallux via medial column propulsion must occur. If a limitation of first MTPJ dorsiflexion is present, whether structural or functional, a lack of windlass mechanism may arise with resultant compensatory outcomes. A common compensation mechanism may be to reduce hip and knee extension due to the failure of the third rocker to permit this motion (Dananberg 1993a; Harradine *et al* 2006). Although causes of a structural hallux limitus are well discussed in literature (Clough 2005; Camasta 1996; Coughlin & Shurnas 2003), the aetiology of functional hallux limitus is less reported (Durrant & Chockalingham 2009). The two main causes are theorised as a prolonged reverse windlass and a functional bony restriction of first MTPJ dorsiflexion (Harradine & Bevan 2009).

PROLONGED REVERSE WINDLASS

This occurs as a result of excessive pronation moments at the STJ. These excessive moments may be due to a

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singular or combination of causes, such as pregnancy (Gijon-Nogueron *et al* 2013), posterior tibial tendon dysfunction (Walters & Mendicino 2014), and weak lateral hip rotators (Snyder *et al* 2009). The resultant prolonged reverse windlass results in drawn out plantarflexory moments at the first MTPJ when dorsiflexion should be occurring. Such increased plantarflexory moments will therefore impede hallux dorsiflexion and so reduce the ability of the foot to propel through the first MTPJ. Pressure may remain lateral, engaging the foot in inefficient propulsion (Bevan *et al* 2004). This, in turn, inhibits the arch rising due to the lack of a windlass mechanism.

FUNCTIONAL BONY RESTRICTION OF FIRST MTPJ DORSIFLEXION

Dorsiflexion of the first ray impedes the ability of the first MTPJ to extend (Roukis *et al* 1996). Pronation will lead to dorsiflexion of the first ray via increased ground reaction forces to the medial column of the foot (Harradine & Bevan 2000). This will limit the ability of the foot to pivot over the first MTPJ leading to sequelae as described with a prolonged reverse windlass mechanism. The resultant effect is similar to that of a structural hallux limitus.

Several compensatory mechanisms may be observed, such as reduced knee and hip extension due to the inability to engage medial column propulsion at the third rocker. This is assessed in the sagittal plane and described further in the hip and knee sections.

2. The foot

Normal: Initially, in walking gait, the heel is used as the first rocker (Perry & Burnfield 2010a). The medial longitudinal arch (MLA) lowers and lengthens initially during stance phase of walking gait. The MLA appears to reach its longest point at 50% of the gait cycle and reaches its lowest point at 80% of the gait cycle, at the contralateral limbs heel strike timing (Stolwijk *et al* 2014; Simon *et al* 2006; Leardini *et al* 2007; Caravaggi *et al* 2009, 2010).

The rearfoot everts and then inverts through a normal stance phase. Eversion occurs for the first 50-60% of the stance phase, followed by inversion (Leardini *et al* 2007; Wright *et al* 1964; Root *et al* 1977; McPoil & Cornwall 1994; Cornwall & McPoil 2007; Campbell *et al* 2016). The calcaneal eversion and inversion is often quoted as a direct representation of STJ pronation and supination (Root *et al* 1977; McPoil & Cornwall 1994).

Abnormal: If supination moments resisting STJ pronation, and so arch lowering, are not of adequate magnitude, abnormal pronation may occur. In relation to the ground, the leg normally externally rotates and applies supinatory moment to the STJ from mid-stance. For the leg to externally rotate, the foot must supinate and so the supinatory moment must be greater than the pronatory moment across the STJ. If there is a lack of applied supinatory moments or increased pronatory moments, this may not occur. The leg may remain internally rotated and, visually, the rearfoot fails to resupinate (Harradine & Bevan 2009; Harradine *et al* 2006). This is assessed in the frontal plane.

In addition, an abnormally supinated foot may invert at heel strike coupled with external hip rotation, when a normal parameter at this time would be eversion with internal hip rotation. Causative factors for this abnormal amount of supination include a laterally deviated subtalar joint axis (Kirby 1997) and a weak peroneal muscle group (Rosenbaum *et al* 2014). This is assessed at the rearfoot in the frontal plane.

3. The ankle

The ankle is the second rocker, used as the body progresses over the weight-bearing limb (Perry & Burnfield 2010a). Motion of the ankle in gait is predominantly in the sagittal plane, consisting initially of plantarflexion, then dorsiflexion (the "second rocker"), and then plantarflexion again. In swing phase, the ankle dorsiflexes to ensure ground clearance of the swing limb (Perry & Burnfield 2010a; Campbell *et al* 2016). Compensatory mechanisms seen for limited mobility at the ankle, such as resultant pronation with equinus (Evans & Catanzariti 2014), may be observed.

4. The knee

Normal: Kozanek *et al* (2009) used a dual fluoroscopic imaging technique to study tibiofemoral kinematics during walking gait. Agreeing with previous authors (Lafortune *et al* 1992), they concluded that the predominant motion of the knee during the stance phase of gait occurred in the sagittal plane. The knee was extended at heel strike, flexed during loading response and reached the first flexion peak of about eight degrees during early mid-stance. Thereafter, the knee began to extend to about 40% of stance phase and remained in slight hyperextension (average 3.5 degrees) throughout mid-stance. Approximately halfway through the terminal stance the knee was observed to flex again and the flexion continued throughout the pre-swing and peaked at toe off when the stance phase ended. The magnitude of this second flexion peak was on average 36 degrees.

During the contact phase the knee internally rotates, followed by gradual external rotation during mid stance and, in the normal population, the knee is externally rotated during late stance and swing phases in the normal population (Kadaba *et al* 1990; Benedetti *et al* 1998; Nester 2000). This motion has been proposed to couple with rearfoot complex pronation and supination, with pronation linked to internal rotation of the lower limb, and supination with external rotation (Rockar 1995). Although supported by later research, the ratio of this coupling should be clinically assessed on an individual basis (Souza *et al* 2010).

Abnormal: A lack of full extension may be due to a failure of the third rocker of the foot (Harradine & Bevan 2009; Harradine *et al* 2006; Dananberg 1993a), but also more intrinsic issues such as a fixed knee flexion deformity. A clinical static assessment would detect or exclude this finding. The knee is not examined in the frontal plane, instead the rearfoot is assessed for resupination as a marker of normal external lower limb rotation in terminal stance phase.

5. The hip

Normal: As stated previously, the lower limb, and so the hip, internally rotates during contact and mid stance and externally rotates throughout the terminal stance phase (Kadaba *et al* 1990; Benedetti *et al* 1998; Nester 2000).

The total range of the sagittal plane motion in the stance phase, beginning with the hip flexed and then extending, is around 20-30 degrees, with both the contact phase flexion and maximum extension each being approximately 10-15 degrees. This is measured from vertical to the floor, with half of this motion being stated as coming from the hip itself and the other half from a combination of pelvic rotation and anterior pelvic tilt (Bergmann *et al* 2001; Foucher *et al* 2012).

Abnormal: Adequate hip and knee extension has been cited as a crucial occurrence for normal walking gait (Perry & Burnfield 2010a; Harradine & Bevan 2009; Harradine *et al* 2006; Dananberg 1993a). This is assessed in the sagittal plane. Owing to clothing and the difficulty in identifying anatomical markers, a lack of hip extension in total is assessed.

6. The back and pelvis

Normal: Callaghan *et al* (1999) conducted 3D analysis on five healthy subjects to quantify movement of the lumbar spine in walking. The sagittal plane demonstrated lumbar flexion in relation to the pelvis and then extension, reaching peak extension around heel contact. Frontal plane motion showed lateral flexion to the contralateral side, i.e. at right heel contact, left lateral flexion of the spine. The lumbar spine laterally flexed following heel contact to the maximum value at toe off. While the range of motion in just these five subjects varied from 1.12" to 7.13", all participants exhibited the same pattern. In the transverse plane, the axial twist motion had peaks at heel contacts and the relative lumbar spine motion showed a twist to the side of heel contact followed by a fairly constant rotation to the opposite side reaching the peak value, coinciding with the consequent heel strike. Again, the five subjects were shown to have a wide variance of range of motion of between 3.51" and 14.69".

Later kinematic studies during walking have demonstrated the same general inclination of the trunk in the sagittal plane, a latero-flexion on each side per cycle in the frontal plane and a phase opposition between higher and lower trunk rotations in the horizontal plane (Feipel *et al* 2001; Lamoth *et al* 2002; Ceccato *et al* 2009). Again, a wide range of normal motion was reported.

Abnormal: There is obviously a large range of normal motion occurring in the back and pelvis in the asymptomatic population. However, stability in the frontal plane of the pelvis is related to conservative approaches to MSK therapy, such as core stability and muscle balance (Rockar 1995; Souza *et al* 2010; Bergmann *et al* 2001; Foucher *et al* 2012; Callaghan *et al* 1999; Feipel *et al* 2001; Lamoth *et al* 2002).

A functionally weaker gluteal complex leads to increased motion of the pelvis in the frontal plane, but also has the effect of increasing pronation (Souza *et al* 2010; Carter *et al* 2003; Leetun *et al* 2004; Elphinston 2008; Chuter & Janse de Jonge 2012). Assessment of the lower back and pelvis in the frontal plane is therefore essential.

Frontal plane trunk bending, or a "side sway", has been cited as a demonstration of abnormal gait (Dananberg 1993b). Patients demonstrate this via trunk bending from the ipsilateral restricted side to the contralateral side at ipsilateral toe off. This compensatory mechanism permits hip extension over a foot with a limited ability to function as a pivot. Dananberg (1993b) describes this as a process to "drag" the trailing limb into a stance phase.

7. The upper limb

Normal: The arm flexes and extends at the shoulder during each stride. Maximum extension is reached during ipsilateral heel contact, and peak flexion occurs with contralateral initial contact (Murray *et al* 1967). Although considerable variation occurs amongst individuals, Perry and Burnfield (2010a) quote from Murray *et al* (1967) that during moderate walking speed the average arc of motion is 32 degrees, with normal extension at 24 degrees and flexion at eight degrees. Faster walking increases the total arc of motion (Murray *et al* 1967).

Meynes *et al* (2013), in a thorough literature review, concluded that arm swing should be seen as an integral part of human bipedal gait and that arm swinging during normal bipedal gait most likely serves to reduce energy expenditure.

Abnormal: Due to the lack of research and range of normal values, assessing arm swing theoretically assumes the better the arm swing, the more efficient and normal gait will be. The theory on the fascial attachments of the upper to lower limb working together to increase efficiency and stability of gait (DeRosa & Porterfield 2007; Gracovetsky 1988; Yizhar *et al* 2009) suggest that there may be a correlation between the lack of hip extension and reduced arm swing. Arm swing would therefore not be expected to decrease following treatment designed to improve gait.

Conclusion

Gait analysis is a well-established part of a clinical MSK examination, used to theoretically aid in our process of diagnosis and decision making. However, there remains no validated method or tool to be used in the completion of this analysis. This article has highlighted the areas most suited for assessment when observing a patient walk and has introduced current evidence on normal and abnormal observational parameters. Such material provides clinicians with useful information with which to practice, but there is a systemic lack of research in this area and further work is required.

About the author

Paul is a clinical podiatrist and Director of The Podiatry Centre Ltd, with clinics around Hampshire and Surrey. Paul lectures on the postgraduate circuit and has published papers in podiatric, physiotherapy and orthopaedic texts. His current areas of interest continue to be variations in foot orthoses production and the amalgamation of differing foot function theory utilising an underpinning unified perspective. Recently, he has begun a part-time PhD upon observational gait analysis, juggling this with triathlon, colts' cricket coaching, natural bodybuilding and five young sons.

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