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Gait Analysis in Orthopedic Foot and Ankle Surgery—Topical Review, Part 1: Principles and Uses of Gait Analysis

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Abstract
Gait analysis, the systematic study of human walking, is a field that has been studied for well over 100 years. With the technological and scientific advancements of the last several decades, there has been substantial improvement in our understanding of the mechanics of human walking. Particularly important has been the advancement in understanding of the differences between normal and pathological gait. The purpose of this paper is to review the principles of gait analysis, with a particular focus on the underlying methods and science. This will assist orthopedic foot and ankle surgeons in better understanding the methods and meaning of gait research and the publications that commonly appear in the orthopedic foot and ankle surgery literature.
Level of Evidence: Level V, expert opinion.

Keywords: gait studies, biomechanics, outcome studies, statistical analysis, arthritis

Introduction

What Is Gait Analysis?

Documented observation of the human gait for clinical purposes has been practiced for thousands of years and has been noted in the writings of Hippocrates and Aristotle.[27] In recent times, the terms *gait analysis* and *biomechanics* have been occasionally confused, poorly defined, or even used interchangeably.[42] This is perhaps attributable to the increasing complexity of the science and inappropriate application of these commonly used terms.[19] As the field of biomechanics expands, so too does the need for a basic understanding of gait and of foot mechanics (Table 1).

The foot and ankle are subjected to large forces and variable terrain. To adapt to this environment, a closely linked system of joints is needed to provide a construct that is both stable and robust. Any change in this system may have adverse effects on the entire limb, both proximally and distally. Both general orthopedic surgeons and orthopedic foot and ankle surgeons have historically been taught the importance of observing gait as a means to assess the cause and effect of musculoskeletal disease.[17,35] Visual gait evaluation is different from formal gait analysis, which is performed in a specialized motion analysis laboratory. Gait analysis objectively records and quantifies human motion. The purpose is to scientifically measure human motion (whether normal or pathological) in order to achieve several goals: (1) to understand the biomechanical properties of human gait (eg, characteristics of normal and/or pathological gait),[18,41,82] (2) to analyze the components of human gait (eg, study the biomechanical components of the foot and their relationship to one another during gait[45]), and (3) to make clinically meaningful inferences regarding the anatomic and biomechanical function (eg, to objectively measure the effect of treatment[6,11,68]).

Commonly Used Terms in Gait Analysis

The gait cycle has been divided into phases, periods, and events to allow identification and isolation of different aspects of the gait cycle to facilitate communication. Although various terms have been used to describe the gait cycle, there are some standardized terms that allow clinicians, surgeons, and scientists to communicate effectively. The gait cycle is divided into the stance and swing phases. The stance phase comprises approximately 60% of each

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Table 1. Glossary of Terms.

Term	Meaning	Where Does This (Typically) Occur?	Primary Purpose
Visual gait evaluation	Visual observation of the gait of patients to aid in clinical evaluation and decision making	In clinics and offices of orthopedic surgeons	Clinical evaluation and decision making
Gait analysis	Use of scientific methods to observe and record objective parameters of human gait	In specialized facilities designed for gait analysis	Objective, scientific characterization of the parameters of human motion
Biomechanics	Discipline that describes, analyzes, and assesses human movement[88]	In facilities specializing in biomechanical evaluation of a subject or target object (eg, living humans, cadaveric portions of human anatomy, tissue samples, etc)	Scientific characterization and modeling of forces and motion

Table 2. Phases, Periods, and Events of the Normal Human Gait Cycle.

Phase	Period	Events
Stance	First rocker	Heel strike
	Second rocker	Foot flat
	Third rocker	Heel rise
		Toe-off
Swing		Foot clearance

gait cycle, while the swing phase accounts for roughly 40%. Both phases are subdivided into periods with identifiable events (see Table 2 and Figure 1). A working knowledge of these events, and their importance in normal gait, is important for understanding, diagnosing, and treating abnormalities of the foot and ankle. Furthermore, the terms used to describe common pathological gait patterns are important for effective communication among musculoskeletal health care professionals.

The Phases of Gait

Stance Phase

The stance phase is responsible for bearing weight while allowing the lower extremity and pelvis to rotate and translate over the fixed foot. This process applies a load to the proximal muscles storing energy, primarily in the hip flexors as the hip passively extends. As the body continues forward and as the fixed foot leaves the ground and enters the swing phase, the anterior hip and leg muscles that have been put under a tensile load by the passive extension of the hip throughout the stance phase act to flex the hip, propelling the foot forward in the swing phase.[17,86] During the stance phase, the foot progresses through 3 "rocker" periods, beginning with heel strike and ending with toe-off. In the first rocker, the heel touches the ground. Eccentric contraction of the ankle dorsiflexors allows the ankle to plantar flex in a controlled manner. In the second rocker, the tibia rolls forward over the ankle to permit continued forward movement of the body. The foot remains planted throughout the second rocker. In the third rocker, the foot is dorsiflexed through the ankle and the metatarsophalangeal joints, culminating in the event of toe-off.

The function of several muscle groups is critical during stance phase, allowing for the energetically efficient process of human gait to occur[17,31] (Table 3). The predictable timing and intensity of activity during normal gait have been well established, and abnormalities have been correlated to disease states, making a basic understanding of this sequence of activity an important consideration during clinical assessment of normal and pathological gait.[17,86]

Motion at the level of individual joints in the foot (specifically in the hindfoot and midfoot) during gait has been difficult to study. In part because of this difficulty, the role that motion in each of the different parts or joints of the foot plays during the stance phase of gait is not yet fully understood. This in part due to the variation that is observed in the anatomy of the foot and likely also due to the capacity for adaptation by the multiple joints in the foot.[18,19,40,46] This has been demonstrated in post–ankle fusion gait. It has been shown that surprisingly normal global gait patterns can exist, despite the elimination of tibiotalar joint motion.[79] This is presumably because the gait cycle progresses through 3 rockers and does not specifically rely on tibiotalar motion for the entirety of the foot and ankle motion in gait. The talonavicular, subtalar, and calcaneocuboid as well as the proximal joints (tibiofibular syndesmosis and knee) can compensate and adapt.[18,24,47,79,85]

Swing Phase

The swing phase of gait is responsible for bringing the foot from a plantar-flexed position at toe-off to a neutral or slightly dorsiflexed position through the concentric contraction of the anterior leg musculature and the peroneus brevis muscle.[17] This allows the foot to clear the floor as the leg is pulled forward by stored energy in the pelvis and proximal thigh musculature. Hindfoot alignment shifts from a supinated position to a pronated position during this time. This

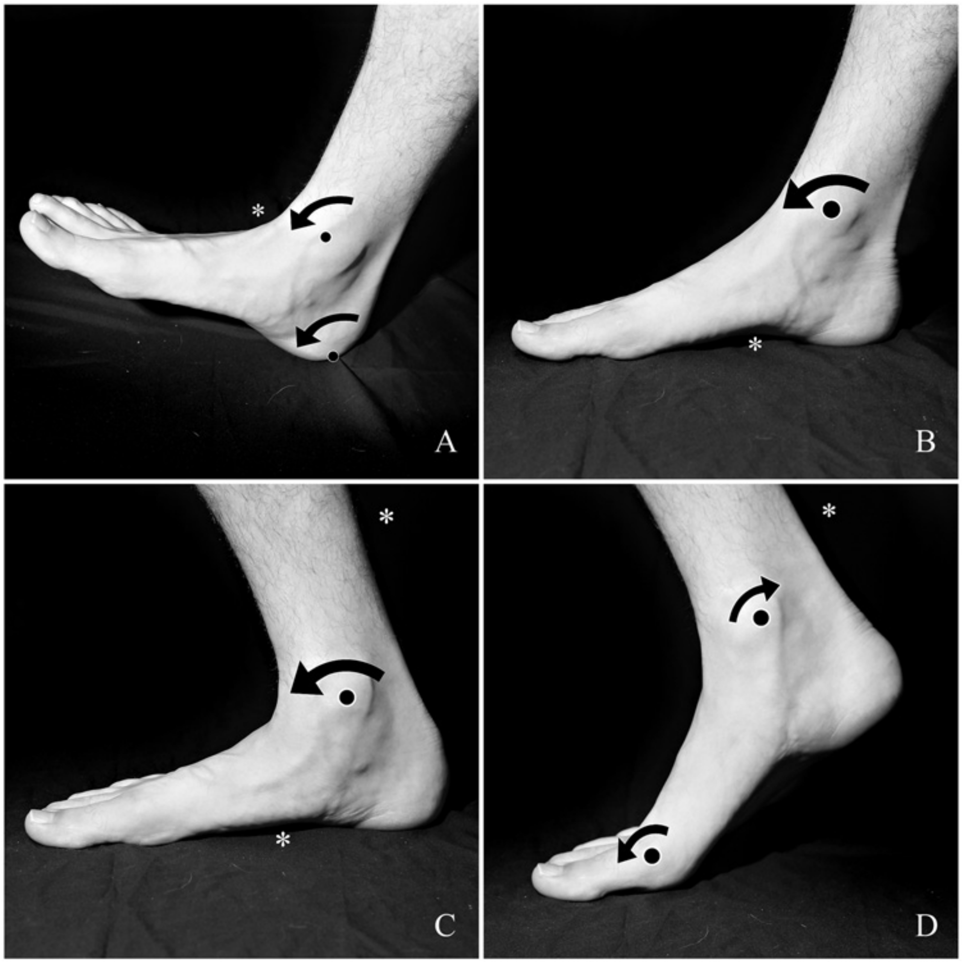

Figure 1. The 3 rockers of gait. (A) During the first rocker, the heel strikes the ground, the foot rotates around this, and the ankle joint axis to come to rest in the flat foot position. Contraction of the anterior compartment muscles* controls this motion. (B) During the second rocker of gait, the tibia is brought "up and over" the talus, rotating around the ankle joint. The intrinsic muscles of the foot and tibialis posterior fire* to maintain a medial longitudinal arch. (C) The terminal portion of the second rocker signals the powerful triceps surae to fire.* (D) During the third rocker, the ankle plantar flexes over a fixed forefoot (about the metatarsophalangeal joints) ending in toe-off, initiating the swing phase of gait.

brings the hindfoot and ankle into a more supple position. This allows for the acceptance and dissipation of the high loads that occur at heel strike. This is in contrast to the more rigid characteristics of the supinated hindfoot, which facilitates push-off.[40] The importance of hindfoot positioning is not limited to the hindfoot itself. It is also critical to the ability of the forefoot to dissipate loads as well.[17] The valgus heel and the "unlocked" and supple midfoot joints are able to dissipate energy to the forefoot, while the more rigid "locked" midfoot seen in supination forces more concentrated energy transfer.[23,61] This is practically noted in a cavovarus deformity, where lateral overload results in painful lateral callus formation, metatarsal stress fractures, and other problems related to overconcentrated forces during the stance phase.[5]

The Classes (Parameters) of Gait Analysis

There are 5 main classes or parameters of gait analysis: (1) temporal-spatial parameters; (2) kinematic parameters; (3) kinetic parameters; (4) integrated biomechanics; and (5) electromyography (EMG).

Temporal-Spatial Parameters

Of all the parameters of gait analysis, temporal-spatial parameters (TSPs) are the easiest to understand and are considered the most immediately clinically applicable (Table 4). TSPs have been referred to as the "vital signs of gait."[42] They typically include gait speed, stride length, cadence, step or stride

Table 3. Muscles Used During the Gait Cycle.

Phase of Gait	Period	Muscles	Contraction Type	Function
Stance	First rocker	• Anterior muscle group[a]	Eccentric	Control the plantar flexion of the foot, preventing the foot from slapping against the ground
	Second rocker	• Intrinsic muscles of the foot (using the plantar fascia[17]) • Peroneus longus • Posterior muscle group[b]	Eccentric	• Intrinsic foot muscles and tibialis posterior maintain the longitudinal arch of the foot throughout the second rocker • Posterior muscle group contracts to control the forward rolling of the tibia over the ankle
	Third rocker	• Posterior muscle group	Concentric	• Locks the Chopart's joint, permitting the heel to rise, rotating about the metatarsophalangeal joints • Provide a small forward propulsive force
Swing	N/A	• Peroneus brevis • Anterior muscle group	Concentric	Dorsiflexion of the foot on the ankle to allow for foot clearance and to prepare the foot for heel strike

[a]The anterior muscle group consists of tibialis anterior, extensor digitorum longus, and extensor hallucis longus.
[b]The posterior muscle group consists of tibialis posterior, flexor digitorum longus, flexor hallucis longus, and the gastrocnemius and soleus muscles.

Table 4. Spatiotemporal Parameters of Gait.

Parameter (Units)	Clinical Relevance
Gait speed (meters/second)	• Has been well correlated with function and degree of dysfunction in orthopedic research, with slower speeds often being correlated with foot pain,[56] more abnormal gait, and poorer function[4,11,41,65] • Correlated with general outcomes in elderly patients (mortality, dependency, institutionalization)[28,90] • Universally measured and reported
Stride length (meters)	• Demonstrated to be correlated with pain in gait (with shortened stride lengths demonstrated in painful foot and ankle conditions),[11,41,56,79] control of gait and steadiness during gait,[51] etc • Correlated with general outcomes measures in elderly patients (mortality, dependency, institutionalization)[28,90]
Cadence (steps/second) Step or stride width (meters)	• Correlated with function and functional improvements following intervention for foot and ankle conditions[11,41,79]
Single limb support time (seconds) Double limb support time (seconds)	• Correlated with foot pain,[56] function, and functional improvements following intervention for foot and ankle conditions[10,11,41,79]
Stance time/duration	• Correlated with function and functional improvements following intervention for foot and ankle conditions[11,41,69,79]

width, single limb support time, double limb support time, and stance time or duration. TSPs make intuitive sense, can often be easily interpreted by the clinician, and have been well correlated with levels of disability and function across multiple disease states in the literature.[33,34,42,66,86]

Gait speed is the product of cadence and stride length (see equation below by Kirtley[42]). Stance duration (or support time) represents how long the supporting limb stays in contact with the ground. Individuals with a painful foot and ankle will avoid weight bearing on the affected limb, which creates the classic "antalgic" gait. This classically creates decreased stance duration in the affected limb.[11] Conversely, individuals with deconditioned or weakened muscles and/or altered foot mechanics will have prolonged stance times, as they are unable to progress through the stance phase at a normal rate.[41,84] Recording the stance duration or support time is just a numeric reflection of these behaviors.

$$\text{Walking Speed} = (\text{Cadence} \times \text{Stride Length}) / 120.$$

In this equation, walking speed does not equal velocity. Walking velocity implies a vector, or direction, whereas speed is an adirectional parameter. The distinction between these two is important, but unfortunately it is not often made in the literature. Cadence is a time-sensitive measure (steps per minute), and it therefore needs to be divided by 120. Cadence consists of steps per minute, whereas speed is expressed in meters per second.

TSPs have been often used to quantify pathological gait patterns or demonstrate the effects of an intervention.[33,34,42,66,86] In the setting of ankle osteoarthritis, several authors have shown significant improvements in gait speed following successful ankle replacement or fusion.[11,26,79] This improvement in gait speed was thought to be reflective of an overall improvement in "walking function" by the authors of one of these publications.[26]

Although TSPs are frequently used to indicate treatment effects, it is important to remember that TSPs are a global expression of gait function and can be directly influenced by several factors, such as the subject's age and sex,[9] the method of measurement,[42] the staff collecting the data,[42] the instructions given to the subject,[42] the time of day,[42] the characteristics of the walking surface or the size of room in which measurements is taken,[39,42,54] the use of footwear versus barefoot walking for analysis,[42,70] auditory cueing at the time of measurement,[42] and pathological factors that are not related to the foot and ankle (eg, nervous system disorders, balance disorders, cardiopulmonary disease).[33,34,42,66,86] Therefore, any research that uses any TSP as a primary outcome must take into account and control for the fact that TSPs are a crude measure, susceptible to potential confounding influences.

Nevertheless, TSPs still provide important quantitative information about an individual's gait and should be included in clinically oriented gait research. Differences in TSPs may represent significantly altered function and have been important in assessing abnormality and functional issues after treatment of several foot and ankle conditions, including ankle arthritis, hindfoot arthritis, hallux rigidus, and hallux valgus.[8,10,11,41,55,60,77,79,82] It is important to note, however, that not all of these data have been compared with normal and appropriately matched patients. Although such "baseline" data for indirect comparison are reported throughout the literature,[9,43] direct comparisons with diseases via well-planned prospective research is ideal.

Kinematics

Kinematics, or the study of motion, refers to the movement of a body or bodies in isolation of the forces that generate the movement.[42] This is most often measured as displacement (either linear or angular), velocity, or acceleration.[42] Kinematic measures may be observed in many ways but are most commonly recorded using motion tracking devices and/or cameras to derive limb trajectories and joint angles (Figure 2). Modern gait analysis uses optical tracking cameras.[86] Although this can be performed using either 2-dimensional (2D) or 3-dimensional (3D) methods, for the purposes of this review only 3D gait analysis is discussed. In the 3D model, a defined volume or space is calibrated so that the movement of markers within this space can be tracked in 3 dimensions with high accuracy. The motion between

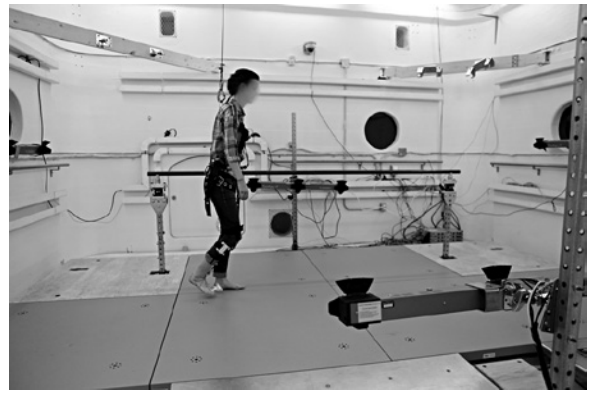

Figure 2. A modern gait analysis laboratory. Cameras located on around the test area allow for 3-dimensional, high-speed collection of temporal-spatial and kinematic data. Force plates are embedded in the walkway for kinetic data collection.

defined segments, as well as a defined "global coordinate system" (a defined set of planes that relates the segments to the surrounding environment), is observed.[72]

Tracking markers are placed on the skin over palpable landmarks to allow the measurement of one "segment" (or portion) of the body of interest in accordance with a validated model, like the model put forward by Leardini et al[45] (Figure 3). They can be either active markers (which transmit a signal, like those shown in Figure 3) or passive markers (which reflect a signal from a transmitting and receiving camera). Attaching markers on the skin of the foot over palpable landmarks is not without limitations. Skin motion has been documented as a source of significant error, with the skin moving as much as 16.4 ± 16.7 mm over the navicular and 12.1 ± 0.3 mm over the calcaneus at toe-off.[78] Further issues related to other soft tissue artifact have been demonstrated and will be discussed in greater detail in part 2 of this series.[40,63] Error has also been recognized in reliably marking the complex anatomy of the foot.[14] Anatomic variation in the normal state or in pathological states contributes to potential issues regarding the accuracy and reproducibility of marker placement.[40] Despite these shortcomings, given the invasive nature of fixation of markers to bone in normal healthy subjects and considering the subcutaneous location of the osseous anatomy of the foot, skin-mounted markers are the acceptable marker arrangement at this time.[42]

The foot and ankle are a collection of a relatively large number of small bones that function in complex and very close anatomic relationships. Separating the motion of the different bones and joints of the foot is therefore a challenge, given our currently available technology. These factors were among the dominant considerations that led to the initial treatment of the foot as a single segment, as is the

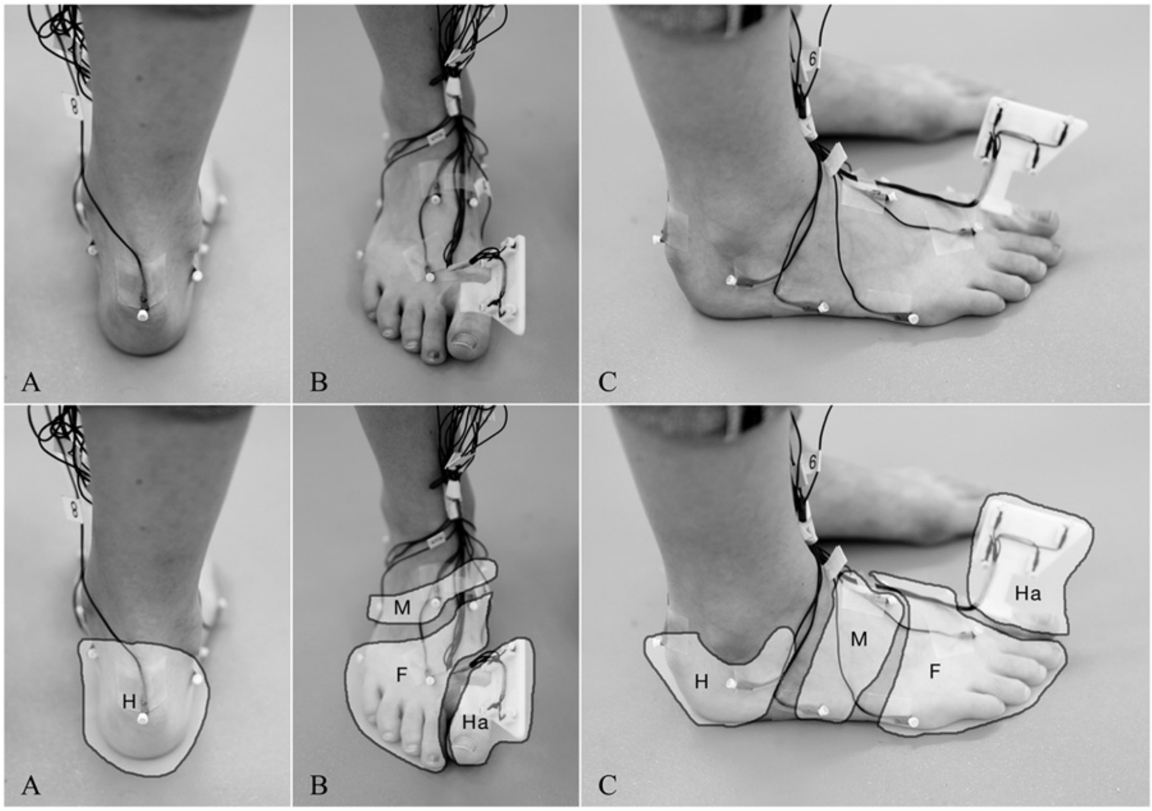

Figure 3. An instrumented foot using the 4-segment model initially described by Leardini et al.[45] The segments of this model are the hallux (Ha), forefoot (F), midfoot (M), and hindfoot (H).

case with the "modified Helen Hayes" marker set that has been widely used in the literature.[10,41,47] Despite widespread use, single-segment models of the foot provide limited and overly simplistic data regarding the foot.[45,50]

With improved technology, there has been an emerging trend to treat the foot as one structure made up of distinct and separate segments, such as the hindfoot, midfoot, forefoot, and hallux[43,60] (Figure 3). The information that can be gained by dividing the foot into different functional units for the purposes of gait analysis can yield important information. Information can be gathered with regard to differences in motion,[20,32,45] observed ground-reaction forces,[12,32] and plantar pressures[20,24] between the different segments using this approach. Increased resolution allows one to differentiate behavior of the foot with respect to normal[43] or pathological gait, such as in persons with ankle osteoarthritis.[60] This knowledge is critical to understanding how different functional areas of the foot compensate for injury or the consequences of surgical treatment. Although this area is in its infancy, the information gained from these recently established techniques will help provide more information about foot and ankle disease and its treatment.[22,49]

Kinetics

Kinetics refers to the study of the forces and moments that cause movement. Within the context of clinical gait analysis, kinetic analyses measure the ground reaction forces (including measurement of center of pressure and plantar pressure distribution), joint moments, and joint mechanical powers.

Force plates are used to measure the ground reaction force (GRF) during the stance phase of gait. The GRF is defined as the force that is applied to the foot by the ground, which according to Newton's third law is equal and opposite to the force that is applied to the ground by the foot. This is measured in newton-meters. GRF curves during the stance phase of normal gait produce a typical M-shaped pattern (Figure 4). The first peak represents the forces exerted during heel strike, and the second peak the forces exerted during heel rise and eventually toe-off. The trough in between the peaks represents midstance, where relatively lower forces are seen. During this time, force is transferred from the heel to the forefoot and hallux. The measurement of the GRF can be helpful as an overall indicator of gait performance, and some abnormalities of the foot and ankle have been found to produce characteristic curve profiles that differ significantly

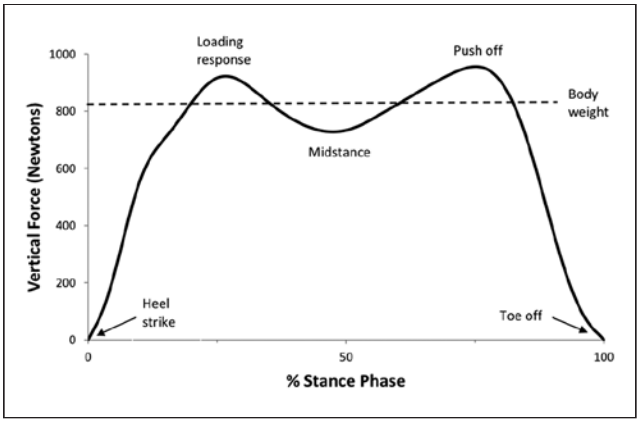

Figure 4. A typical kinetic curve during stance phase of normal gait. The graph shows the initial spike at heel strike; the trough at midstance as pressure on the sole of the foot shifts from the heel to the metatarsophalangeal joints; and the final spike under the metatarsophalangeal joints that occurs at third rocker/toe-off.

from normal controls.[2,7,18,37,60,82] Despite this body of evidence, compensatory and/or pathological movements of the lower extremity, trunk, and upper extremity can influence the observed GRF, making this measure prone to many confounding factors.[42] It is therefore useful as a global or overall method of characterizing gait.

Center of pressure measurement. The center of pressure (COP) is a kinetic measurement commonly used in the literature. It represents the mean of all of the vectors of the forces acting on the bottom of the foot during the stance phase of gait. This differs from pure kinetics in that the COP represents a mean of all of the forces, rather than a raw observation. COP is measured using the same instruments (ie, force plates) that detect and measure forces and their vectors. During normal gait, the COP reliably travels from the heel, at heel strike, to the first ray at toe-off. The reliability of the location and timing of COP makes it useful for conceptualizing and understanding the effect that disease or injury has on gait. This is well illustrated by the COP observed in pes cavus, which is characterized by a center of pressure that is lateralized. This explains the presence of lateral foot and lesser metatarsal overload and keratosis. In contrast, a pronated foot, as in pes planus, will typically show a medialized COP.[86] This measure has been practically used for many purposes, such as assessing the effects of shoe type and orthoses,[15,67] attempting to predict outcomes following surgery for Charcot arthropathy,[58] and evaluating prostheses for partial foot amputation design.[21]

Plantar pressure measurement. COP is a single vector representing the average forces under the foot. However, the measured force is actually distributed over the entire area of the foot that is in contact with the ground. To analyze this distribution, plantar pressure measurement (defined as the force per unit area) can be determined.[42] It is measured either using force plates, as is the case with kinetic measures, or using piezoresistive technology. Plantar pressure has several practical advantages over COP measurement and has been advocated for its clinical applicability and practical utility in the treatment of patients.[42,86] It produces a "map" of the pressure distribution of the plantar surface of the foot. Figure 5 provides a visual demonstration of this common use of plantar pressure mapping. This technology is also used for the custom fabrication of orthotics for conditions like rheumatoid arthritis,[13] to assist in intra-operative decision making,[71] and to help guide the foot and ankle care of patients with diabetic foot disease and track their outcomes.[36,38,48] Notwithstanding issues related to the pressure sensor type, the method of calibration, and the method of reporting of the data, this measurement concept is well supported in the literature.[42] In recent years plantar pressure measurements have been more rigorously studied, with reproducibility for this technique demonstrated in both altered walking conditions[3,76,91] and pathological states.[2,7,24,83] This wealth of information already available in the literature can be used for rigorous study planning and validation of methods.

Integrated Biomechanics

The use of TSPs and kinematic, kinetic, and pressure measures in isolation, although somewhat helpful, may not give the full picture. Specifically, the underlying cause of the movement or the reasons for changes in movement may not be fully understood.[11] This has led to the development and validation of integrated biomechanical measures, most notably joint moments and power.[42]

Joint moments. Joint moments are the result of mathematical modeling that estimates the force experienced by a joint using both kinetic and kinematic data. This is accomplished by knowing the anthropometric characteristics (ie, how much mass a segment has, where its center of gravity is located) of the body parts being studied, in combination with the observed GRF and kinematic data. Using this information it is possible to work backward mathematically (termed *inverse dynamics*) to estimate the directional forces applied to a joint by the muscles that surround it. Moments represent the net effect of all muscle activity about the joint of interest (ie, flexors or extensors). Direct clinical testing of these inverse dynamics calculations has been found to produce relatively reliable and accurate results.[42]

Determination of joint moments produces clinically useful information. Contraction of muscles around a joint like the ankle during gait generates contact between the cartilaginous surfaces of the ankle joint. Patients with arthritis, probably in an attempt to avoid having painful, arthritic surfaces driven together, avoid strong muscle contractions

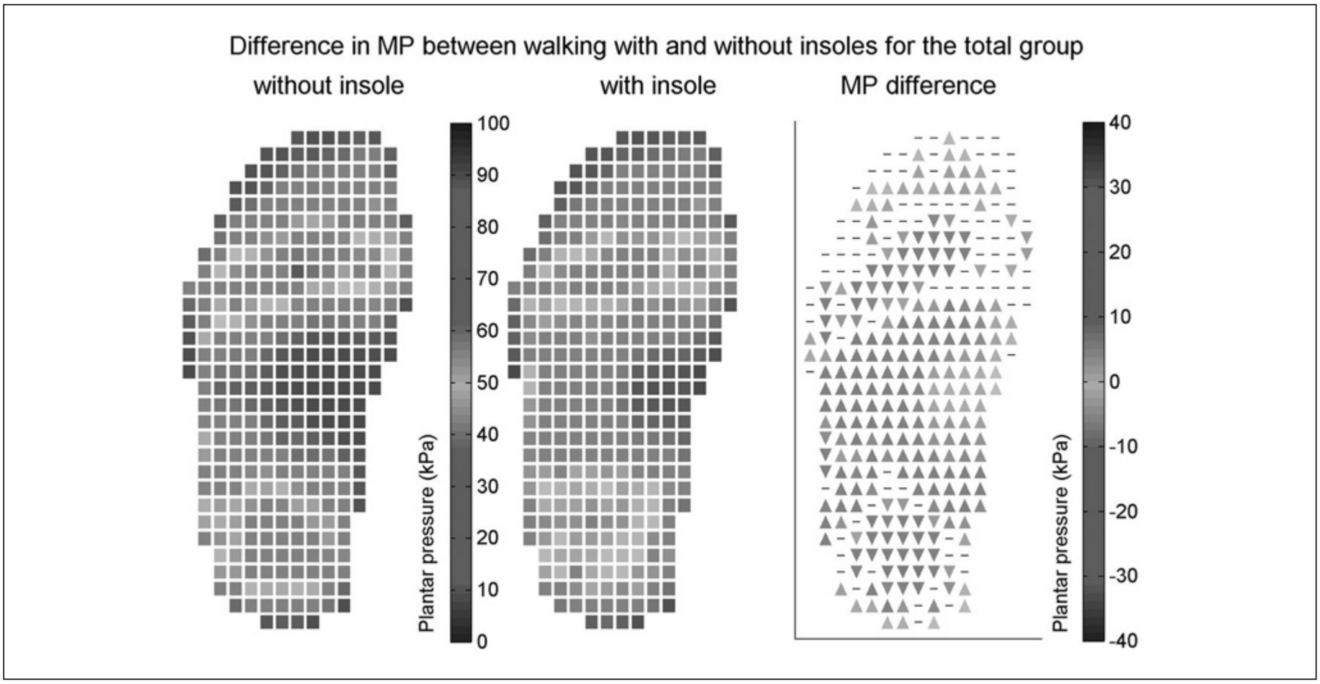

Figure 5. An example of the "map" created by plantar pressure measurement, and how it can demonstrate very useful information with a single glance. (From Stolwijk NM, Louwerens JW, Nienhuis B, Duysens J, Keijsers NL. Plantar pressure with and without custom insoles in patients with common foot complaints. Foot Ankle Int. 2011 Jan;32(1):57-65; with permission: SAGE Publications).

around arthritic joints and maximize the use of passive restraints for stability (eg, ligamentous support and gravity).[42] This leads to measurably lower moments of force at the diseased joint.[41,44,82] The joint moment here becomes a surrogate measure for a subject's willingness and/or ability to contract the muscles around a joint of interest.

This measure cannot determine why the changes have occurred. Trying to determine whether a patient is inhibiting muscle contractions around a joint of interest because of pain or instability or any other cause is difficult. This difference must be further teased out, if possible, by using other clinical measures in concert with the gait analysis.

Power. Power, measured in watts, is a product of the net muscle moment and the angular velocity of a segment. It is a scalar quantity and therefore does not have direction. The net joint power provides valuable information regarding the function of a muscle contraction. Power is generated via concentric contraction of the musculature when the moment acts in the same direction as the intended motion. The more forceful the contraction, the greater the angular velocity will be, leading to greater power generation. Conversely, eccentric muscle contraction functions to absorb power, as the moment acts in the opposite direction as the angular velocity of the studied body part. Measuring the resultant power generated by muscle contraction across the gait cycle provides a more functional measure, offering a glimpse into the role individual joints and surrounding muscles play in gait. These are likely the factors driving its increasing use in the orthopedic foot and ankle literature.[11,53,60,73,82,89]

Electromyography

Electromyography (EMG) directly measures the electrical activity of muscles. EMG analysis can provide insight into when a muscle is active and the degree of motor recruitment that is occurring. It can also provide incomplete information on the force applied by the contraction.[86] Because of technical issues, however, EMG cannot be used to calculate force of contraction in dynamic assessments. Furthermore, EMG does not tell us why the muscle is contracting (ie, eccentrically to absorb power, concentrically to generate power). As with any measurement tool, several limitations exist with data obtained using EMG. Issues of cross-talk, where electrodes record unwanted signals from adjacent muscles, as well as motion artifact, which is induced by relative movement of the electrodes on the skin, can make interpretation of an EMG problematic.[86]

Despite the limitations of EMG, clinically applicable information can be gained from EMG studies. This includes frequency, or the rate at which motor units that are being signaled fire (temporal summation) and the extent to which additional motor units are recruited to fire (spatial summation). This can give a realistic picture of the overall activity of the neuromuscular units being studied. As well, when EMG is used appropriately to augment other forms of analysis, like moments and powers, it can provide a very robust picture of when and how muscles are acting around a joint of interest.

EMG can practically be used to study disease states such as arthritis and diabetes[59,74,87] as well as to quantify effects of treatment.[30,81] EMG has been used to assess the outcome of tendon transfer surgeries.[52,64] It has been also been used as a tool to assess fixation strategies in tendon transfers,[29] to assist in preoperative planning of tendon transfer surgeries,[25,57,62] and to predict the success of planned transfers.[75] Recent attempts to measure age, gait parameter, and dominant-side related differences have added to the baseline data required to study the effects of altered or diseased states in different populations. This has produced control population data that could be useful for comparison or standardization.[1,16,80]

Conclusions

Gait analysis has enjoyed a rapid development over the past several decades. The results of gait analysis research are increasingly reported in the orthopedic foot and ankle literature. A substantial portion of this research is designed to answer clinical questions and to assist with clinical decision making. Part 2 of this series will focus on the foot models commonly utilized in the clinical gait analysis literature.

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