Lecture # 3

Artificial Limbs I

QUALITATIVE GAIT ASSESSMENT

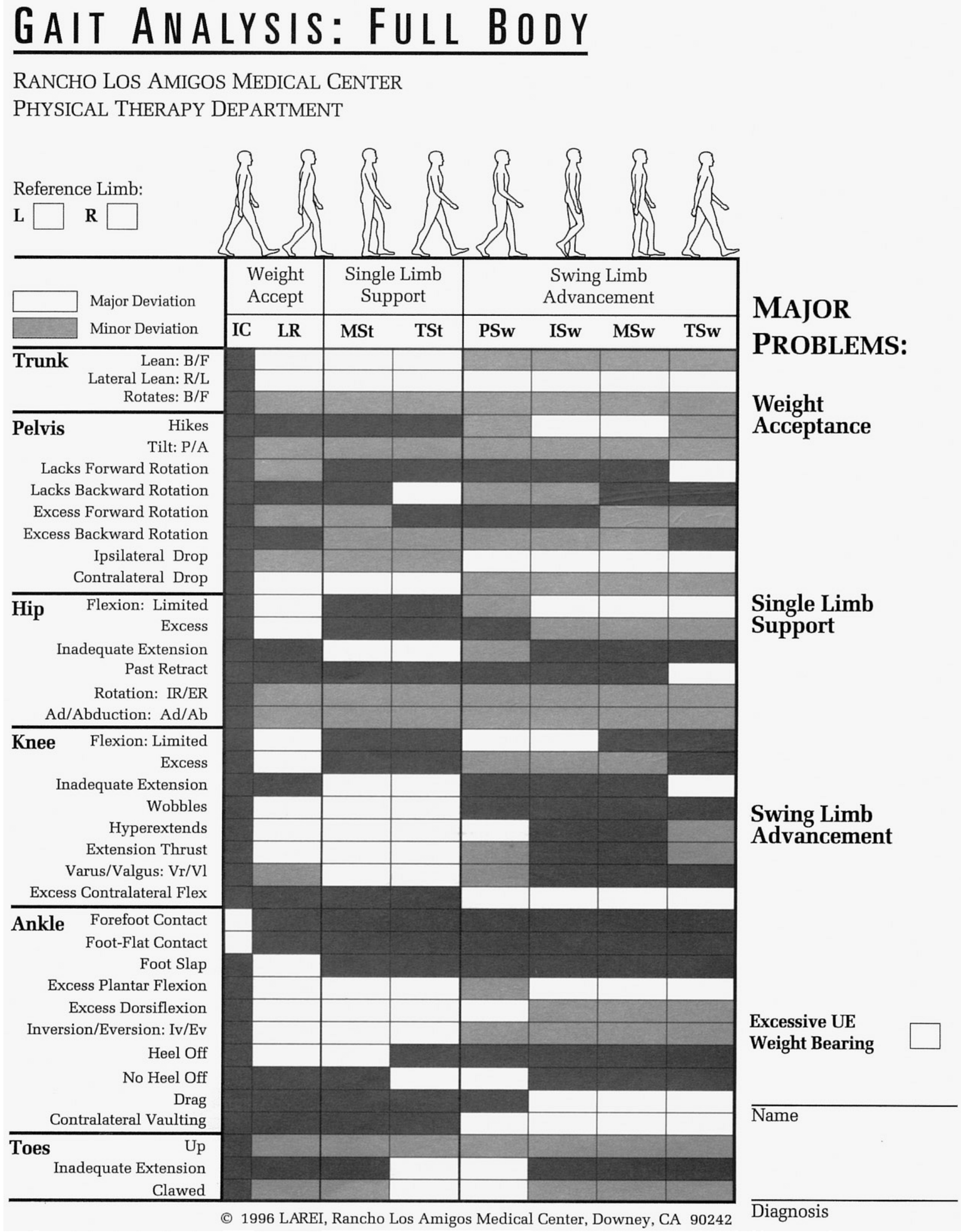
Qualitative methods for identification and recording of gait deviations have played a role in patient care for decades. In 1925, Robinson described pathological gait patterns and attempted to correlate them with specific disease processes. In 1937, Boorstein identified disease processes that could be diagnosed with gait assessment. He described seven major gait deficit groups. In the late 1950s, Blair Hangar, the founder of Northwestern University's School of Prosthetics and Orthotics, and Hildegard Myers, a physical therapist at Rehabilitation Institute of Chicago, collaborated to develop the first comprehensive system of clinical gait analysis for persons with transfemoral amputation. They identified 16 gait deviations and suggested numerous clinical and prosthetic causes for each. The first Normal and Pathological Gait Syllabus was published by the Professional Staff Association of Rancho Los Amigos Hospital in 1977. This syllabus uses parameters of normal gait as a comparative standard for abnormal or pathological gait. It focuses on identifying gait deviations that affect the three functional tasks of walking: weight acceptance, single limb support, and swing limb advancement. A form listing the most commonly occurring gait deviations in each subphase of gait is used to record any observed gait deviations that interfere with these functional tasks (Figure 1). Problems in each of the six major body segments are noted with a check in one of the boxes, beginning with the toes, then the ankle, knee, hip, pelvis, and trunk.

This format allows the clinician to consider systematically the following questions:

- Are the toes up, inadequately extended, or clawed?
- Is there forefoot-only contact (toe walking), foot-flat contact, foot slap, excess plantar flexion, or dorsiflexion? Is heel-off, foot drag, or contralateral vaulting present?
- Is knee flexion adequate, absent, limited, or excessive? Is extension inadequate? Does the knee wobble, hyperextend, or produce an extension thrust (recurvatum)? Is varus or valgus present, or is excessive contralateral flexion seen?
- Is hip flexion adequate, absent, limited, or excessive? Is adequate extension seen? Is retraction of the thigh during TSw from a previously attained degree of flexion seen? Can internal or external rotation, abduction, or adduction be observed?
- Does the pelvis hike? Does it tilt anteriorly or posteriorly? Is forward or backward rotation seen? Does it drop to the ipsilateral or contralateral side?
- Does the trunk lean or rotate backward or forward? Does it lean laterally to the right or left?

Qualitative gait assessment is an important component of preorthotic assessment because it assists the clinician in identifying the functional task and the subphase of gait, that are problematic and can be addressed with orthotic intervention. Similarly, deviations observed during gait analysis can identify the need for adjustment of prosthetic alignment.

QUALITATIVE GAIT ASSESSMENT


GAIT ANALYSIS: FULL BODY

RANCHO LOS AMIGOS MEDICAL CENTER
PHYSICAL THERAPY DEPARTMENT

Reference Limb:
L ☐ R ☐

☐ Major Deviation
☐ Minor Deviation

	Weight Accept		Single Limb Support		Swing Limb Advancement			
	IC	LR	MSt	TSt	PSw	ISw	MSw	TSw
Trunk Lean: B/F								
Lateral Lean: R/L								
Rotates: B/F								
Pelvis Hikes								
Tilt: P/A								
Lacks Forward Rotation								
Lacks Backward Rotation								
Excess Forward Rotation								
Excess Backward Rotation								
Ipsilateral Drop								
Contralateral Drop								
Hip Flexion: Limited								
Excess								
Inadequate Extension								
Past Retract								
Rotation: IR/ER								
Ad/Abduction: Ad/Ab								
Knee Flexion: Limited								
Excess								
Inadequate Extension								
Wobbles								
Hyperextends								
Extension Thrust								
Varus/Valgus: Vr/Vl								
Excess Contralateral Flex								
Ankle Forefoot Contact								
Foot-Flat Contact								
Foot Slap								
Excess Plantar Flexion								
Excess Dorsiflexion								
Inversion/Eversion: Iv/Ev								
Heel Off								
No Heel Off								
Drag								
Contralateral Vaulting								
Toes Up								
Inadequate Extension								
Clawed								

MAJOR PROBLEMS:

Weight Acceptance

Single Limb Support

Swing Limb Advancement

Excessive UE Weight Bearing ☐

Name

Diagnosis

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Figure 1: The Rancho gait analysis system facilitates recording any observable activity that interferes with the three functional tasks of walking: weight acceptance, single limb support, and swing limb advancement.

INSTRUMENTED GAIT ANALYSIS

Instrumented gait analysis records the process of walking with measurable parameters collected through the use of equipment. Such basic techniques would have enabled measurement of walking velocity (distance traversed per unit of time) and cadence (steps per unit of time). Marks, a New York City prosthetist, offered a more precise qualitative description of pathological gait in 1950, when he described the gait process in eight organized phases and discussed the implications of prosthetic component design on walking function. Marks praised “kinetoscopic” photography as a potential diagnostic tool for optimizing pathological gait.

Today we record gait parameters with instruments as common as a stopwatch or as complex as the simultaneous integration of three- dimensional kinematics, kinetics, and electromyographic (EMG) methods. A simple, inexpensive footprint mat has been used for decades to record barefoot plantar pressures. Clinics use individual or multiple mats to record step and stride length as well as walking base width. Early on, video technology with slow-motion capabilities made more precise qualitative description of the gait cycle possible. The continued development of inexpensive video gait assessment software has made clinical quantitative applications more practical as well. Most quantitative and qualitative video systems, however, measure joint angles in two dimensions, which does not offer a complete analysis of the three- dimensional walking activity.

Measuring Temporal and Distance Parameters

Temporal (time, distance) parameters enable the clinician to summarize the overall quality of a patient's gait. Temporal data collection systems might be one of the most effective components available for assessment in the clinical setting. In the gait laboratory, microswitch-embedded pads taped to the bottom of a patient's shoes or feet can record the amount of time that the patient spends on various anatomical landmarks over a measured distance. Portable pressure-sensitive gait mats, connected to a laptop computer with gait analysis software for time and distance parameters are also commercially available to use in clinical settings (Figure 2).

A

Parameters

Distance (cm)	281.9
Ambulation time (sec)	2.50
Velocity (cm/sec)	112.7
Mean normalized velocity	1.44

Functional ambulation profile: 99

Cadence (steps/min)	120.0
Step time differential (sec)	0.01
Step length differential (cm)	0.36
Cycle time differential (sec)	0.01

Walk # / footfall #	L/R	Mean (%CV)	All ages
Step time (sec)	L	0.494 (2)	0.53 0.59
	R	0.504 (3)	
Cycle time (sec)	L	0.994 (3)	1.06 1.18
	R	1.007 (1)	
Swing time (sec)	L	0.356 (2) /35.8	36 44
/ %GC	R	0.382 (2) /37.9	
Stance (sec)	L	0.638 (3) /64.2	56 64
/ %GC	R	0.625 (0) /62.1	
Single support (sec)	L	0.382 (2) /38.4	38 42
/ %GC	R	0.356 (2) /35.4	
Double support (sec)	L	0.269 (3) /27.1	16 24
/ %GC	R	0.269 (3) /26.7	
Step length (cm)	L	56.587 (5)	58 85
	R	56.229 (3)	
Stride length (cm)	L	113.665 (2)	116 170
	R	112.429 (1)	
Base of support (cm)	L	9.56 (36)	
	R	11.41 (17)	
Toe in / out (deg)	L	7 (33)	
	R	11 (13)	

B

Figure 2: A, The GAITRite system is an example of a portable pressure- sensitive walkway used to assess temporal and distance parameters of gait. B, The walkway is connected to a laptop computer, and the operator is able to quickly generate values for velocity, stride and step lengths, cadence, time and percent of cycle spent in stance, single and double limb support, and swing.

For example, the GAITRite system, which consists of an electronic walkway connected to a computer, records the temporal and spatial characteristics of patients while walking as well as while performing other functional or occupational tasks.

Assessing the Energy Cost of Walking

Metabolic data reflect the physiological “energy cost” of walking. **The traditional measures of energy cost are oxygen consumption, total carbon dioxide generated, and heart rate. Other relevant factors include volume of air breathed and respiratory rate.** All these parameters are viewed in relation to velocity and distance walked over the collection period. The primary limitation of energy cost as an assessment tool is that, although it can inform the investigator about body metabolism relative to the patient's gait, it cannot explain why or how an advantage or disadvantage was obtained.

Kinematic and Kinetic Systems

Most kinematic systems provide joint and body segment motion in graphic form. This information includes sagittal, coronal, and transverse motions that occur at the ankle, knee, hip, and pelvis. The patient is instrumented with reflective spheres that are placed on well-recognized anatomical landmarks (Figure 3).

Figure 3: This individual is wearing reflective spheres. An infrared camera system can track limb segment motion as the patient walks across the field of view.

Typically, an infrared light source is positioned around each of several cameras. This light is directed to the reflective spheres, which in turn are reflected into the cameras. Each field of video data is digitized, an operator manually identifies the markers, and the coordinates of the geometric center of each marker are calculated with computer software. Resultant data are displayed as animated stick figures that represent the actual motions produced by the patient. The operator can freeze any frame and enlarge the image at any joint to examine gait patterns in greater depth. The operator can extract raw numbers that represent joint placement and motion in space or produce a printout showing joint motion in all planes plotted against the percentage of the gait cycle (Figure 4). Angular velocities, accelerations, and joint and segment linear displacements can be calculated. Data from other systems (force platforms and EMG) collected during the same time sequence as the motion data are often integrated with the kinematics.

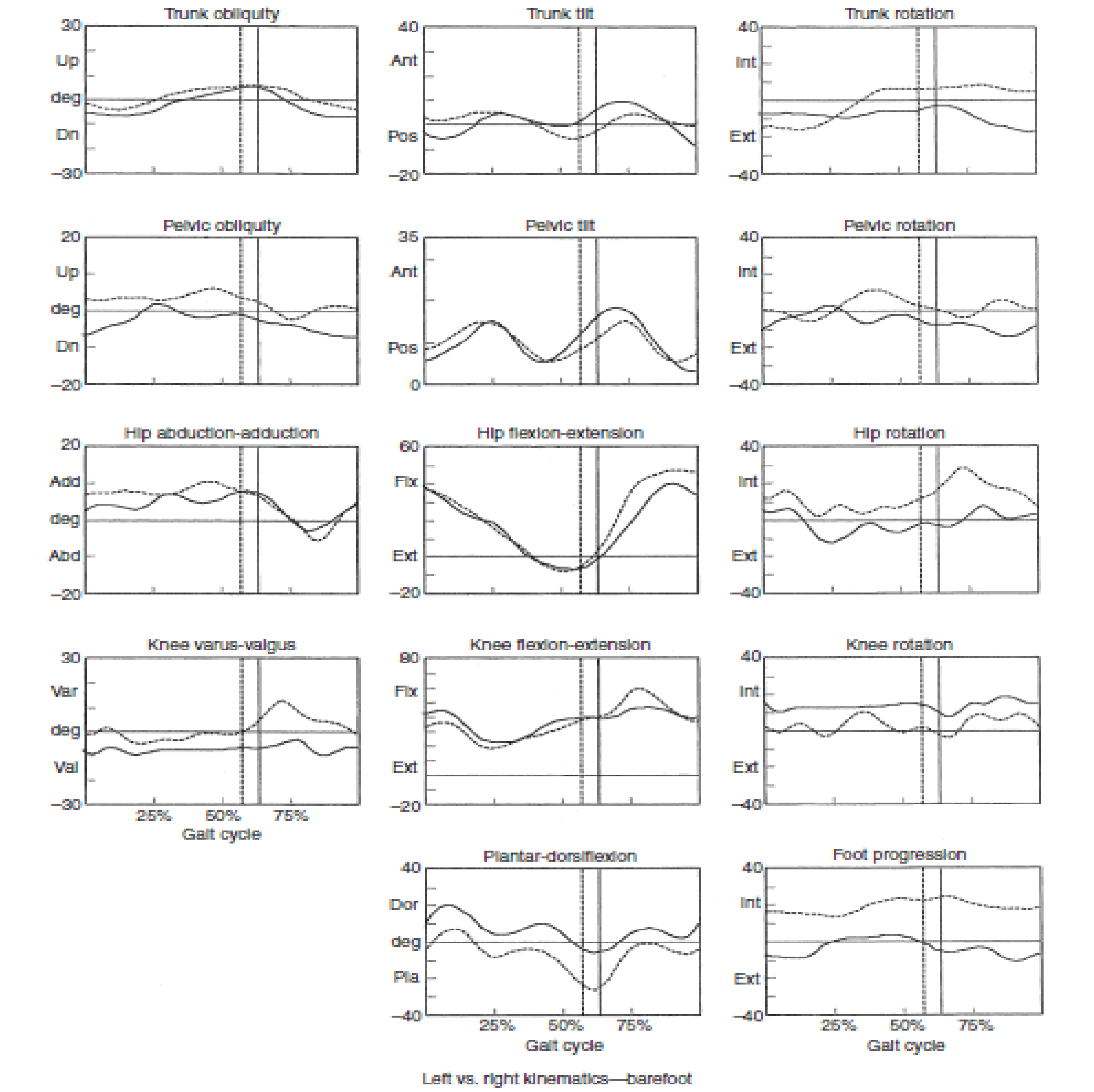


Figure 4: The output generated by a computer-based motion analysis system includes graphs of the mean range of motion at each body segment or joint (trunk, pelvis, hip, knee, and ankle) in coronal (left column), sagittal (middle column), and transverse (right column) planes as the individual being evaluated progresses through multiple gait cycles. This is the output of an 8-year-old child with spastic diplegic cerebral palsy.

When an individual takes a step, he is exerting force against the surface he is walking on. This kinetic information is obtained from one or more force platforms, which collect data on the three components of the ground reaction force: vertical, fore-aft (anterior-posterior), and medial-lateral (Figure 5). While the typical force platform system provides data about forces and moments occurring at the ground, or center of pressure progression, it can be combined with kinematic data to provide additional information. By combining these two data sets, the moments and power acting at the joints can be calculated. This information is useful in measuring the dynamic joint control of an individual throughout stance, particularly when used in conjunction with EMG. Similarly, information about joint moments, sometimes referred to as torque, is also often reported as an outcome measure in research studies.

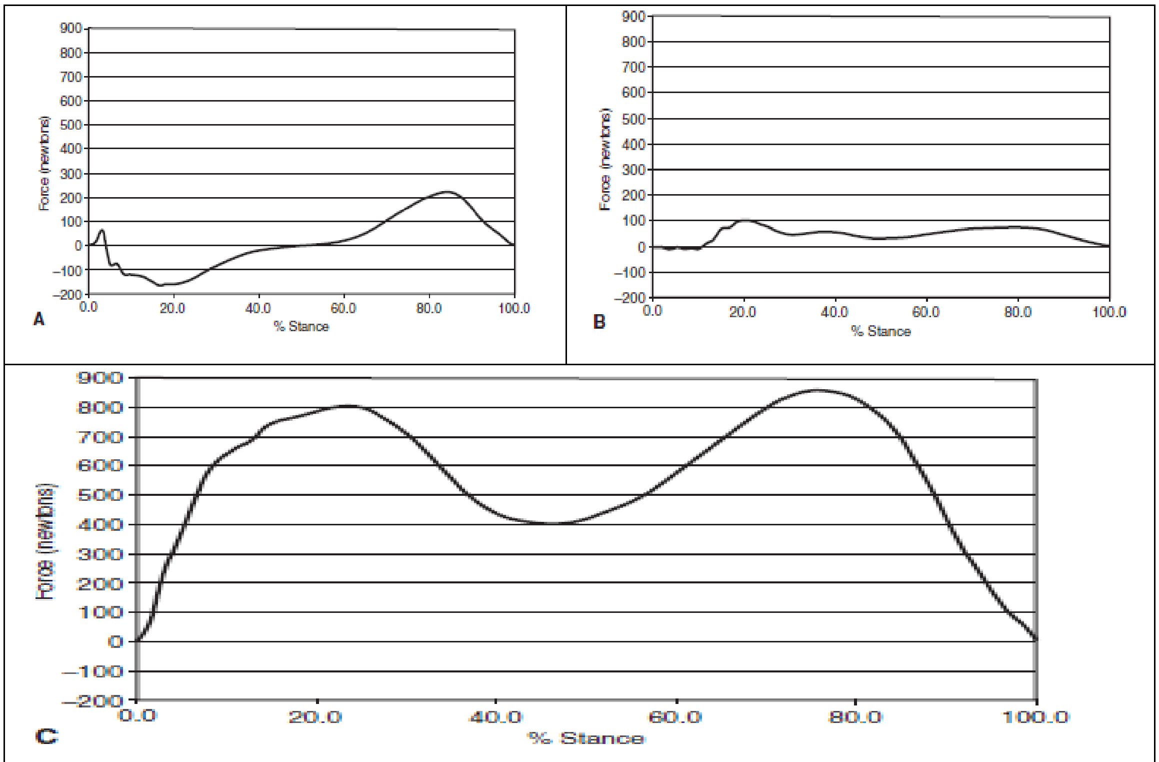
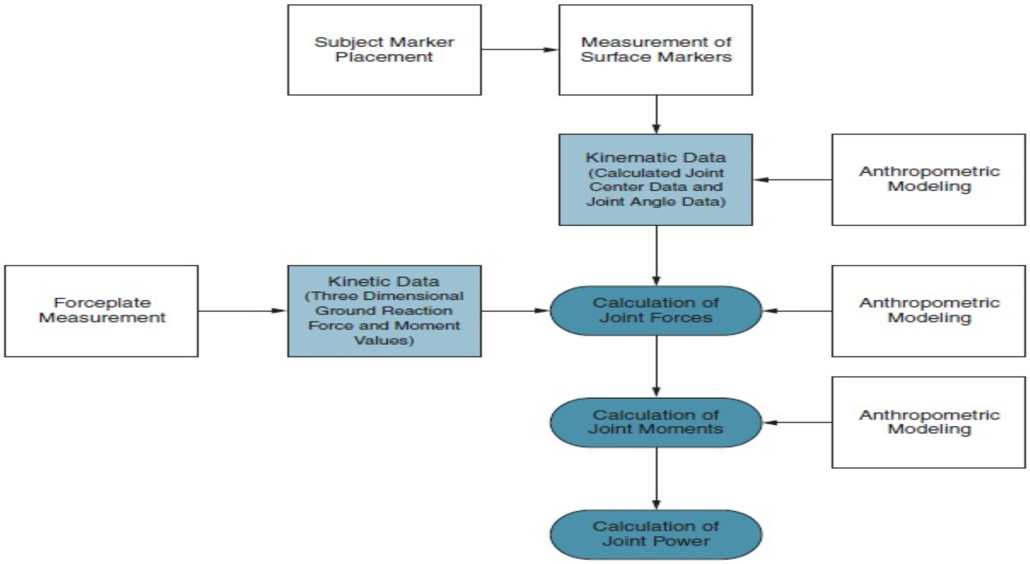


Figure 5: Example of output generated by a forceplate as the individual being tested progresses through stance phase. A, The anteroposterior component of the ground reaction force (GRF). B, The medial lateral component of the GRF. C, The vertical component of the GRF.

The calculation process begins with the determination of the ground reaction forces, which are obtained through the direct measurement of an individual stepping on a force platform. Once that information is available, it is combined with kinematic data, derived from a two- or three-dimensional motion capture system for each lower extremity body segment, so that the joint reaction forces can be calculated. As the forces at each of the joints are determined, then the associated moments acting on each segment can also be calculated. Ultimately, the power can be calculated as well (Figure 6).

Like virtually all biomechanics models, certain assumptions must be made in order for the calculation to be carried out in a practical manner. With assumptions come the opportunity for additional error introduction throughout the process. This is why it is important to understand the limitations associated with them.

- The subject has no limb deficiencies and essentially normal musculature.
- The knee and ankle joints are frequently modeled as simple hinge joints.



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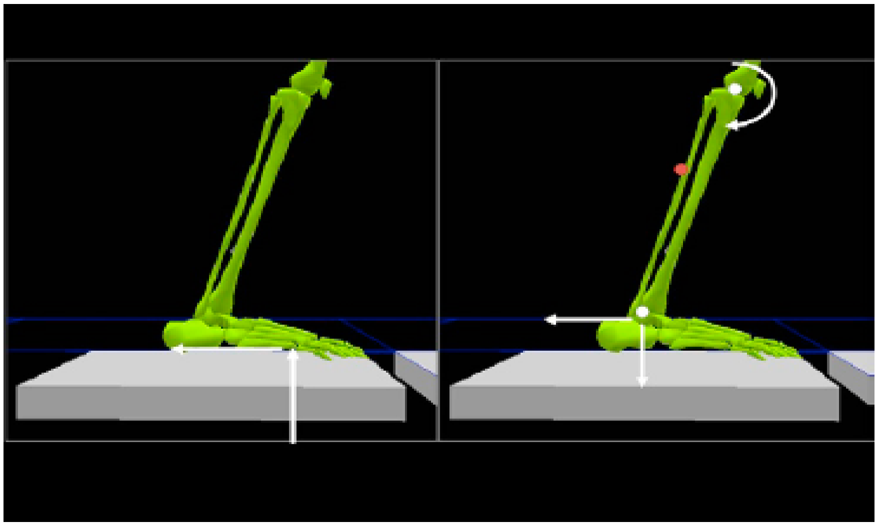

B

Figure 6: A) Calculation flowchart: the kinematic data collected from the motion analysis system is entered into series of calculations based on the person's anthropometric data to produce the instantaneous position of every joint and segment. These data are then combined with force plate data collected at the same time to calculate joint forces, moments, and powers. B) Example of joint moment calculation. Vertical and anteroposterior ground reaction forces recorded from a force plate. Joint moments are calculated by combining ground reaction forces and kinematic data, taking into account the segment's center of mass.

Electromyography

Muscle action beneath skin and subcutaneous tissue cannot be directly measured, but through the use of EMG, the activity can be approximated and studied in relation to the action, size of muscle, and signals obtained. EMG records the muscle activity by the electrical signal detected from the contraction and chemical stimulation of the respective musculature.

EMG instrumentation can vary, such as is seen with **surface EMG** or **fine-wire EMG**. With surface EMG the electrode pad is adhered to the skin above the muscle being studied, while fine-wire EMG uses wire electrodes directly inserted into the belly of the respective muscle. EMG records the motor unit activation of muscle fibers in the specific muscle being studied. This is very useful but can be problematic with surface electrode applications, in that they can pick up the signal from surrounding musculature during testing. EMG characterization allows for timing, relative intensity of muscular effort, as well as resultant muscle force, all of which are necessary to understand normal and pathological gait.