

Model Basics

Adam Rozumalski, MS
Gillette Children's Specialty Healthcare



Clinical Gait Analysis: A Focus on
Interpretation, May 14-17, Leuven - Belgium

Objectives

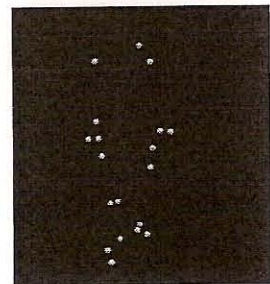
- Describe what motion capture is
- Describe how it can be used to analyze gait
 - Examples using the most common model

Clinical goal

- Human gait is complex and 3-dimensional
- Need an accurate picture for:
 - Physical Therapy
 - Drug Therapy
 - Orthotics
 - Surgery

Technological Tools

- Motion Capture
 - Track small reflective balls (markers) through space



Technological Tools

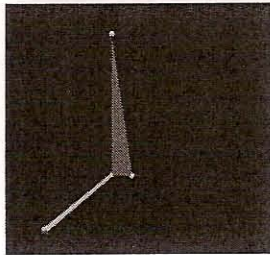
- Model application
 - Make a skeleton fit into the motion of the markers



How do we make that happen?

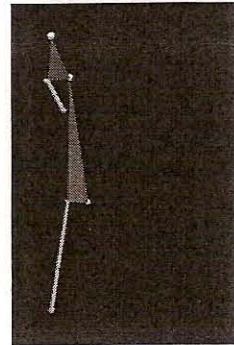
3-Dimensional motion

- Need at least three points on an object to know the location and orientation
- Define a coordinate system relative to that object



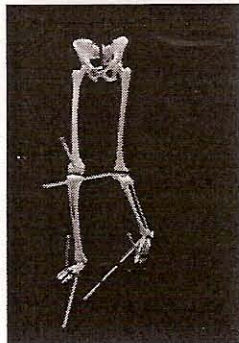
3-Dimensional motion

- Relative orientation of two objects
- Need two coordinate systems



3-Dimensional motion

- Model describes each body segment as an "object" with a coordinate system



Aha! Now we're getting somewhere!

Brief Summary

- Track points
 - Define coordinate systems
 - Body segment location and orientation
-
- however ...

Minor problem

- Skin mounted markers do not track the skeleton
- Need model calibration

Model calibration

- Technical Coordinate System (TCS)
 - Uses physical markers only



- Anatomical Coordinate System (ACS)
 - Makes use of anatomically referenced virtual markers

What is a virtual marker?

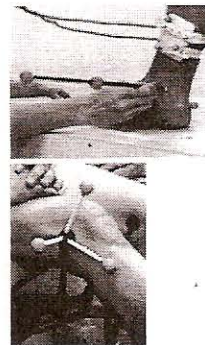
- Physical marker
 - Actual marker on skin
- Virtual marker
 - Point relative to the physical markers
 - Moves exactly like the defining physical markers
 - Anatomical reference
 - Physical markers not practical

How to define a VM

- Regression
 - Based on physical exam measurements

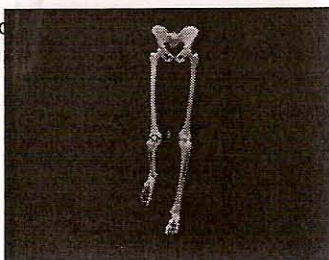
How to define a VM

- Devices
 - Pointer
 - Variety of shapes
 - KAD
 - Knee center and axis



How to define a VM

- Body segment model
 - Functional Model Calibration



Brief Summary

- Track points
- Define coordinate systems
- Body segment location and orientation
- Anatomical reference points

- however ...

- Which anatomical landmarks do you use?
- Depends on which gait model you use.
 - Davis RB, Ounpuu S, Tyburski D, Gage JR. (1991) "A Gait Analysis Data Collection and Reduction Technique." Human Movement Science, 10: 575-587.

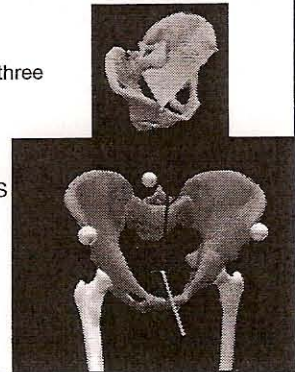
Gait model

- Standard lower extremity model
 - 7 rigid segments
 - pelvis, femora (2), tibiae (2), feet (2)
- Joints
 - Hips: 3 rotations
 - Knees: 3 rotations
 - Ankles: 2 rotations (1-dimensional foot)

Segment Definitions

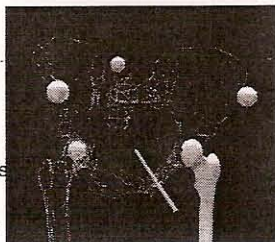
Pelvis

- In the ASIS-PSIS plane
 - Requires palpation of all three landmarks
- Coordinate System
 - e_2 = inter ASIS
 - e_1 = mid ASIS – mid PSIS resolved perp. to e_2
 - e_3 = perpendicular to e_2 and e_1



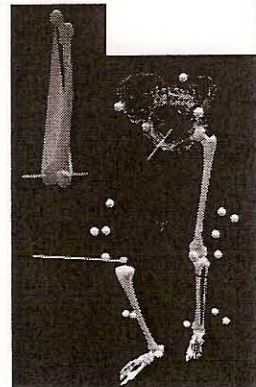
Hip Joint Centers

- Method 1: anthropometric regression equations
 - Fixed offsets from pelvic markers
 - Based on cadaver studies
- Method 2: functional calibration
 - Based on observed motions and constraints
 - Many available techniques



Thigh

- In the plane of the *hip center* and *knee axis*
- Coordinate System
 - e_3 = knee center – hip center
 - e_2 = knee axis
 - e_1 = perpendicular to e_2 and e_3



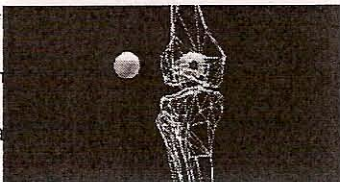
Knee Axis/Center

- Method 1: Knee Alignment Device

- Manual palpation of axis
- Center ½ width from condyle along knee

- Method 2: functional calibration

- Based on observed motions and constraints
- Many available techniques

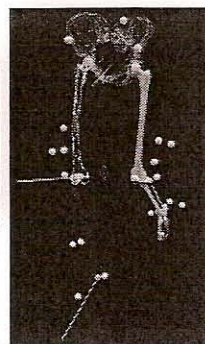


Tibia

- In the plane of knee center and ankle axis

- Coordinate System

- e_2 = inter ASIS
- e_1 = mid ASIS – mid PSIS resolved perp. to e_2
- e_3 = perpendicular to e_2 and e_1



Foot

- One vector only
- Through the ankle center and M23 junction



Kinematics

The motions of the segments in space, and relative to one-another

Joint Rotations

- Gimbal Joint Articulations
 - rotation only (no translation)
 - fixed center of rotation (joint center)
 - ordered rotations (Euler/Cardan angles)

Standard Biomechanics Order

- Flex/Extension (sagittal plane)
followed by
- Ab/Adduction (coronal plane) *→ frontal*
followed by
- Int/External Rotation (transverse plane)

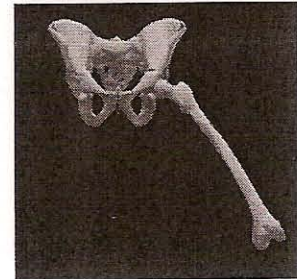
First Rotation

- Flexion - Extension:
 - Sagittal Plane
 - rotation about the mutual Medial-Lateral axis



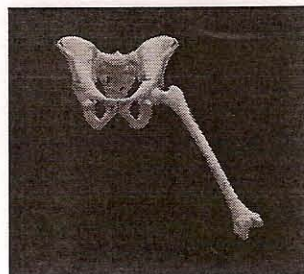
Second Rotation

- Ab - Adduction *from medial*
 - Coronal Plane
 - rotation about the distal anterior-posterior axis



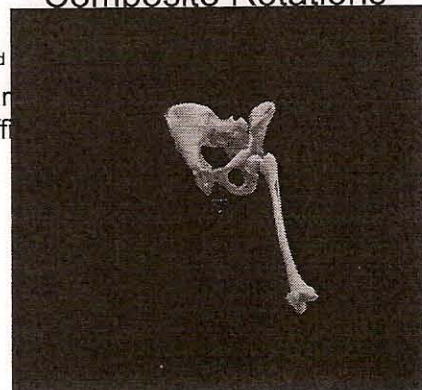
Third Rotation

- Internal-External Rotation
 - Transverse Plane
 - rotation about the distal longitudinal axis



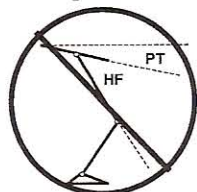
Composite Rotations

- 2nd
par
diff



Planar Projections

- True angle definitions \neq planar projections
 - Special case: out-of-plane angles all = 0.0



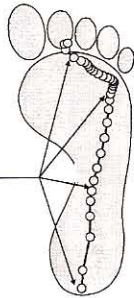
- Planar projections "close enough"?
 - Perhaps... for qualitative understanding only

Kinetics

The forces, moments, and power related to movement

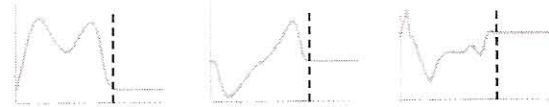
Ground Reaction Force

- Measure Ground Reaction Force (GRF)
 - vertical force (weight) and horizontal forces
- Measure GRF position
 - Center of pressure



Ground Reaction Force

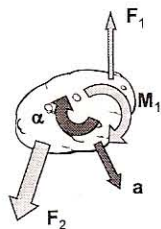
- Vertical: support of body
- Anterior/Posterior: braking/propulsion
- Medial/Lateral: balance and sway



Newton/Euler Equations

$$\sum \mathbf{F} = m\mathbf{a}$$

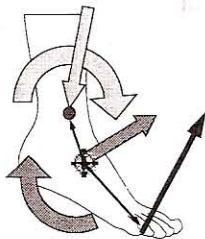
$$\sum \mathbf{M} = I\alpha$$



Inverse Dynamics

- Given kinematics: $\sum \mathbf{F} = m\mathbf{a}$
 $\sum \mathbf{M} = I\alpha$
- Solve for kinetics: $\sum \mathbf{F} = m\mathbf{a}$
 $\sum \mathbf{M} = I\alpha$

Bottom-up Approach



Inertial Properties

- Segment Mass, Moment of Inertia
- Segment center of mass locations
 - Anthropometric data
 - MRI
 - Experiment
- Sensitivity varies
 - larger masses more important
 - moment of inertia less important for walking/slow movements

Moment Reference System

- Moments expressed relative to single coordinate system
- Three choices
 - proximal body
 - distal body
 - global
- Distal body most common

Propagation of Errors

- Errors propagate “upstream”
 - Alternatives :

Kuo AD, *Least-squares estimation approach to improving the precision of inverse dynamics computations*, Journal of Biomechanical Engineering, Transactions of the ASME, v 120, n 1, Feb, 1998, p 148-159

Things to be aware of

- Better feet
- Alternate models
- Functional models
- Not mutually exclusive!