

Functional Methods for Modeling Joints

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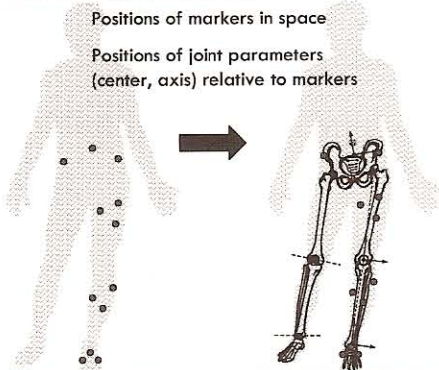
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Background

What is Model Calibration?

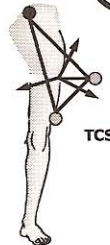
Model

Positions of markers in space
Positions of joint parameters
(center, axis) relative to markers

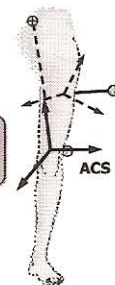


Model Calibration

Technical Coord. System (TCS)

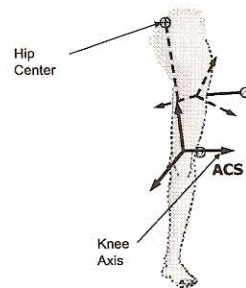


Anatomical Coord. System (ACS)



Model Calibration

Joint Parameters



Pelvic Coordinate System

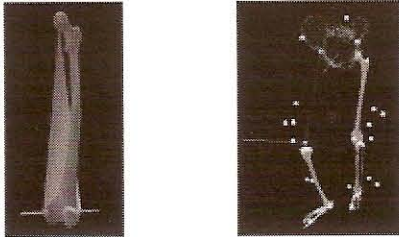
□ In the ASIS-PSIS plane

■ Requires palpation of all three landmarks



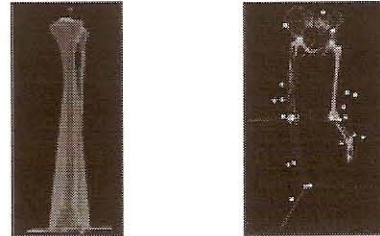
Thigh Coordinate System

- ☐ In the plane of the hip center and knee axis



Tibial Coordinate System

- ☐ In the plane of knee center and ankle axis



Functional Model Calibration (FMC)

What is Functional Model Calibration?

FMC uses motions of the subject's body segments to define the joint parameters

Functional Methods

- ☐ Many exist
- ☐ Originally proposed in 1984 by Aurelio Cappozzo
Cappozzo A (1984) Gait analysis methodology. Human Movement Science 3, 27-50.
- ☐ Several modifications to Cappozzo's model
- ☐ Other approaches also developed
 - Gamage
 - Halvorsen
 - Schwartz
- ☐ More on the way!

All models give similar results

Differences

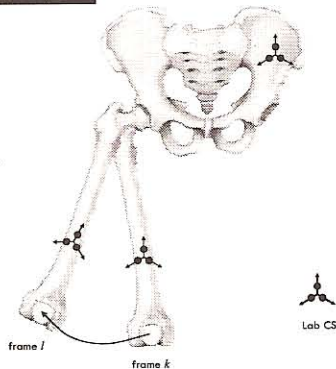
- ☐ sensitivity to noise/soft-tissue-artefact
- ☐ robustness with respect to range-of-motion
- ☐ computation time

Focus on method of Schwartz & Rozumalski

- ☐ Familiarity
- ☐ Availability of data
- ☐ Availability share-able software
- ☐ Some advantages of the method
 - Shown to be robust w.r.t. small ROM
 - Single model computes hip center, knee center, knee ROM
 - All methods work well if properly implemented

A few technical details

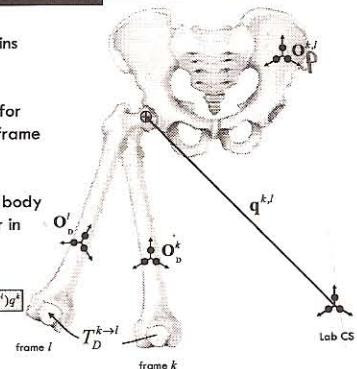
- Two body segments (usually adjacent)
- Motion across joint
 - Frame k (original) to frame l (final)



A few technical details

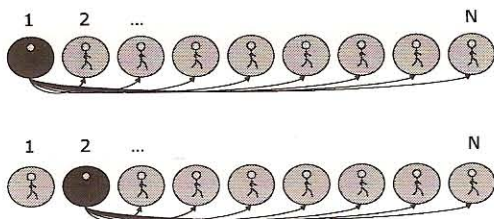
- O are the segment origins
- T are transformations (translation + rotation) for the bodies going from frame $k \rightarrow l$
- q is the vector from the body origin to the joint center in the proximal body

$$(O_l^k - O_k^k) + (T_l^{k+1} O_l^k - T_l^{k+1} O_k^k) = (T_l^{k+1} - T_l^{k+1}) q^k$$



Compare Frames

- Compare each frame to each other frame
 - $N(N-1)/2$ comparisons



Hip Trial

- Two planes of motion
 - "star-arc" pattern is quasi-optimal

An optimized protocol for hip joint center determination using the functional method
Valeriano Caporossi*, Andrea Cristofari, Giuseppe Vignola, Antonio Caporossi
Department of Biomechanics and Sports Sciences, University of Rome, Italy. *Corresponding Author. E-mail: valeriano.caporossi@uniroma1.it

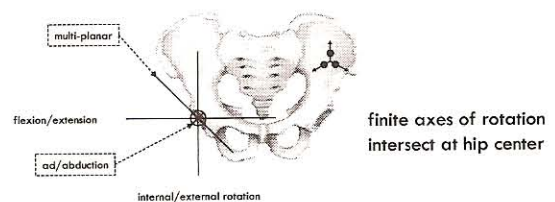


Knee Trial

- Passive Knee ROM
 - Avoid end ranges-of-motion
 - Possible to use walking trial

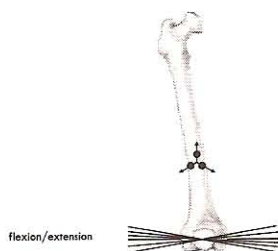


Graphical Explanation: Joint Center



Circumduction →

Graphical Explanation: Joint Axis



- Joint must have "primary" axis of rotation (i.e. must be "hinge-like")
- Find the most likely (mode) of the axes – robust with respect to outliers and skewed distributions

Implementation

Perceived obstacle: time required

~~□ "It takes too long to do the ROM tests"~~

- ROM tests take less than 10 minutes

~~□ "It takes too long to process the data"~~

- Data processing takes approximately 5 minutes

~~□ "It takes too long to generate the reports"~~

- Report generation is automated

Some Statistics

Gillette Center for Gait and Motion Analysis

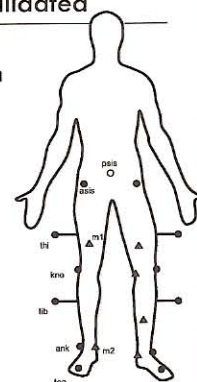
- Over 600 clinical patients per year
- Over 400 complete analyses
 - kinematics, kinetics, physical exam, video, EMG, oxygen
- Over 50 research subjects per year
- Since 2004...
 - Functional modeling of all pts/subjs
 - Clinical reporting of all functional data along with conventional gait model (CGM)
 - Testing capacity increased

Perceived Obstacle: difficulty obtaining ROM

- Hip and Knee trials can be therapist aided
- During 2004 – center saw 32 different diagnoses
 - Adult CVA, Attention deficit hyperactivity disorder, Autism, Brain malformation, Brain tumor, Cerebral palsy, Childhood CVA, CNS infection/injury, Developmental delay, Developmental variants, Expressive language disorder, Foot disorder, Genetic disorder, Gross cognitive delay (MR), Hip disorder, Hydrocephalus, Knee disorder, Learning disability, Leg length inequality, **Miscellaneous condition**, Myelomeningocele, Neurological unspecified, Neuromuscular unspecified, Normal, **Other**, Seizure disorder, Spinal cord injury, Spine disorder, Traumatic/acquired brain deficit, Unknown, Upper extremity injury, Vision/hearing disorder
- Difficulty/Inability to cooperate caused FMC failure in only 1 patient

Perceived Obstacles: not yet validated

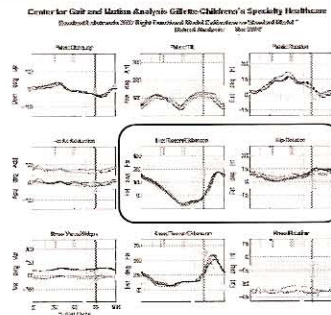
- "Belt-and-Suspenders" approach
- Single marker set accommodates conventional (Plug-in-gait) and functional models
- Report both sets of data



Data Reporting

□ Data similar

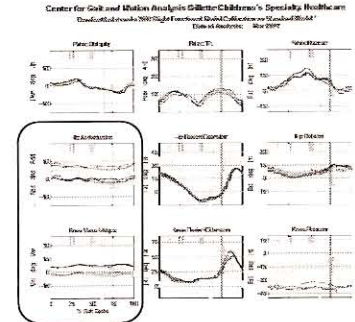
concurrent validation of
the two models



Data Reporting

□ Data different

need to determine which
model "seems" better



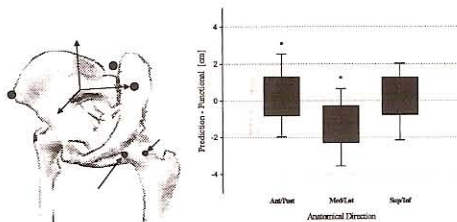
There is limited/no "validation" of
conventional gait models

only face validity has been established...and
some even question that!

Determining Validity

Concurrent validity using Plug-in-gait as
standard

Functional vs. Regression Based Hips



Functional hips are
lateral (13.9 mm) and
posterior (2.9 mm)

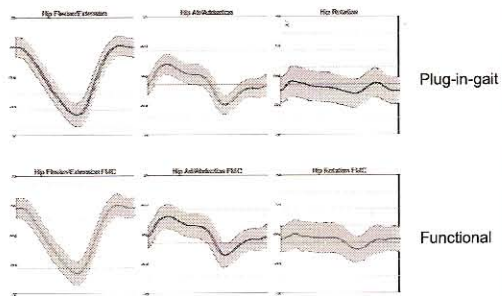
13.9mm

Gait Kinematics and Kinetics

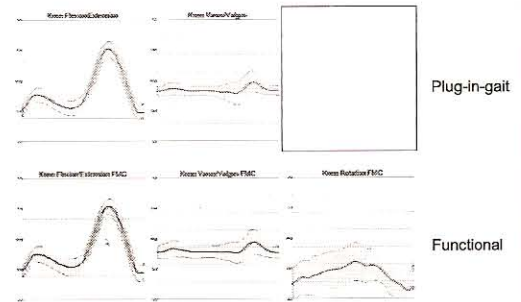
Control Subjects (N=83)

Wu, Chen

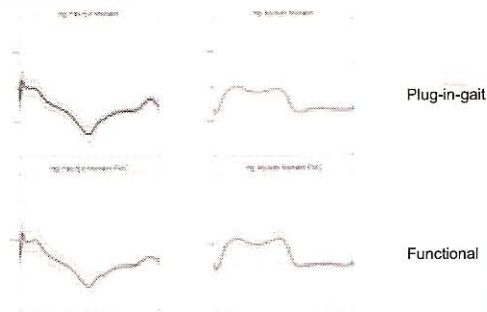
Hip Kinematics



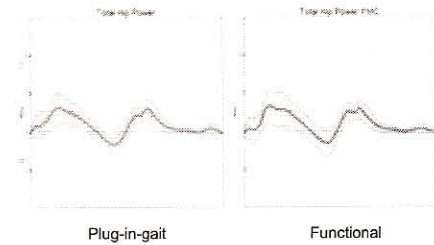
Knee Kinematics



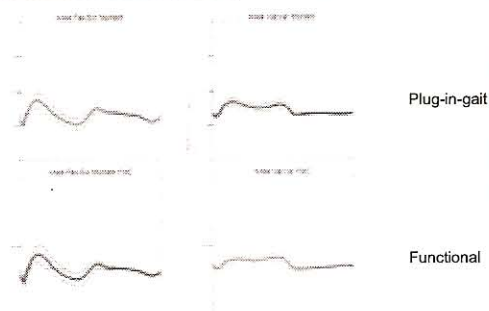
Hip Moments



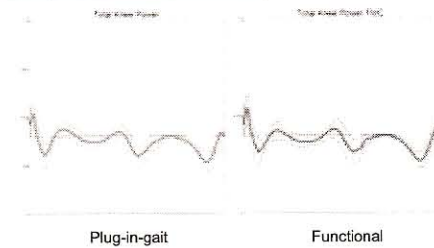
Hip Power



Knee Moments



Knee Power



Gait Kinematics:

Clinical Subjects

350 Sequential Patients

Model Differences

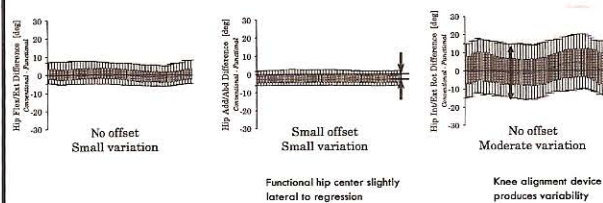
□ Point-by-point difference (PIG – FMC)

Box = 25%^{ile} - 75%^{ile}

Whiskers = 10%^{ile} – 90%^{ile}

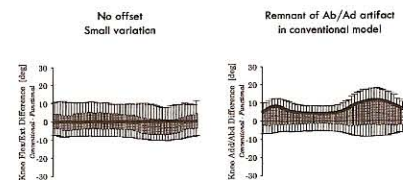
Hip Kinematics

conventional - functional



Knee Kinematics

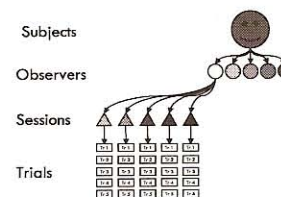
conventional - functional



Reliability

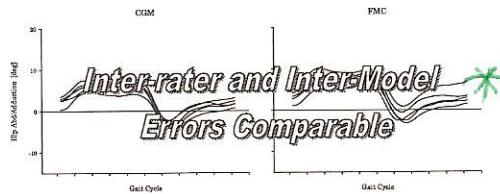
Repeated Measures Design

part of ongoing QA efforts

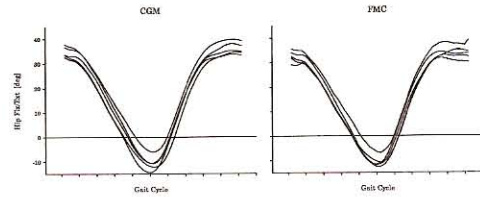


quality outcome

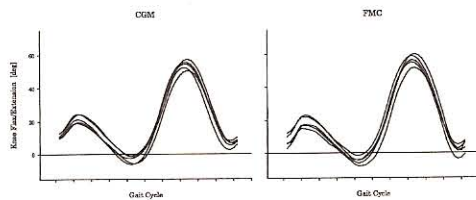
Hip Abd/Adduction



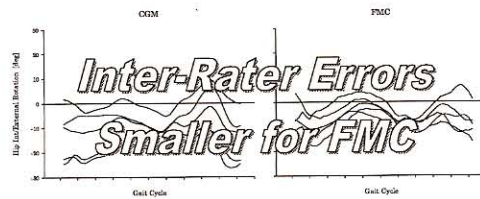
Hip Flex/Extension



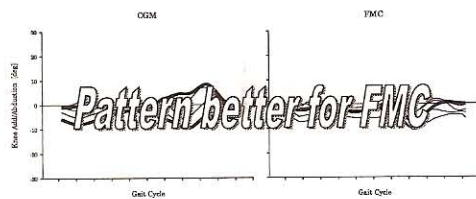
Knee Flex/Extension



Hip Int/External Rotation



Knee Abd/Adduction



Conclusions After 3.5 Years

- ☐ Functional and Conventional models are clinically equivalent (on average)
- ☐ Functional models are SUBJECT SPECIFIC
- ☐ Functional models are OBJECTIVE, and require no palpation
- ☐ Simultaneous processing = "second opinion"
- ☐ Functional data helps teach proper application of conventional model (Learning Effect)

Learning Effect

- 1994–2002: Knee Add/Abduction ROM with conventional model

$>15^\circ$

- 2005: Knee Add/Abduction ROM with conventional model

$<10^\circ$



A great part of courage is the courage of
having done the thing before

Ralph Waldo Emerson (1803–1882)