Plug in Gait WebEx Training
Session 3

Interpreting PiG results: PiG biomechanical modelling

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INTRODUCTION

What is Plug in Gait??

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Plug in Gait is the commercial name used by Vicon for the implementation of what is commonly called ‘Conventional Gait Model’ (CGM)

The CGM is a biomechanical model for the lower limbs developed by Kadaba, Davis and the Helen Hayes Hospital.

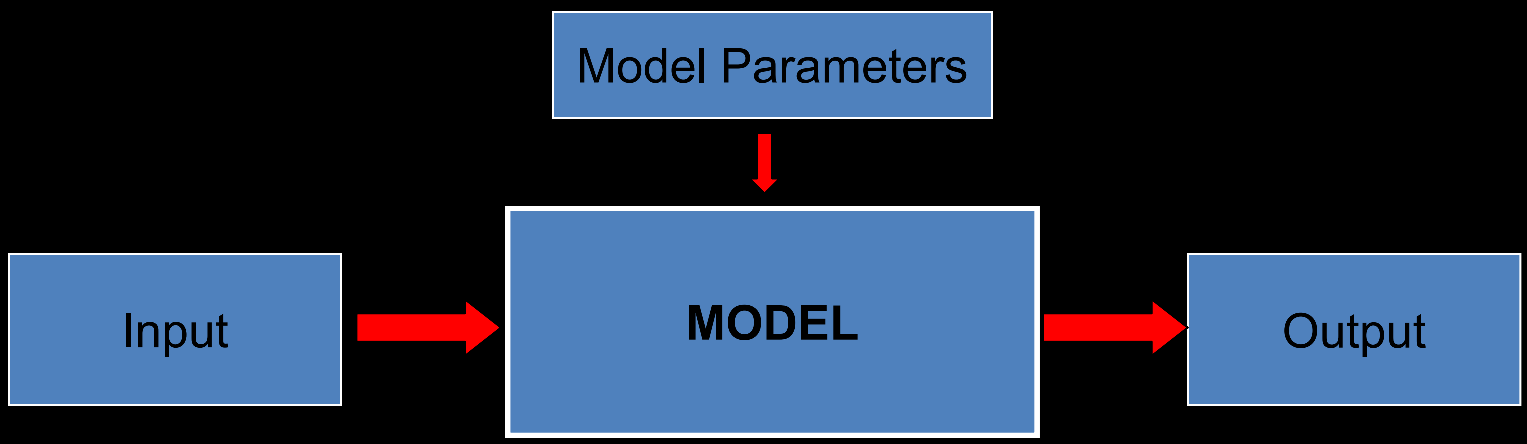
Kadaba et al., 1989, Journal of Orthopaedic Research.

Kadaba et al., 1990, Journal of Orthopaedic Research.

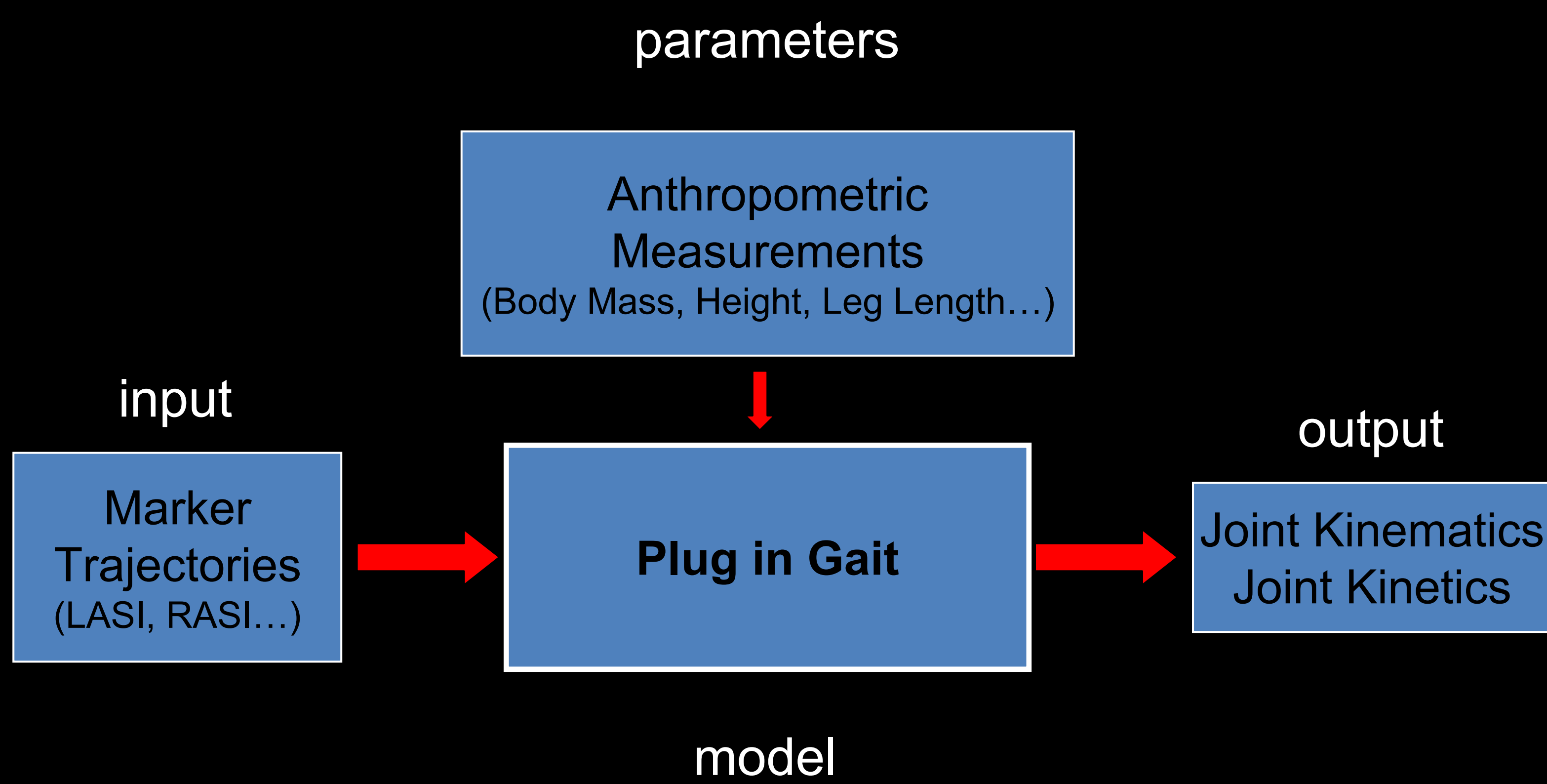
Davis et al., 1991, Human Movement Sciences.

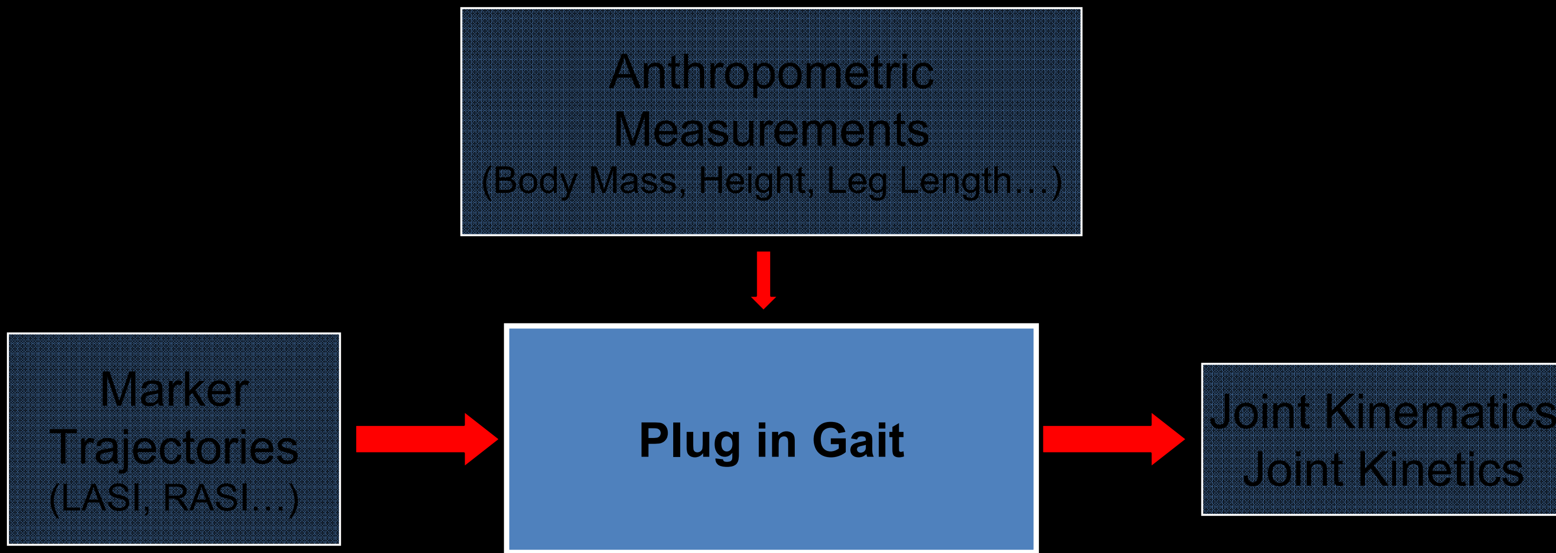
WHAT IS A MODEL?

IN GENERAL, A MODEL IS A MATHEMATICAL RELATION THAT ALLOWS FORESEEING THE BEHAVIOR OF THE SYSTEM THAT HAS BEEN MODELLED, GIVEN SOME KNOWN INPUTS AND PARAMETERS



BIOMECHANICAL MODELLING AND PLUG IN GAIT





Plug In Gait contains four modelling modules:

1. Lower Body kinematic model
2. Upper Body kinematic model

→ Rigid body segments definition

Joint Angles, Joint Centers

3. Lower Body kinetic model
4. Upper Body kinetic model

→ Mass and Inertia Integration

Joint Forces, Moments and Power

PLUG IN GAIT GENERAL KINEMATIC MODELLING CONSIDERATIONS

1. Rigid Body Hypothesis
2. Rigid segments are defined starting from
   1. Physical markers
   2. Virtual markers calculated using physical markers and subject measurements
3. Rigid segments are defined on a frame-to-frame basis

↓

It is vitally important to place the markers accurately and to get good and stable 3D marker positions reconstructions

PLUG IN GAIT GENERAL KINETIC MODELLING CONSIDERATIONS

1. Kinetic calculations are always performed alongside kinematics
2. If Force Platforms (FPs) are present, the Ground Reaction Forces (GRFs) are added automatically to the processing workflow
3. Kinetic modelling is performed even when no FPs are present
    1. In this case, the kinetic calculations are only valid during swing phase
4. The anthropometric measures – segment masses, centres of gravity and radii of gyration – are taken from David Winter's tables (add ref)
5. Joint kinetics are calculated using the inverse dynamics procedure

PLUG IN GAIT SUBJECT MEASUREMENTS

Subject Measurements represent the parameters of the model

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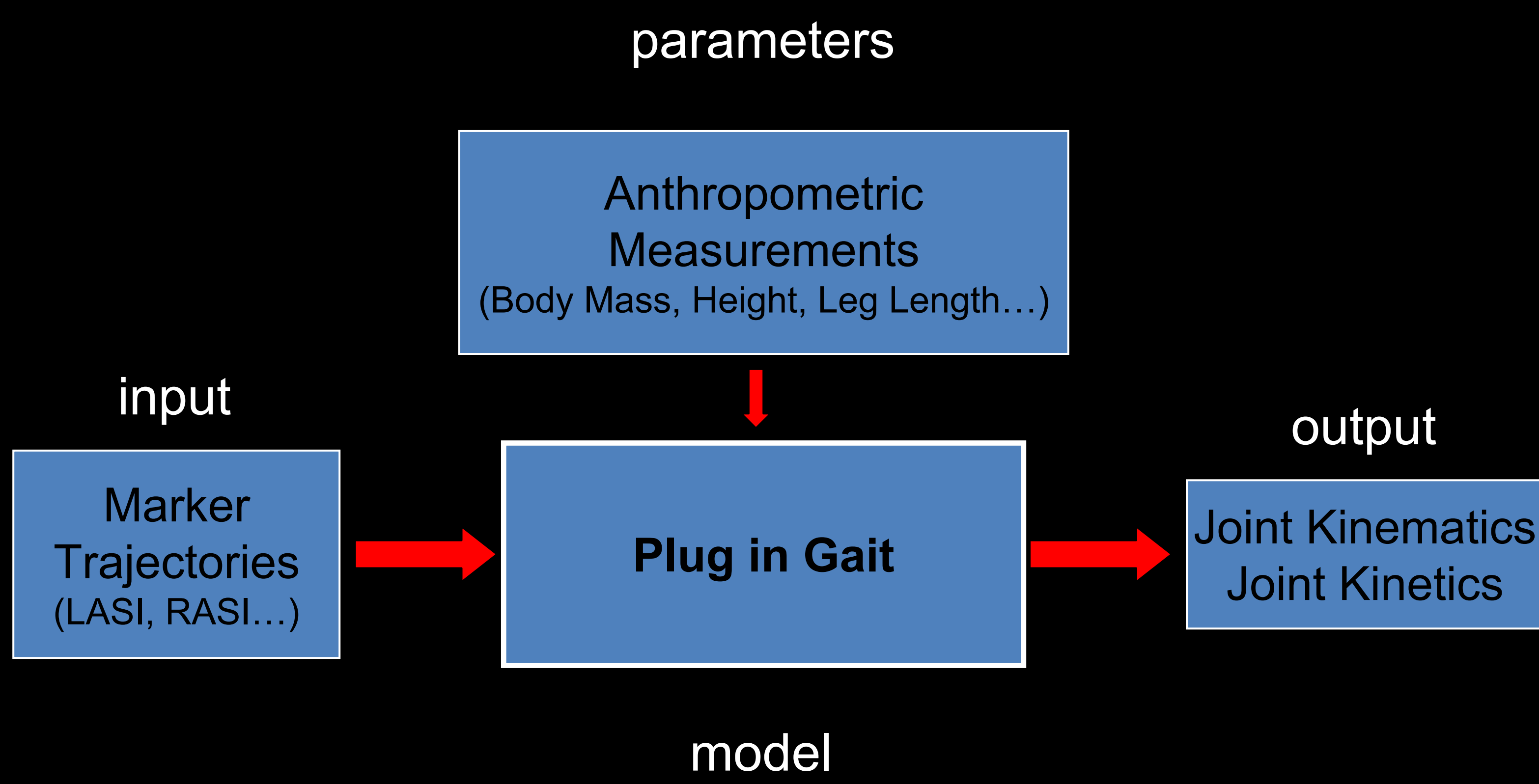


Subject Measurements represent the parameters of the model

REQUIRED SUBJECT MEASUREMENTS

General

Body Mass

Height

Lower Body

Leg Length

Knee Width

Ankle Width

Upper Limbs

Shoulder Offset

Elbow Width

Wrist Width

Hand Thickness

PLUG IN GAIT INPUT

1. A minimum number of markers need to be present in the trial
    1. Pelvis markers for lower body model
    2. Thorax markers for upper body model
2. Alternative marker sets possible
    1. SACR marker or PSI markers
    2. Wand markers for SACR, THI, TIB
    3. KADs
    4. Medial malleolus

EACH OF THE ABOVE ALTERNATIVES IS VALID AND NO SPECIAL ACTION NEEDS TO BE TAKEN TO RUN IT.

PLUG IN GAIT OUTPUT

The outputs generated by PiG are saved as trajectories in the c3d file

Each PiG output is in fact a vectorial physical entity – i.e. is composed by three components X, Y, Z – the same as the trajectory of a physical marker

A message regarding the successful or unsuccessful running of PiG appears in the Nexus processing log, by clicking on the *Log* tab in the *Communications* window

PiG outputs are visible within Nexus, under the subject data tree in the *Resources* tools pane

KINEMATICS

1. Joint Angles

a. Relative angles between two rigid segments, i.e. joint angles. Always ordered as Flexion, Abduction, Rotation.

b. Absolute angles between a rigid segment and the laboratory fixed reference. Always ordered as rotations around the global X, Y and Z axes

2. Bones

a. A set of four virtual points will be associated to each modelled body segment

b. *segName#O*: Origin of the *segName* segment

c. *segName#L*: Direction of the lateral axis of the *segName* segment

d. *segName#A*: Direction of the anterior axis of the *segName* segment

e. *segName#P*: Direction of the vertical axis of the *segName* segment

f. The Bones output section is mainly used for positioning the bone meshes in Polygon

KINETICS

1. Joint Forces

a. Net Joint Forces expressed in the local reference system of each rigid body segment

b. Units: [N/Kg]

2. Joint Moments

a. Net Joint Moments estimated solving the equations of motion for the segments of the lower limbs – excluding the Pelvis (Ramakrishnan et al, 1987)

b. Anthropometric Measurements from published tables (Winter)

c. ‘External Forces’ convention is used: a GRF that would cause extension produces a positive extension moment

d. Net Joint Moments ordered as Flexion, Abduction, Rotation

e. Units: [Nmm/Kg]

3. Joint Powers

1. Scalar product between Joint Moments and Joint Angular Velocities
2. Joint Powers can be expressed as a scalar or as three components
3. Units: [W/Kg]

PLUG IN GAIT LOWER BODY KINEMATIC MODELLING

PLUG IN GAIT LOWER BODY KINEMATIC MODELLING

Let's revise the main hypotheses behind PiG kinematic modelling:

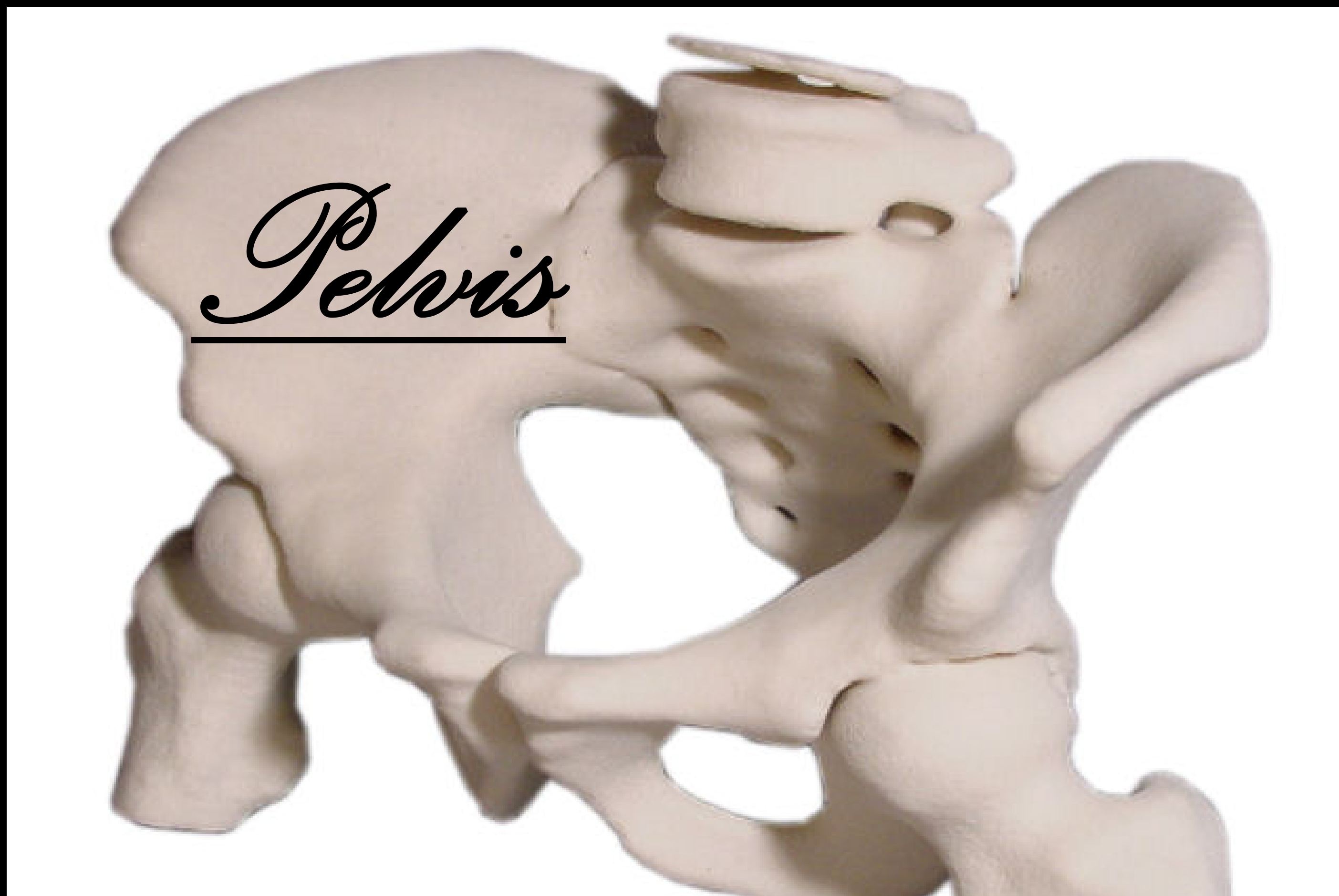
1. Rigid Body Hypothesis
2. Rigid segments are defined starting from
    1. Physical markers
    2. Virtual markers calculated using physical markers and subject measurements
3. Rigid segments are defined on a frame-to-frame basis

↓

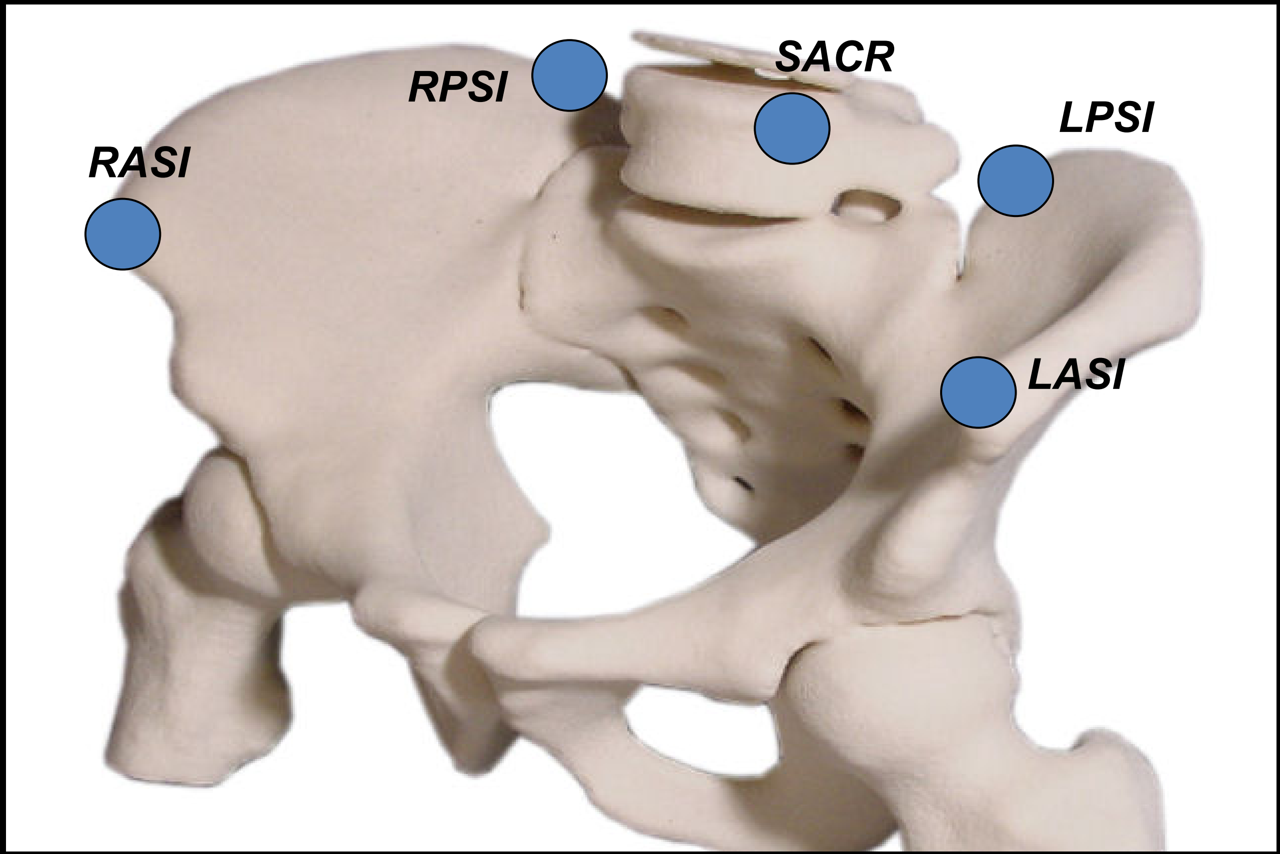
It is vitally important to place the markers accurately and to get good and stable 3D marker positions reconstructions

The lower body PiG kinematic model includes 7 rigid segments:

1. Pelvis
2. Left Thigh
3. Right Thigh
4. Left Shank
5. Right Shank
6. Left Foot
7. Right Foot


Pelvis

PELVIS MARKERS

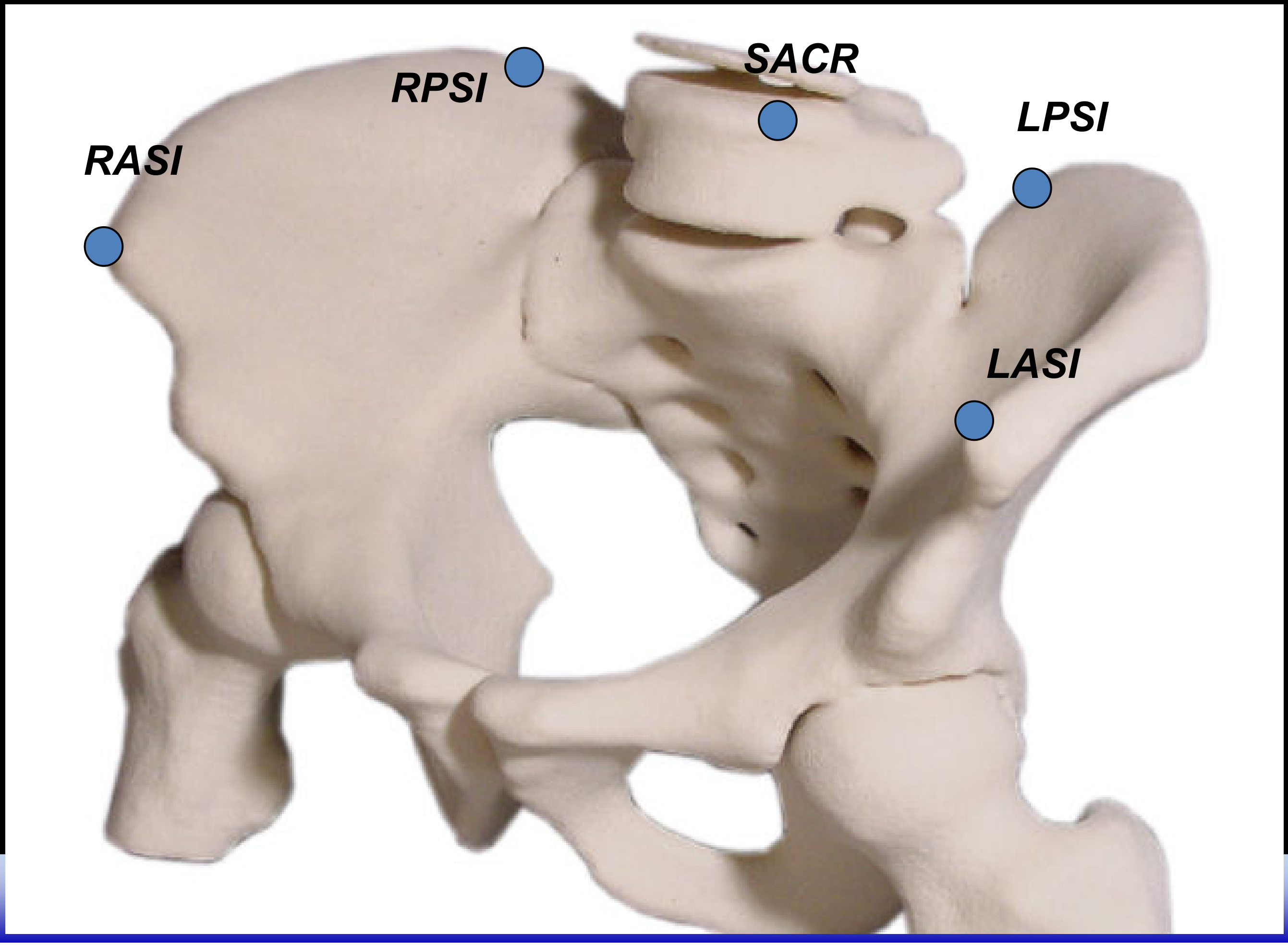


NOTE: Using the two posterior *PSI* markers or the *SACR* marker is irrelevant.

When the *SACR* marker is present, it will be used for modelling.

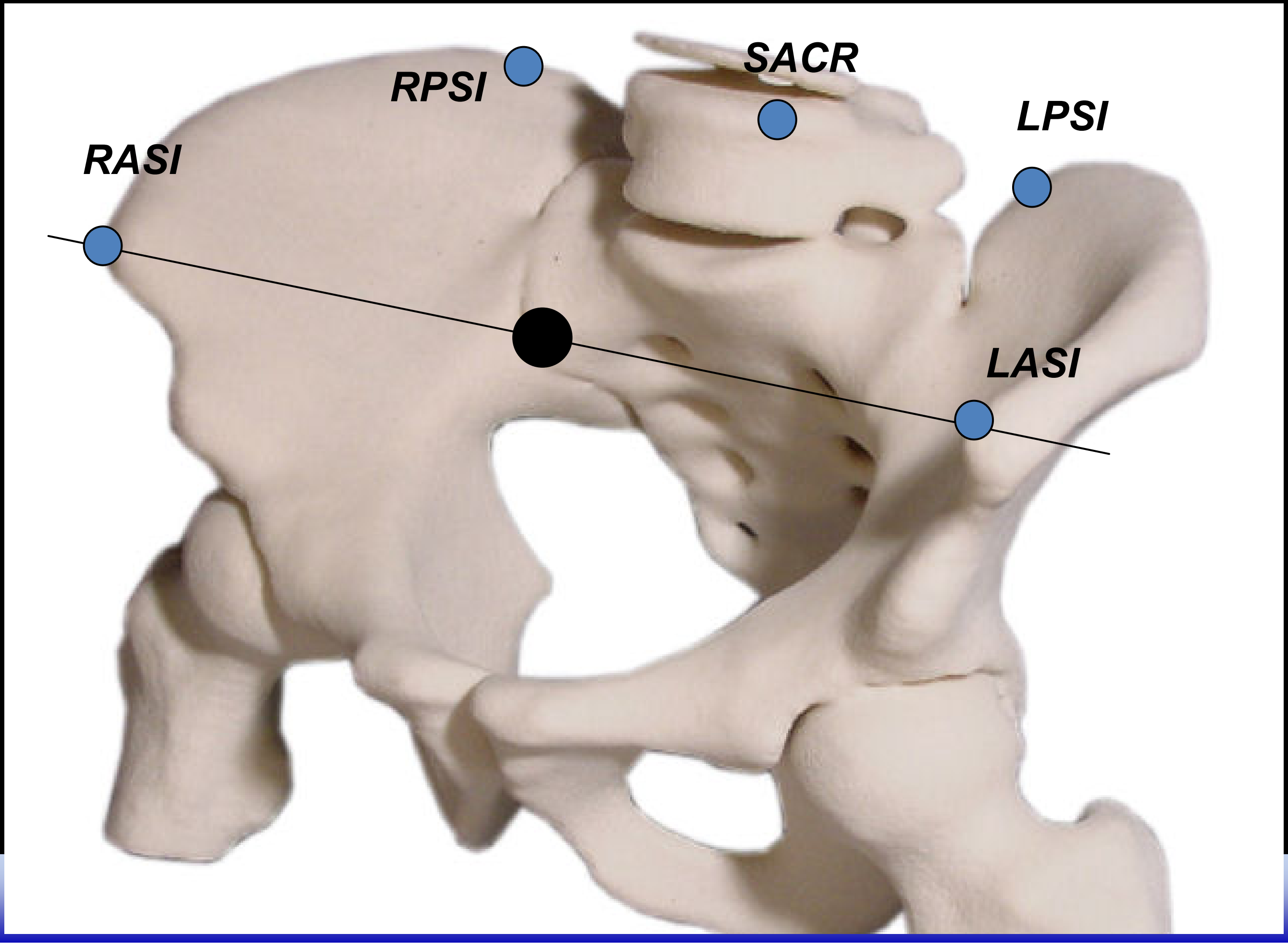
When the *PSI* markers are present, the mid point between them will be calculated and used for modelling. If only one *PSI* marker is visible, that will be used for modelling

PELVIS TECHNICAL REFERENCE SYSTEM



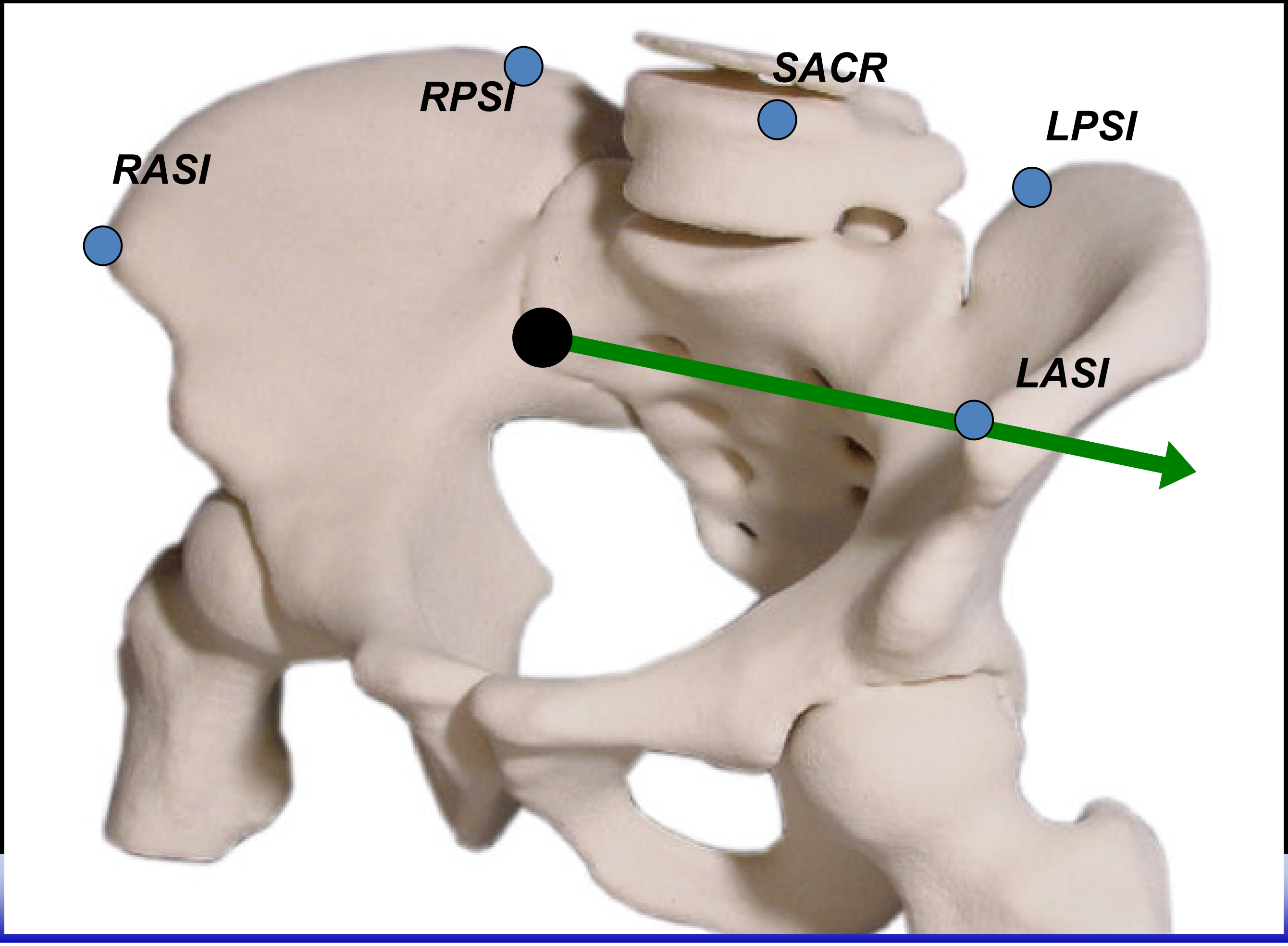
PELVIS TECHNICAL REFERENCE SYSTEM

- Origin: (*RASI* + *LASI*)/2



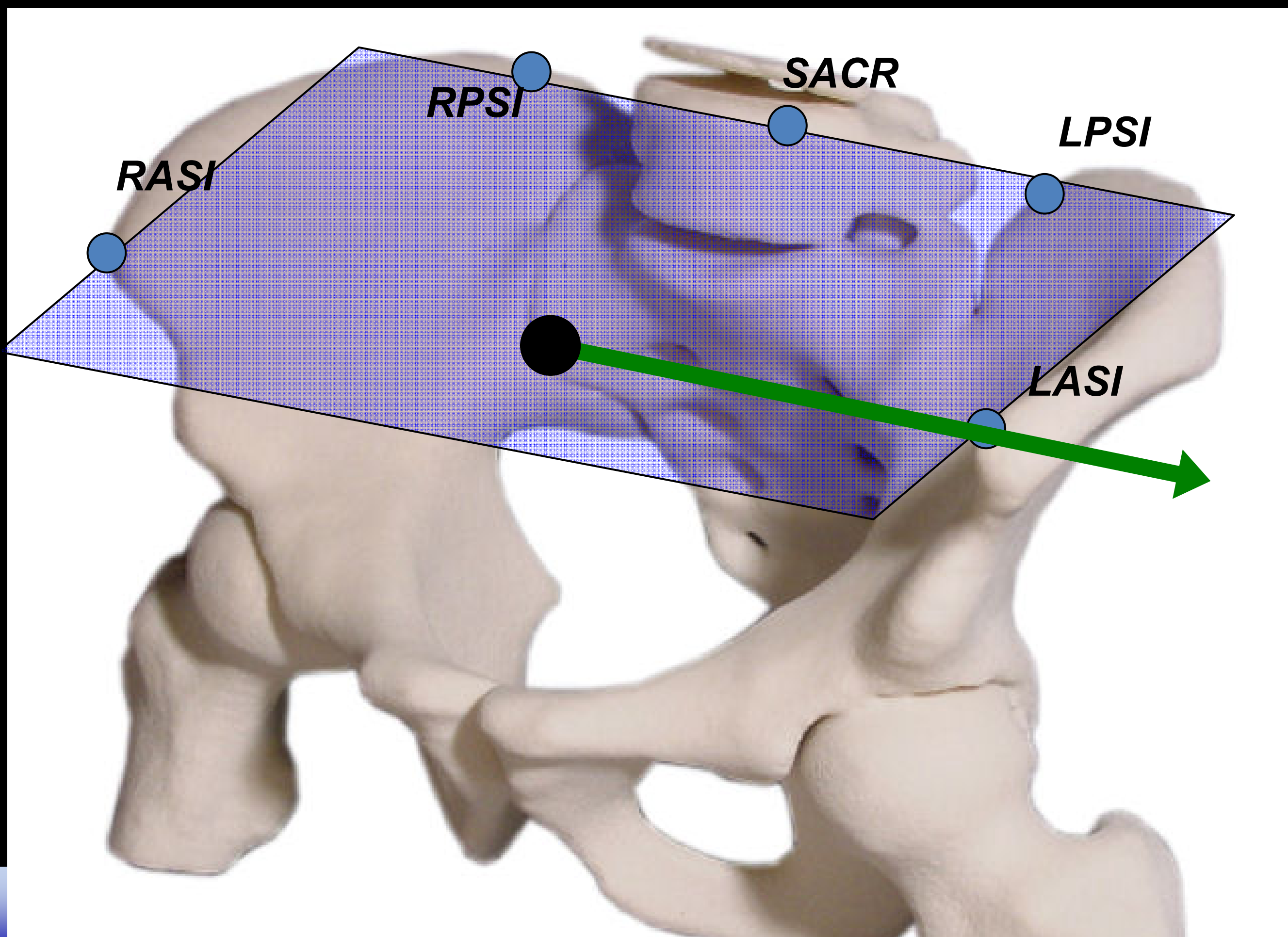
PELVIS TECHNICAL REFERENCE SYSTEM

- Origin: (*RASI* + *LASI*)/2
- Y axis direction: *RASI* → *LASI*



PELVIS TECHNICAL REFERENCE SYSTEM

- Origin: (*RASI* + *LASI*)/2
- Y axis direction: *RASI* → *LASI*
- Z axis direction: Perpendicular to the plane defined by *LASI, RASI, SACR*



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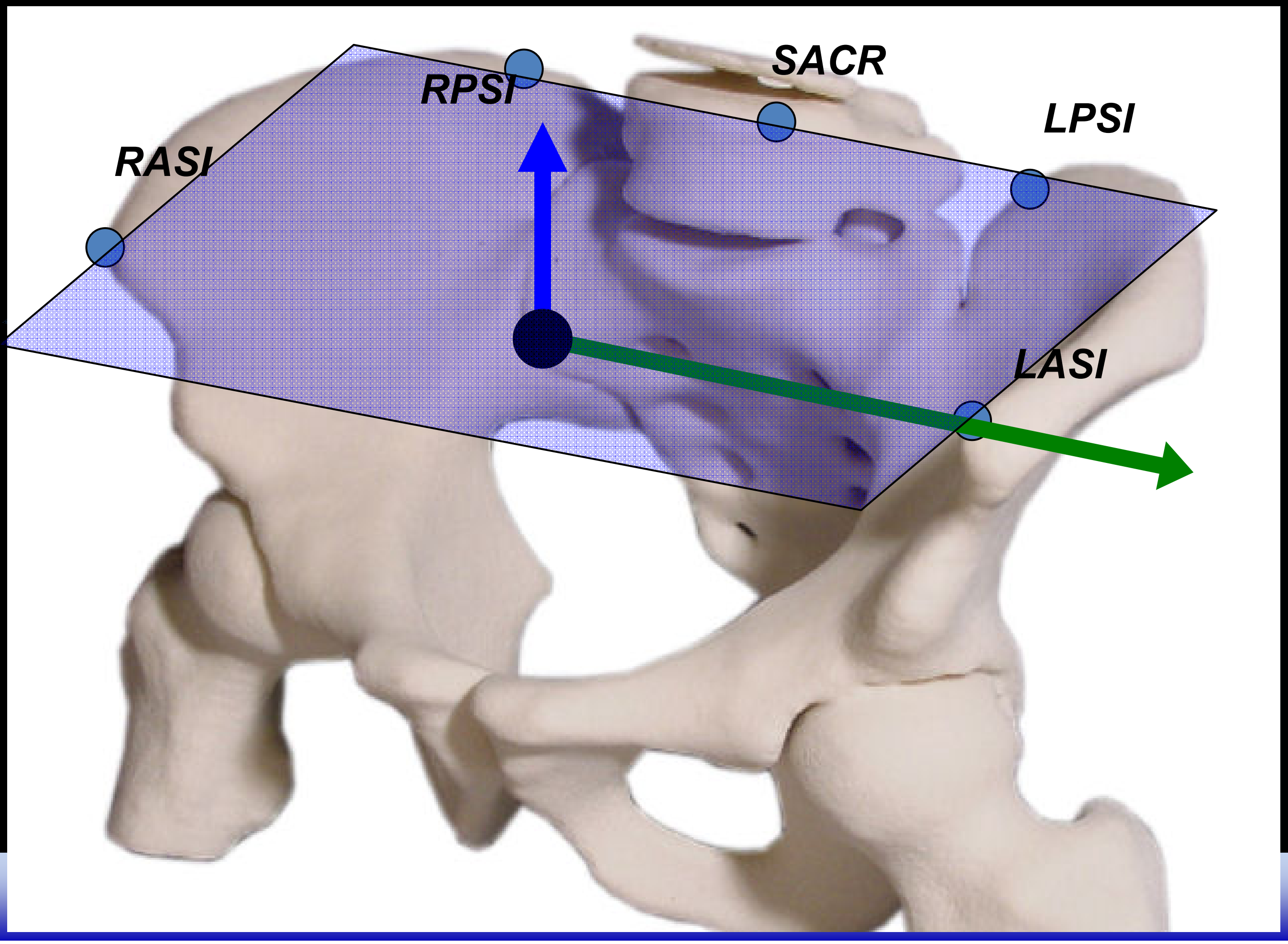
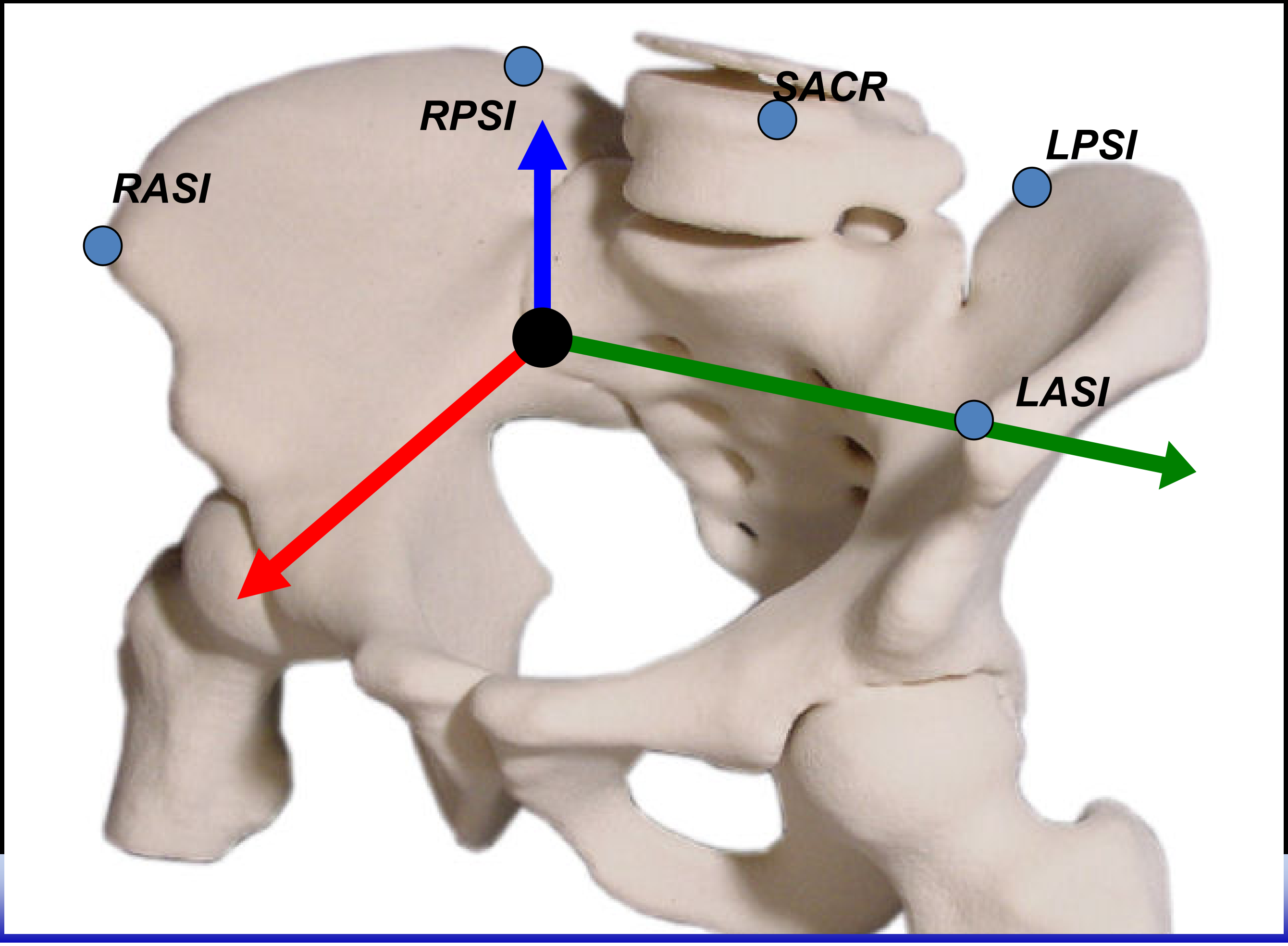


PELVIS TECHNICAL REFERENCE SYSTEM

- Origin: (*RASI* + *LASI*)/2
- Y axis direction: *RASI* → *LASI*
- Z axis direction: Perpendicular to the plane defined by *LASI, RASI, SACR*
- X axis direction: cross product between Y and Z unit vectors



HIP JOINT CENTRES CALCULATION

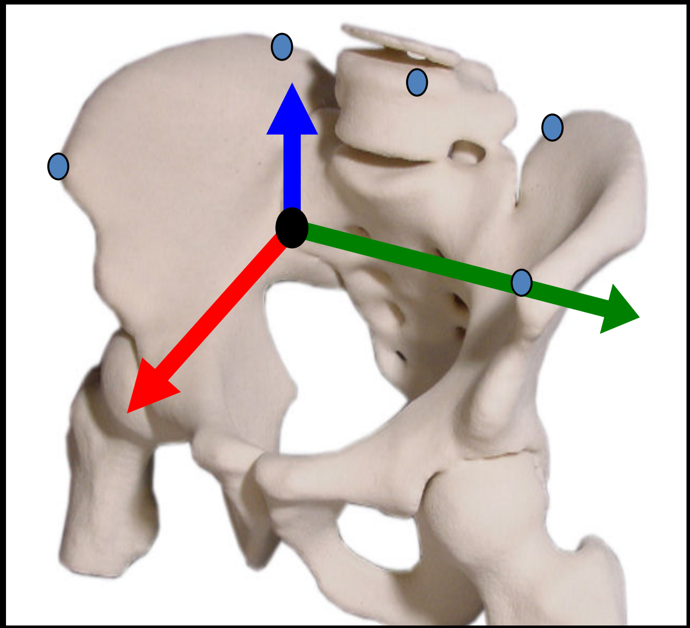
- Newington – Gage model used for defining the positions of the Hip Joint Centres (HJCs) in the pelvis technical reference system (Davis et al, 1991)
- The Newington – Gage model uses the **Asis to Trochanter distance** and the **Inter-Asis distance** to create the position vector of the HJCs in the Pelvis technical reference system
- Asis to Trochanter and Inter-Asis distances can be manually added to the subject measurements (optional measurements)
- Asis to Trochanter and Inter-Asis distances can be automatically calculated by PiG, if not present in the subject measurements
    - Inter-Asis = DIST(LASI,RASI)
    - AsisTrocDistance = 0.1288 * LegLength – 48.56

HIP JOINT CENTRES CALCULATION

$$LHJC_x = C * \cos(\vartheta) * \sin(\beta) - (AsisTrocDist + mm) * \cos(\beta)$$

$$LHJC_y = -(C * \sin(\vartheta) - aa)$$

$$LHJC_z = -C * \cos(\vartheta) * \cos(\beta) - (AsisTrocDist + mm) * \sin(\beta)$$



Where:

$$\vartheta = 0.5 rad$$

$$\beta = 0.314 rad$$

AsisTrocDist = 0.1288 * LegLength – 48.56 *

C = MeanLegLength*0.115 – 15.3

aa = (InterAsis)/2

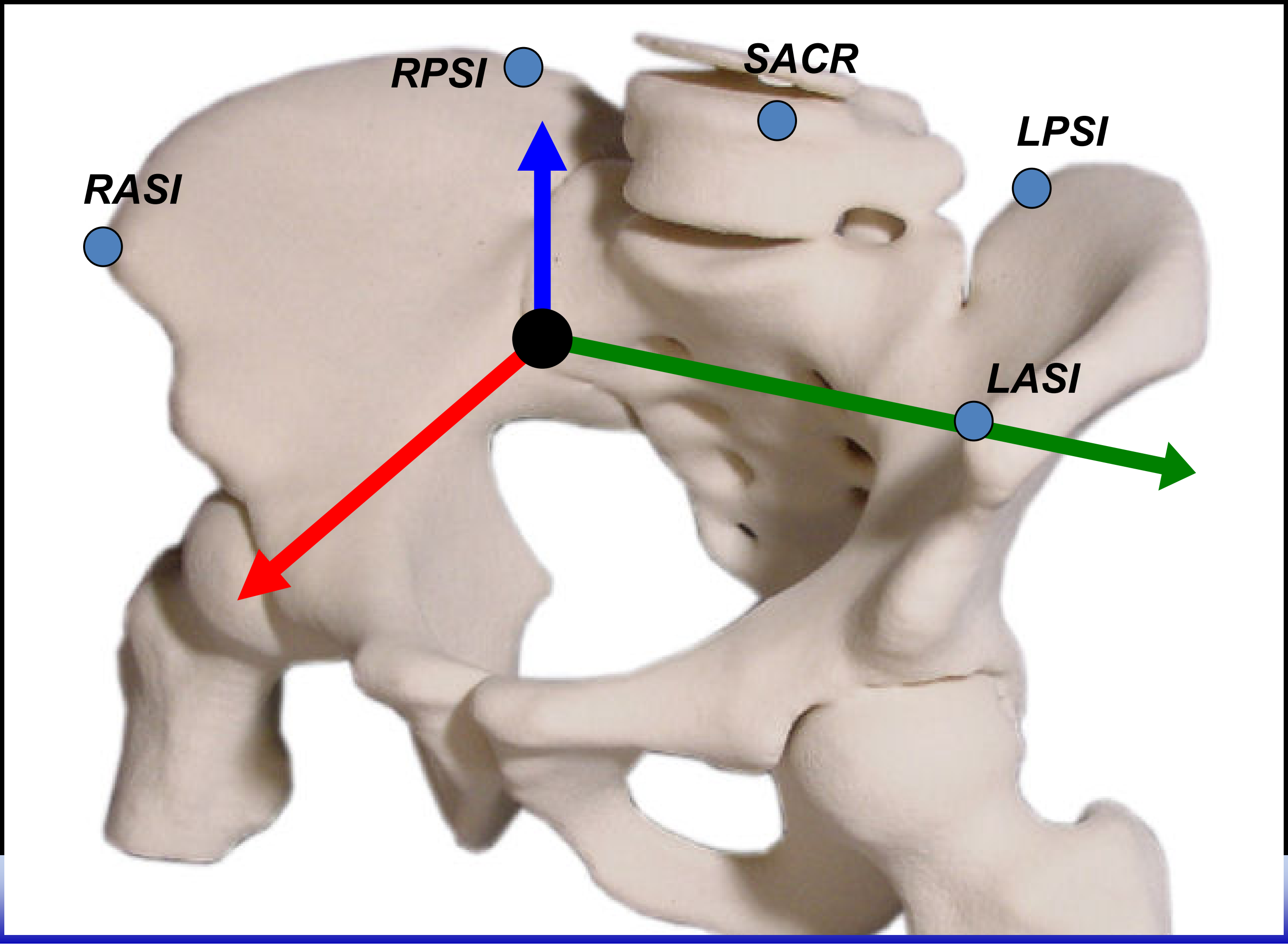
mm = marker radius

*: It can also be entered in the Subject Measurements

PELVIS ANATOMICAL REFERENCE SYSTEM

Once the HJCs are defined, the origin of the reference system associated to the Pelvis segment is shifted to the mid point of the HJCs.

The axes orientation remains unchanged



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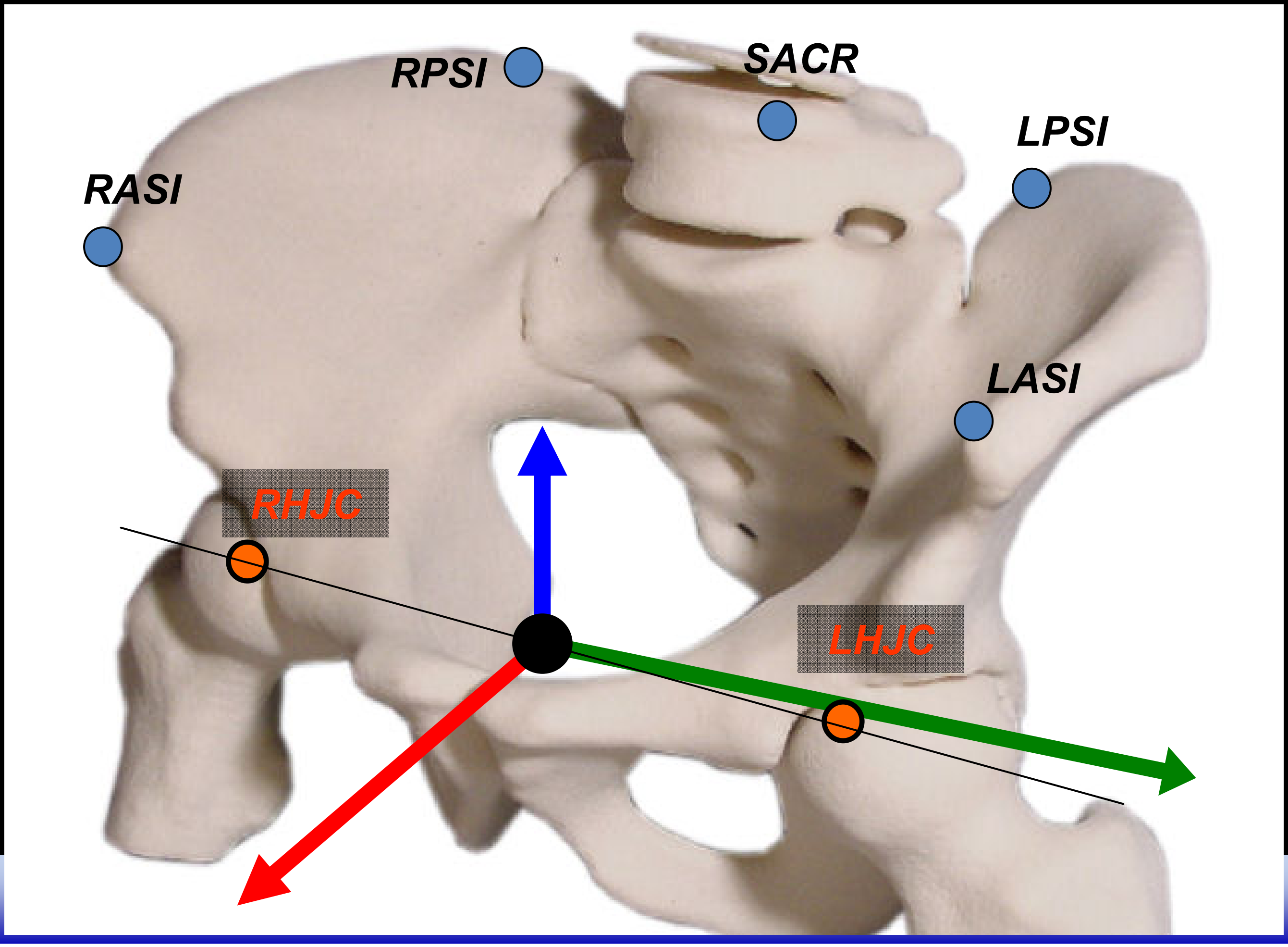


PELVIS SUMMARY

- Markers
  - *LASI, RASI, LPSI, RPSI*

    OR

  - *LASI, RASI, SACR*

- Technical reference definition

- Hip Joint Centres calculation
  - InterAsis distance from subject measurements OR calculated by PiG
  - *ASIS* to Trochanter distance from subject measurements OR calculated by PiG

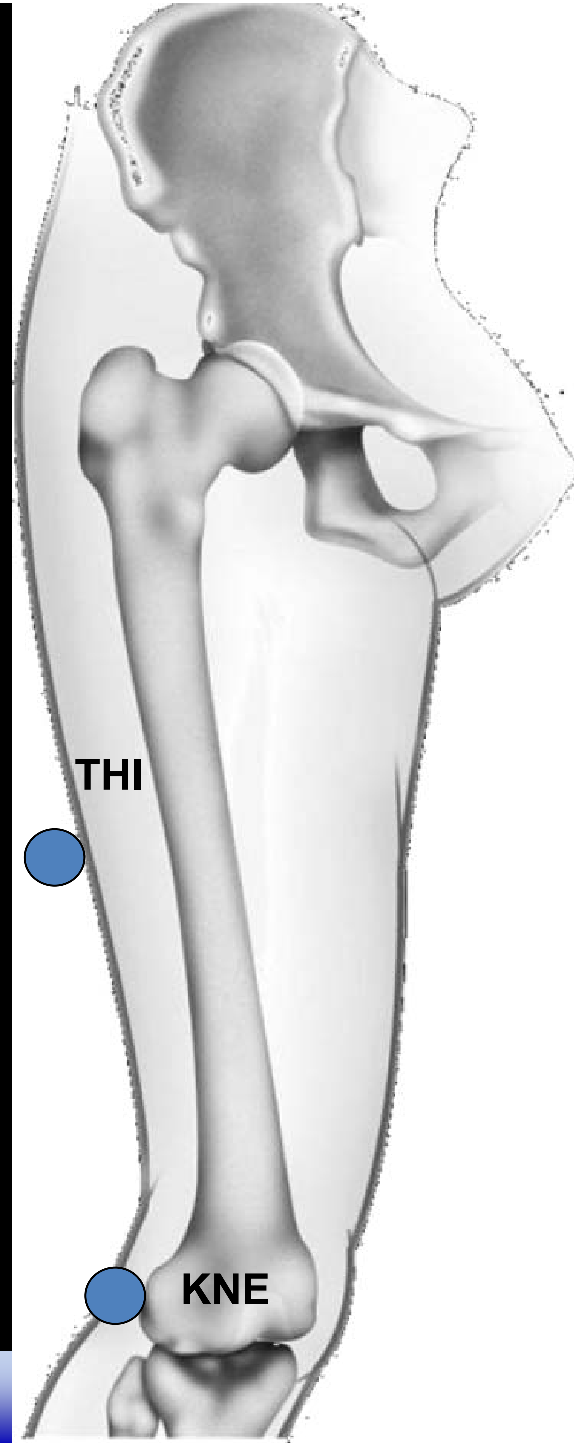
- Anatomical reference definition
  - Origin: (*RHCJ* + *LHJC*)/2
  - Y axis direction: *RASI* → *LASI*
  - Z axis direction: Perpendicular to the plane defined by *LASI, RASI, SACR*
  - X axis direction: cross product between Y and Z unit vectors

Thigh

THIGH MARKERS

- ***KNE***: On the most lateral aspect of the femur lateral condyle
- ***THI***: On the lateral aspect of the thigh lying on the femural frontal plane – defined by *HJC*, lateral and medial femural condyles. <u>Height not critical.</u>

NOTE: The *THI* marker placement is very important since, together with the *KNE* marker and the Hip Joint Center, defines the orientation in space of the femural frontal plane



THIGH ANATOMICAL REFERENCE SYSTEM

By looking at the marker set for the thigh we notice that there are only two physical markers attached to the thigh segment.

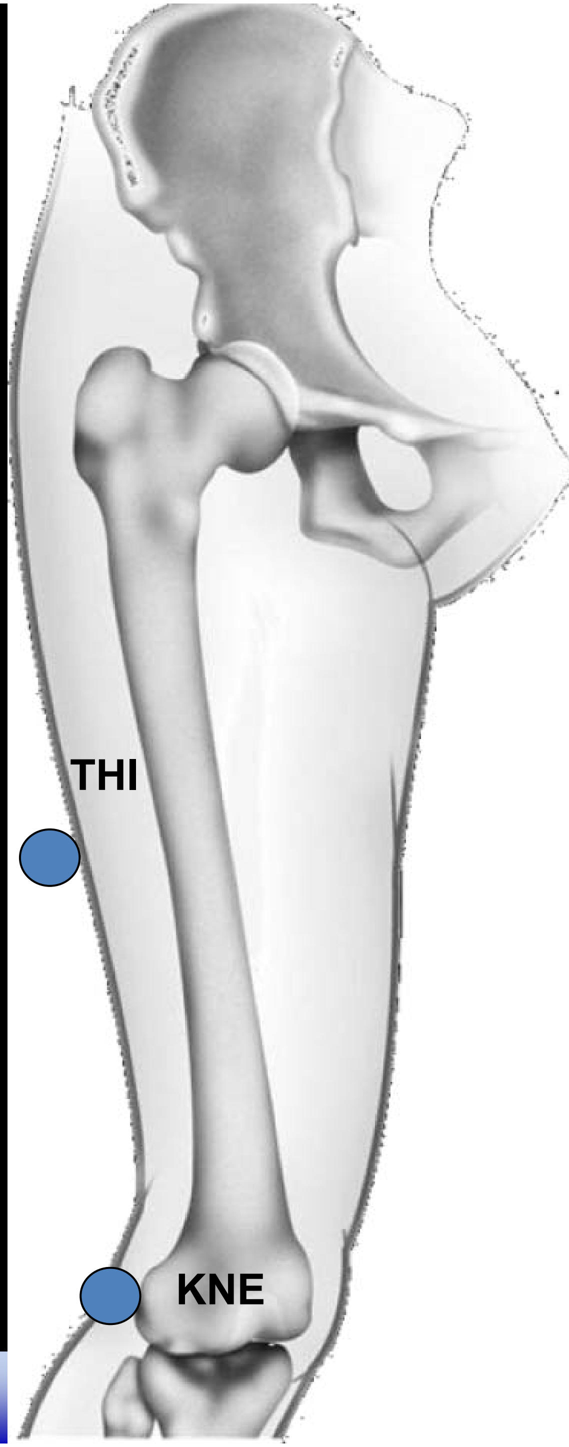
To describe a rigid body motion in space at least three points are needed.

HJC?

Yes, but not only.

PiG in fact calculates the location of the Knee Joint Center (*KJC*) so that the direction of the longitudinal axis of the femur can be defined.

The *KJC* position is determined by applying what we call the CHORD function.



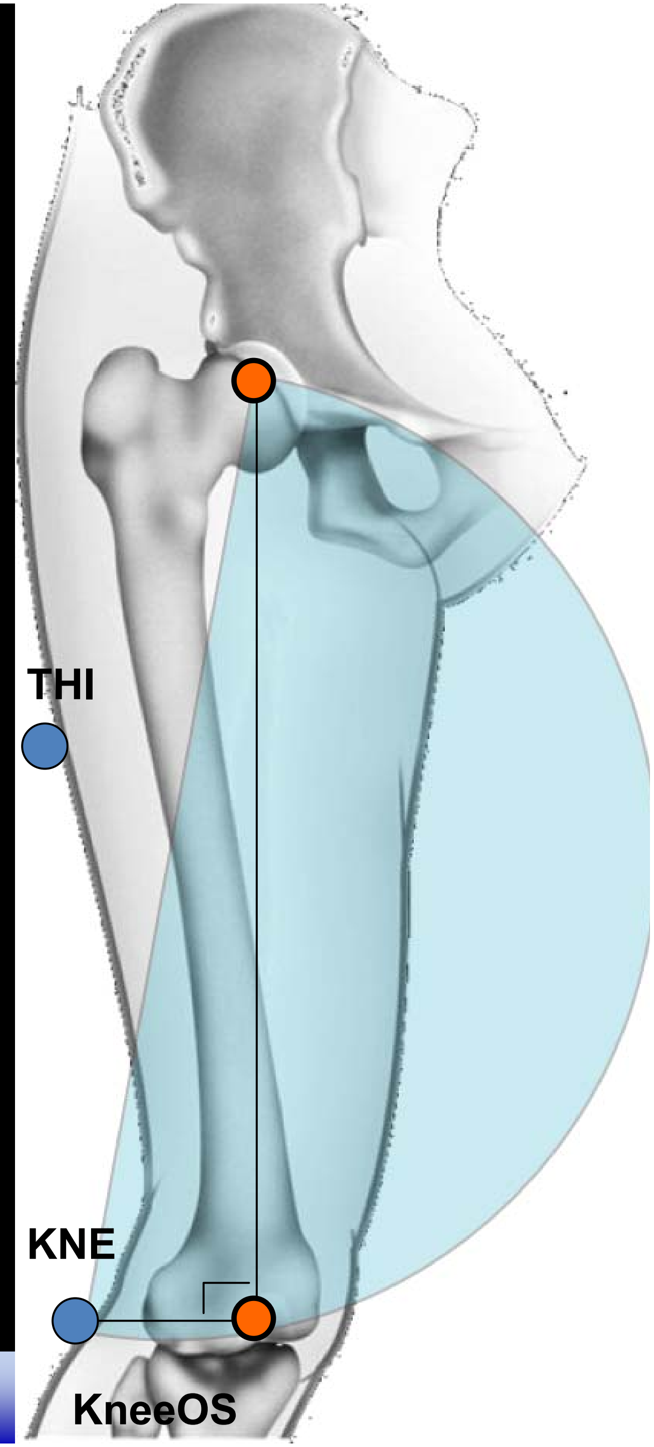
KNEE JOINT CENTER CALCULATION

The *KJC* is defined as the point at distance *KneeOS* from the *KNE* marker in the plane defined by *KNE, THI* and *HJC*.

The angle *KNE-KJC-HJC* must be 90°

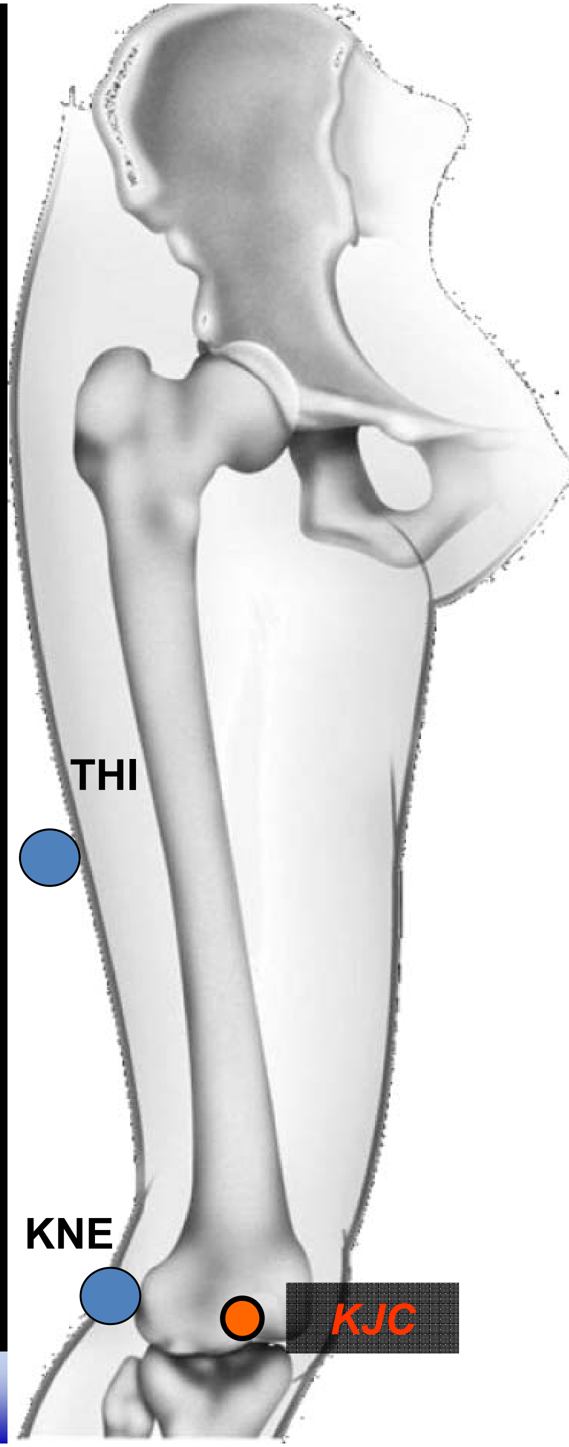
KneeOS = (*MarkerDiameter*+*KneeWidth*)/2

KneeWidth from Subject Measurements (**Required**)



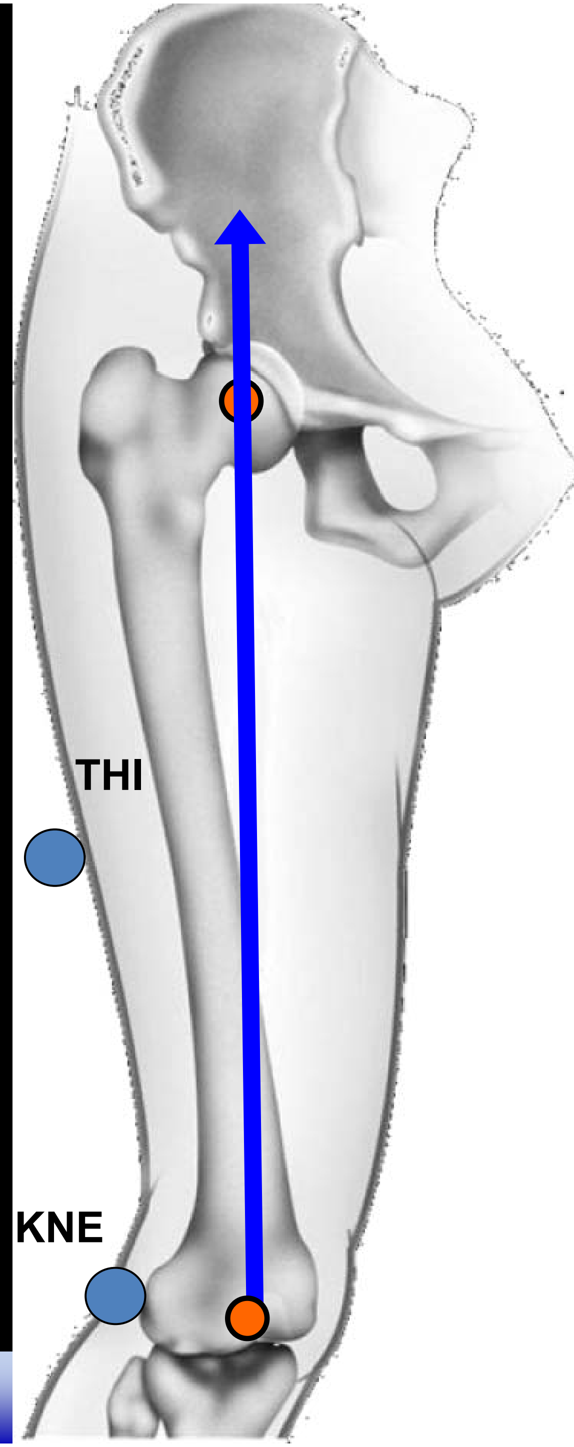
THIGH ANATOMICAL REFERENCE SYSTEM

- Origin: *KJC*



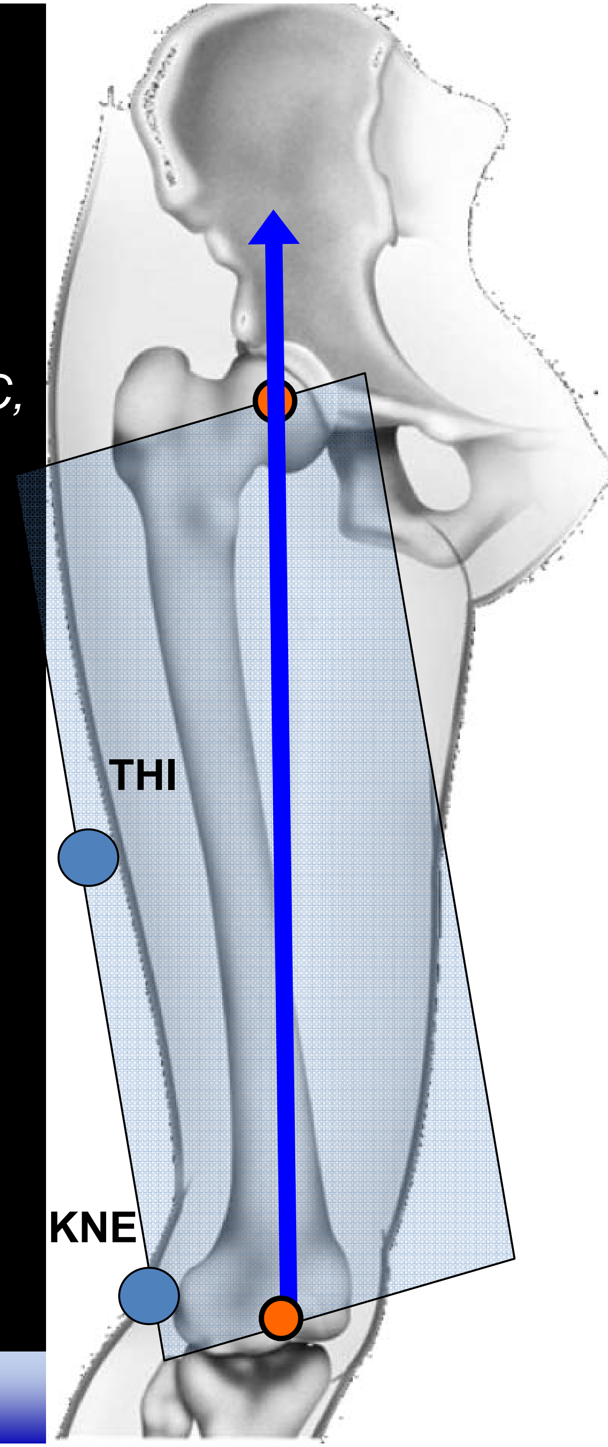
THIGH ANATOMICAL REFERENCE SYSTEM

- Origin: *KJC*
- Z axis direction: *KJC* → *HJC*



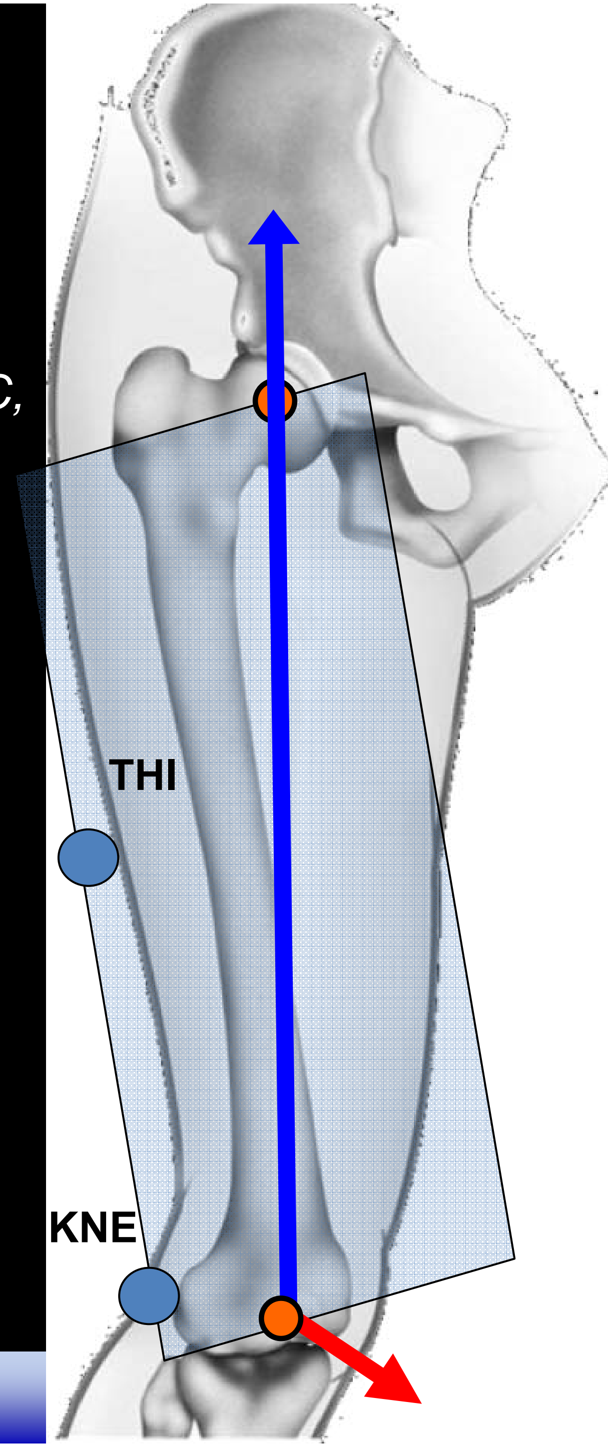
THIGH ANATOMICAL REFERENCE SYSTEM

- Origin: *KJC*
- Z axis direction: *KJC → HJC*
- X axis direction: perpendicular to the plane defined by *HJC, KNE, THI*



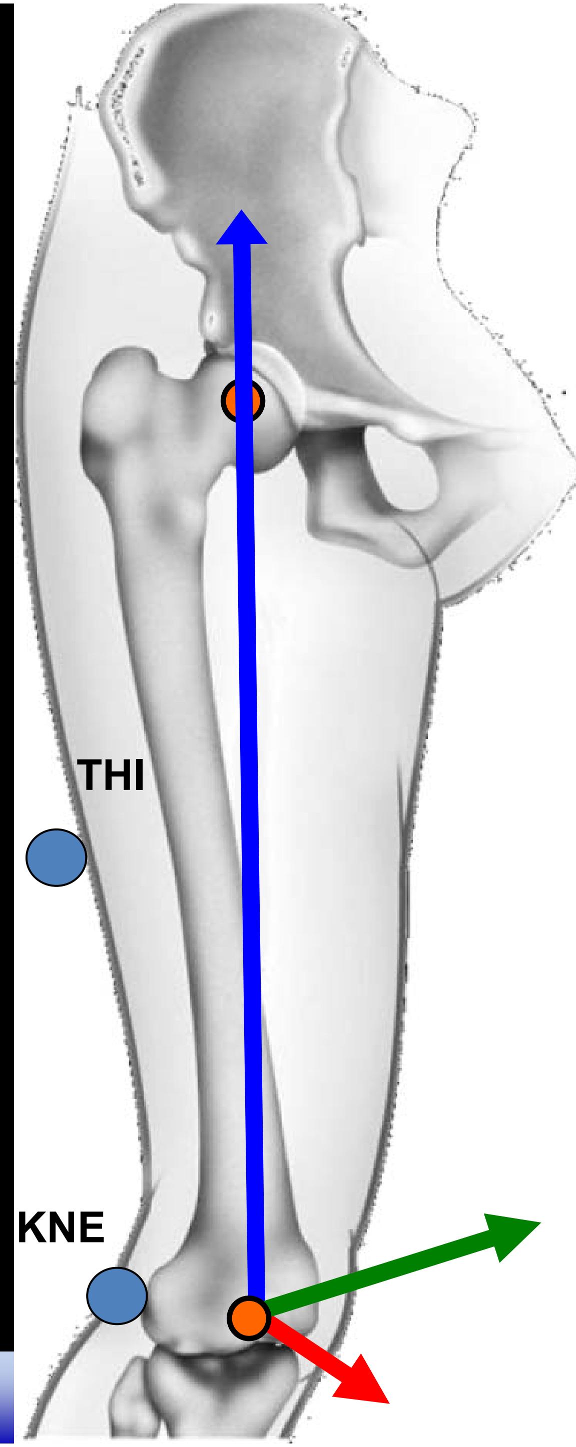
THIGH ANATOMICAL REFERENCE SYSTEM

- Origin: *KJC*
- Z axis direction: *KJC* → *HJC*
- X axis direction: perpendicular to the plane defined by *HJC, KNE, THI*



THIGH ANATOMICAL REFERENCE SYSTEM

- Origin: *KJC*
- Z axis direction: *KJC* → *HJC*
- X axis direction: perpendicular to the plane defined by *HJC, KNE, THI*
- Y axis direction: cross product between Z and X unit vectors



THIGH SUMMARY

☺ Markers

- ☺ *KNE, THI*
- ☺ The anterior-posterior position of the *THI* marker sets the orientation of the femural frontal plane

☺ Knee Joint Center calculation

- ☺ The CHORD function creates a virtual point (*KJC*) at a distance *KneeOS* from the *KNE* marker, on the plane defined by *KNE, THI, HJC*
- ☺ The *KNE-KJC-HJC* angle is 90°

☺ Anatomical reference definition

- ☺ Origin: *KJC*
- ☺ Z axis direction: *KJC* → *HJC* (up)
- ☺ X axis direction: Perpendicular to the plane defined by *HJC, KNE, THI* (anterior)
- ☺ Y axis direction: cross product between Z and X unit vectors (towards the left for both left and right limbs)

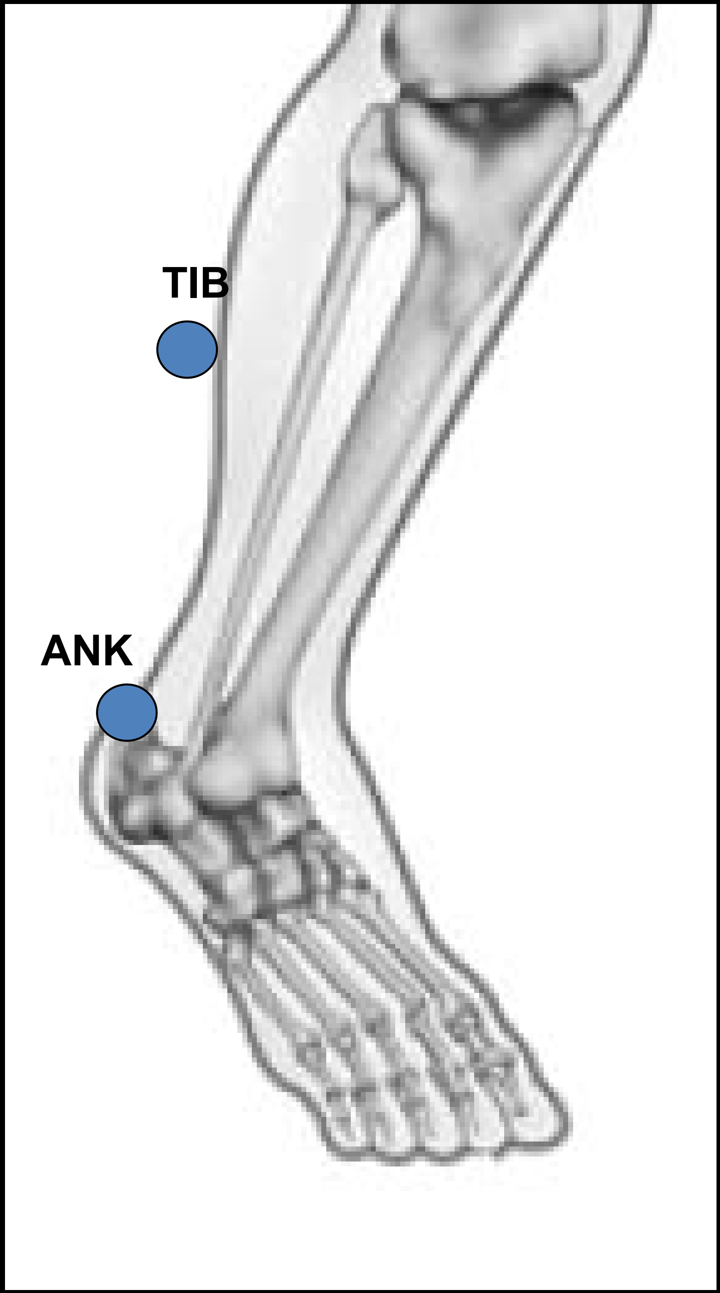
Shank

SHANK MARKERS

•***TIB*****:** On the lateral aspect of the shank lying on the tibial frontal plane – defined by *KJC*, lateral and medial malleoli. Height not critical.

•***ANK*****:** On the most lateral aspect of the lateral malleolus

NOTE: The *TIB* marker placement is very important since, together with the *KJC* and the *ANK* marker, defines the orientation in space of the tibial frontal plane



SHANK ANATOMICAL REFERENCE SYSTEM

By looking at the marker set for the shank we notice that there are only two physical markers attached to the segment.

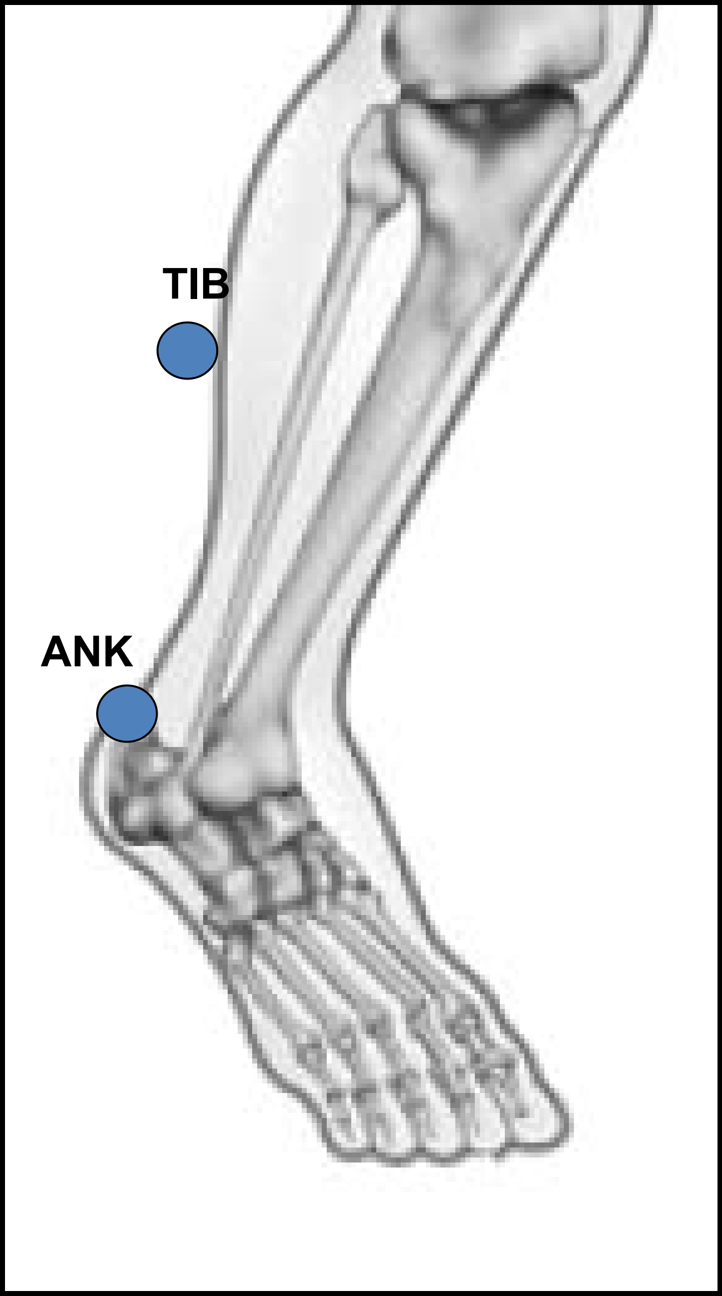
To describe a rigid body motion in space at least three points are needed.

KJC?

Yes, but not only.

PiG in fact calculates the location of the Ankle Joint Center (*AJC*) so that the direction of the longitudinal axis of the femur can be defined.

The *AJC* position is determined by applying the CHORD function, similarly to the thigh segment



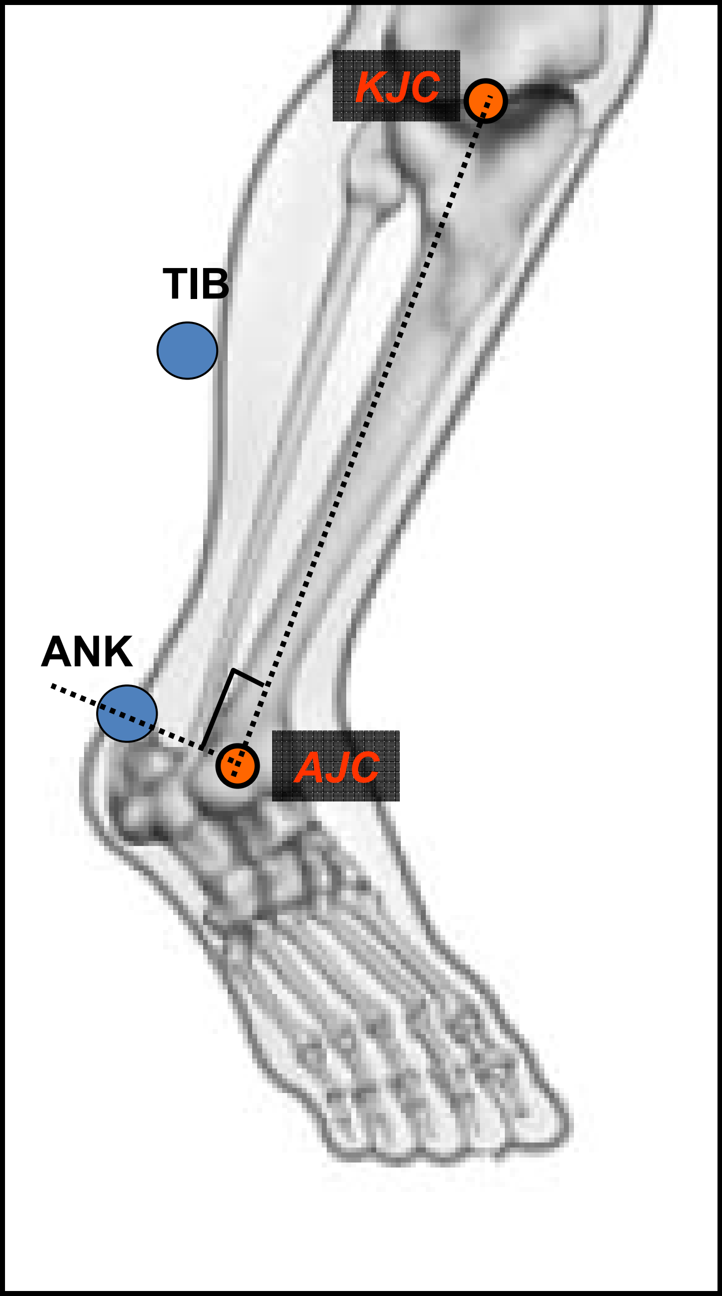
ANKLE JOINT CENTER CALCULATION

The *AJC* is defined as the point at distance *AnkleOS* from the *ANK* marker in the plane defined by *ANK, TIB* and *KJC*.

The angle *ANK-AJC-KJC* must be 90°

AnkleOS = (*MarkerDiameter* + *AnkleWidth*)/2

AnkleWidth from Subject Measurements (**Required**)



SHANK ANATOMICAL REFERENCES

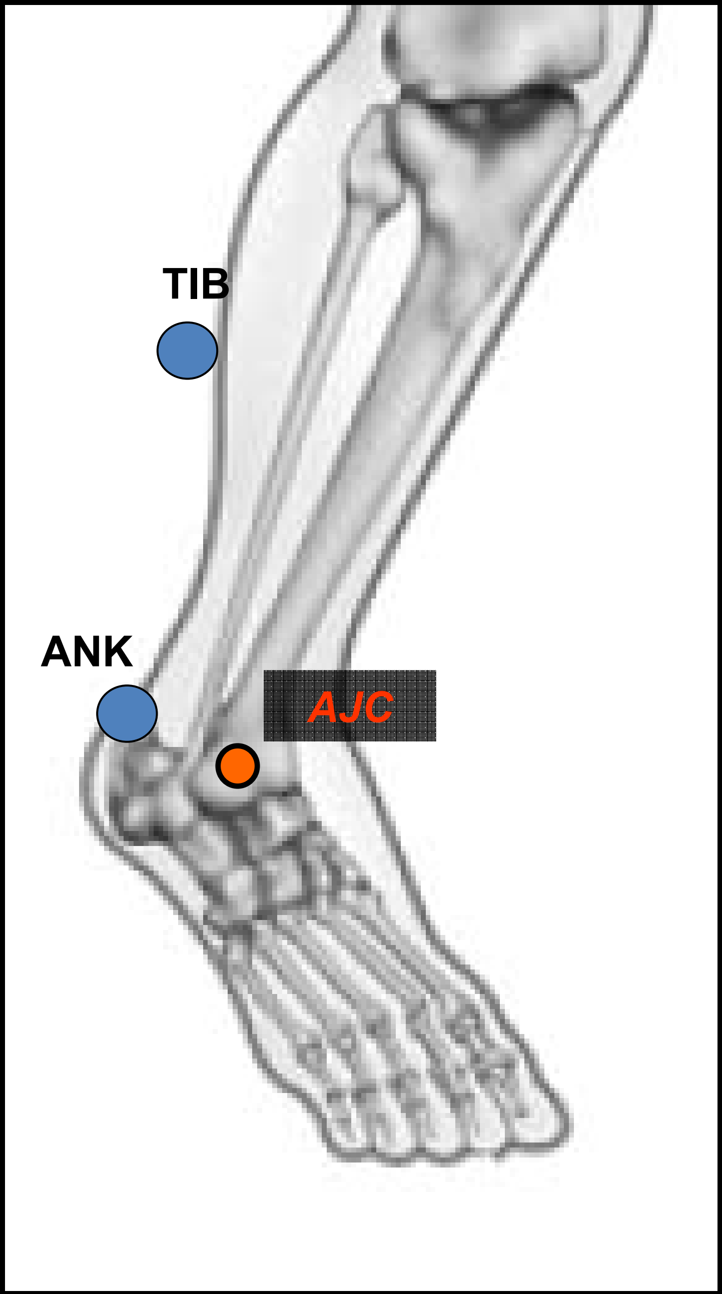
PiG creates two anatomical shank references.

- TORSIONED TIBIA
  - Tibial frontal plane being defined by *ANK, TIB* and *KJC*
  - Used to describe the distal motion of the shank complex (*ankle angles*)

- UNTORSIONED TIBIA
  - Torsioned Tibia segment rotated around its z axis by *Tibial Torsion* degrees
  - The *Tibial Torsion* is entered in the subject measurements **(optional)**
  - The direction of the segment’s frontal plane is parallel to the knee flexion axis
  - Used to describe the proximal motion of the shank complex (*knee angles*)

TORSIONED TIBIA

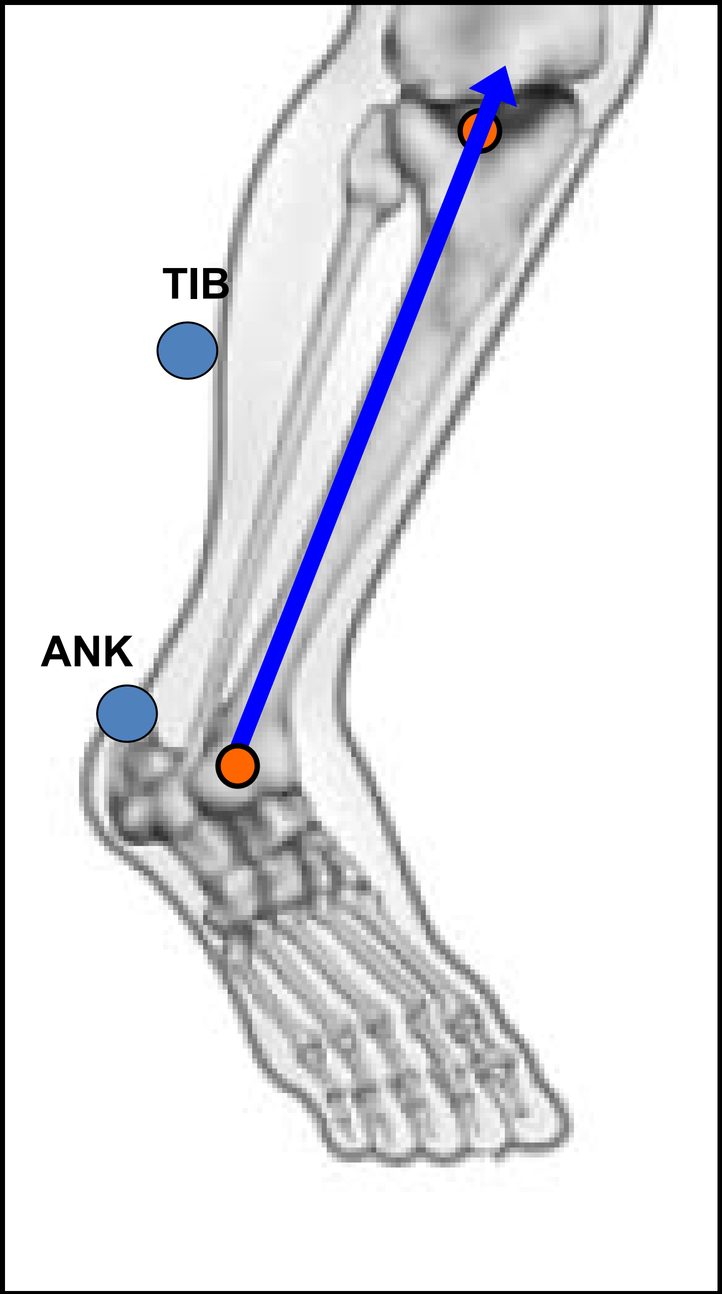
- Origin: AJC



SHANK ANATOMICAL REFERENCE SYSTEM

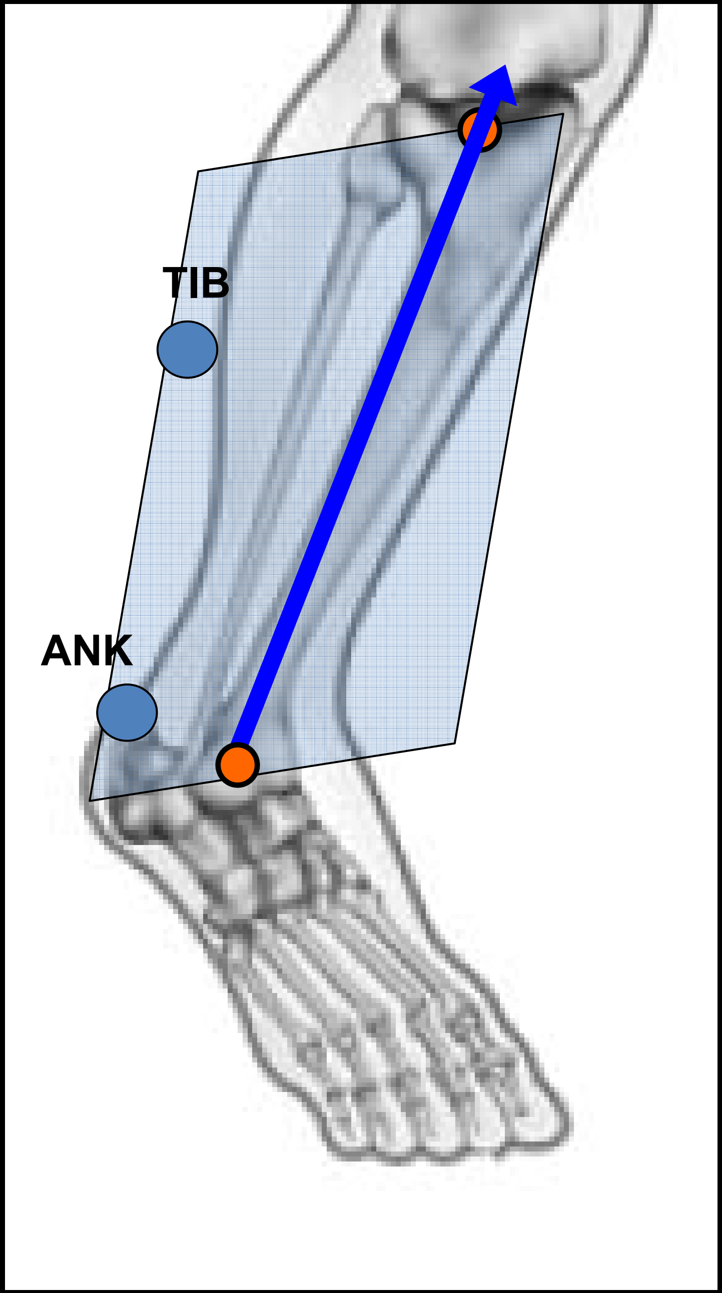
<u>TORSIONED TIBIA</u>

- Origin: AJC
- Z Axis direction: AJC → KJC



TORSIONED TIBIA

- Origin: AJC
- Z Axis direction: AJC → KJC
- X axis direction: perpendicular to the plane formed by TIB, AJC, KJC



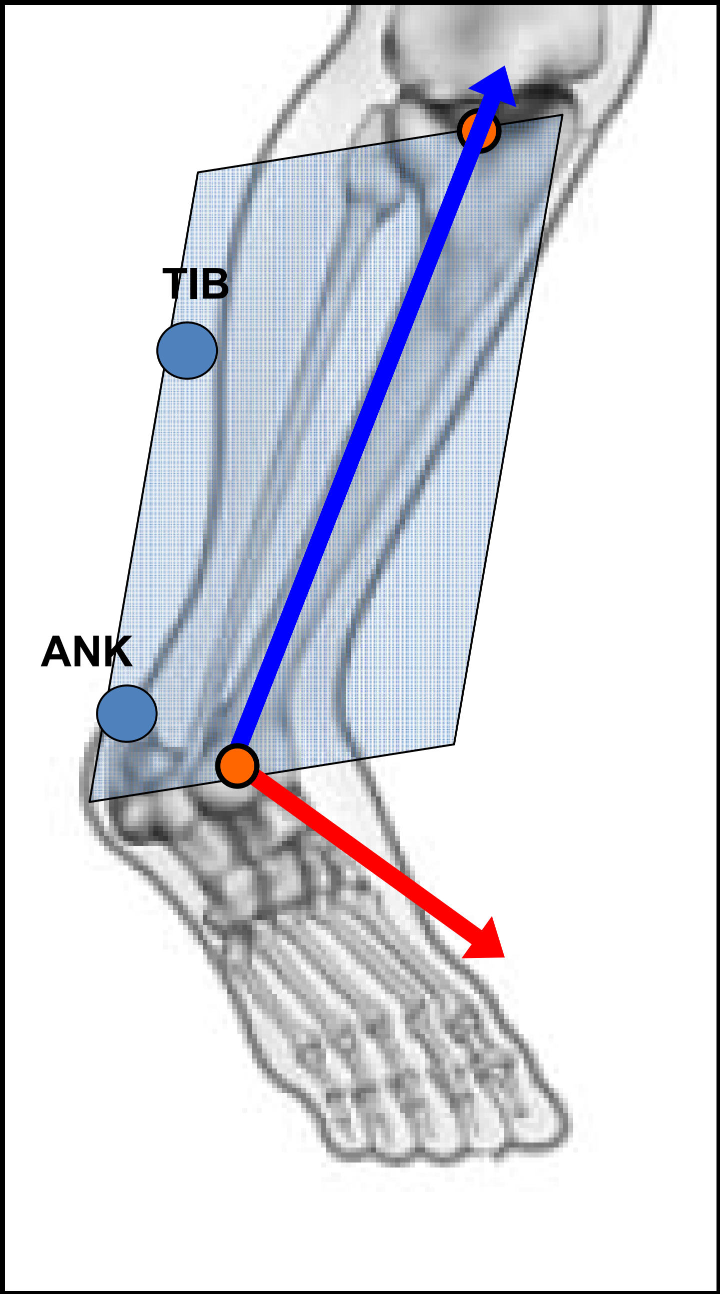
SHANK ANATOMICAL REFERENCE SYSTEM

<u>TORSIONED TIBIA</u>

•Origin: AJC

•Z Axis direction: AJC → KJC

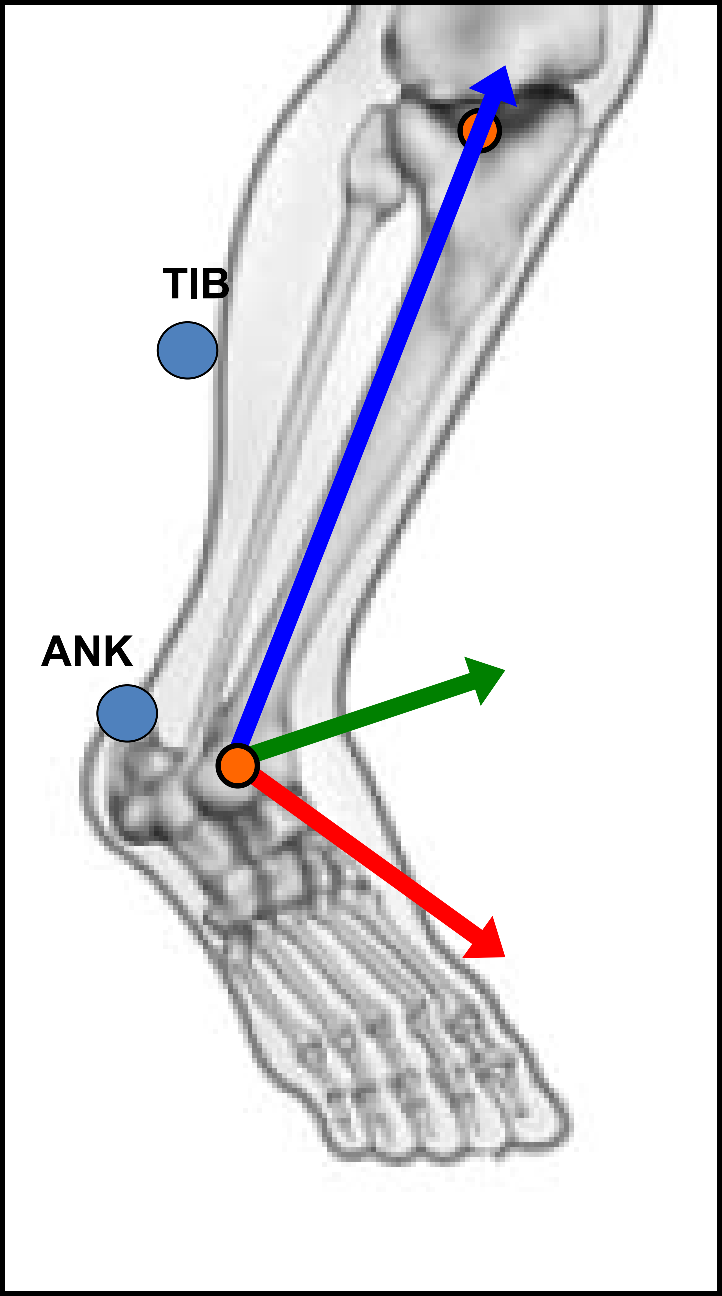
•X axis direction: perpendicular to the plane formed by TIB, AJC, KJC



SHANK ANATOMICAL REFERENCE SYSTEM

TORSIONED TIBIA

- Origin: AJC
- Z Axis direction: AJC → KJC
- X axis direction: perpendicular to the plane formed by TIB, AJC, KJC
- Y axis direction: cross product between Z and X unit vectors

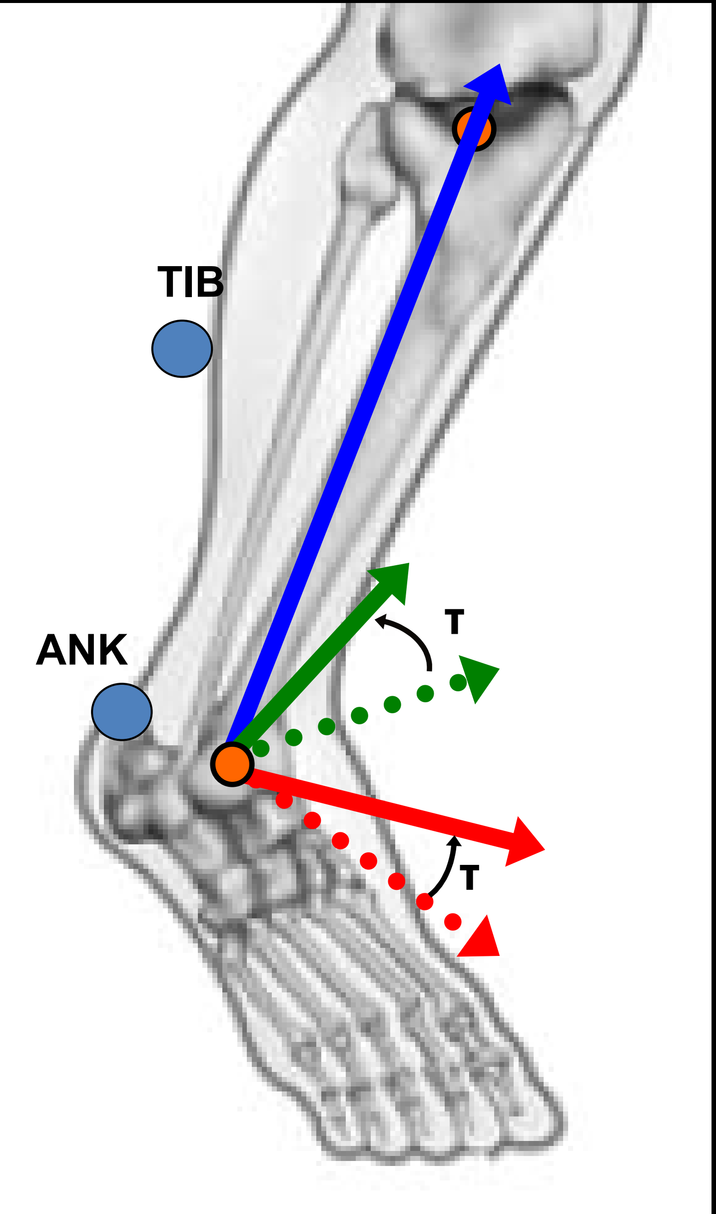


SHANK ANATOMICAL REFERENCE SYSTEM

UNTORSIONED TIBIA

- Origin: AJC
- Z Axis direction: AJC → KJC
- X axis direction: perpendicular to the plane formed by THI, KJC, HJC – **same as Thigh segment!!!**
- Y axis direction: cross product between Z and X unit vectors

NOTE: To obtain the untorsioned tibia, Plug In Gait rotates the torsioned tibia around its Z axis by *Tibial Torsion* degrees (from the subject measurements)

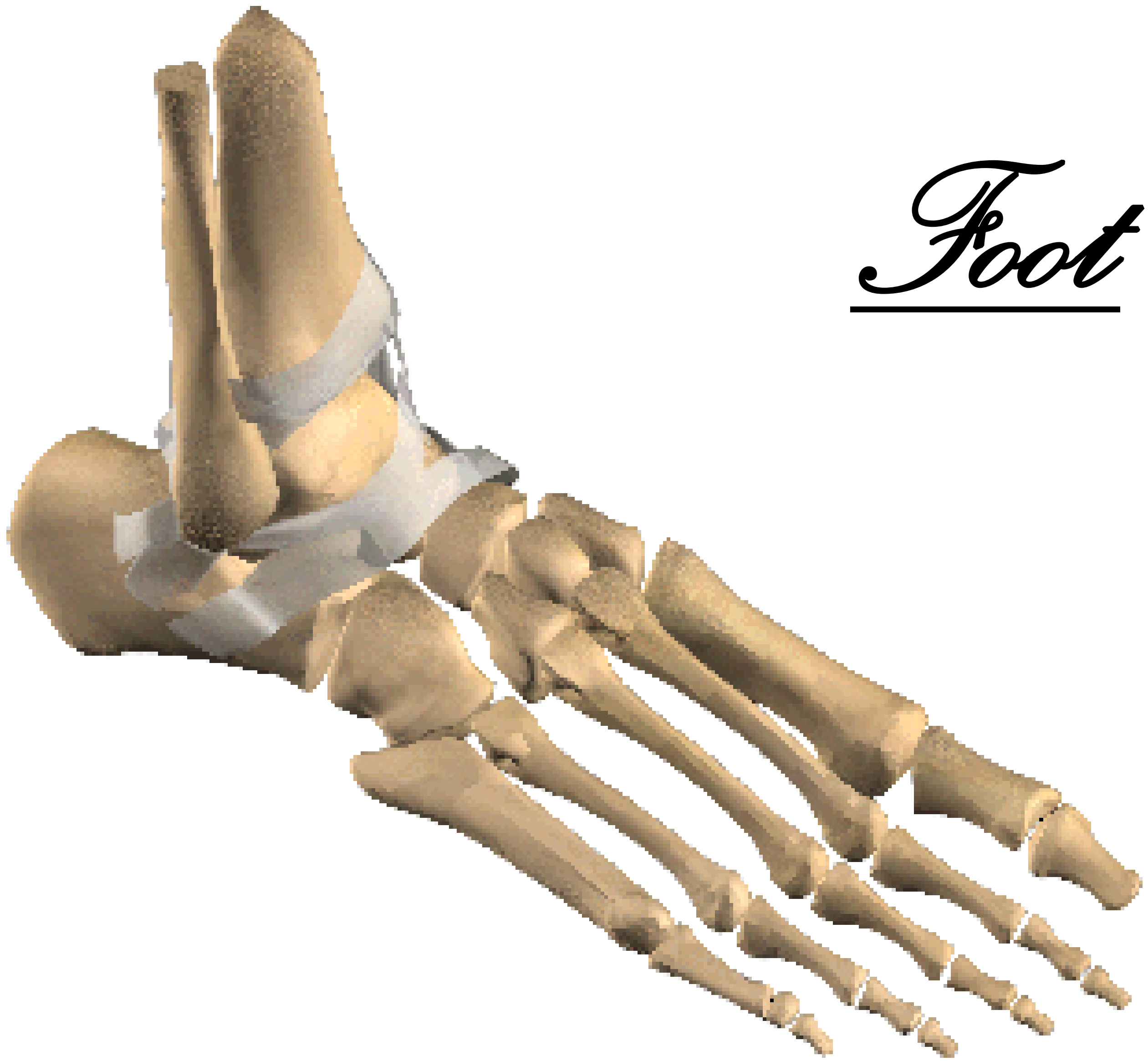


τ: *Tibial Torsion*

SHANK SUMMARY

- ☺ Markers
  - ☺ *TIB, ANK*
- ☺ Ankle Joint Center calculation
  - ☺ *AJC* at a distance *AnkleOS* from the *ANK* marker, on the plane defined by *ANK, TIB, KJC.* The angle *ANK-AJC-KJC* measures 90°
- ☺ Shank Segments Definition
  - ☺ Torsioned Tibia
  - ☺ Untorsioned Tibia
- ☺ Anatomical reference definition
  - ☺ Origin: AJC
  - ☺ Z axis direction: AJC → KJC (up)
  - ☺ X axis direction: Perpendicular to the plane defined by ANK, TIB, AJC (anterior)
  - ☺ Y axis direction: cross product between Z and X unit vectors (left)

Foot

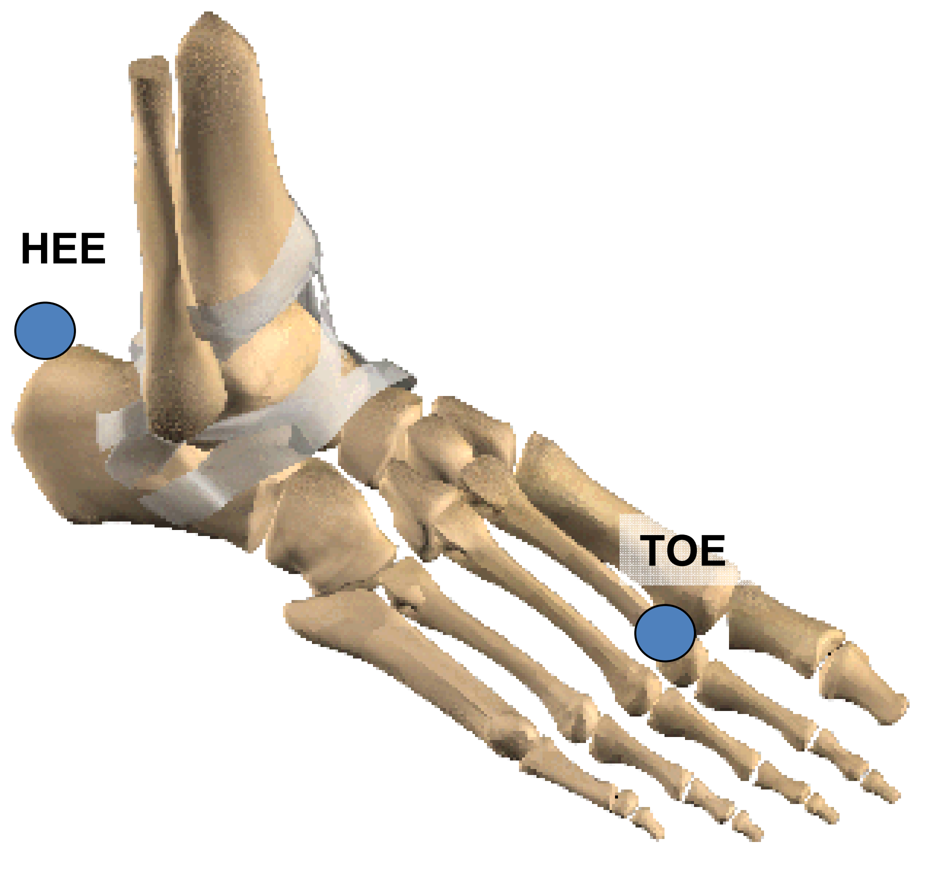


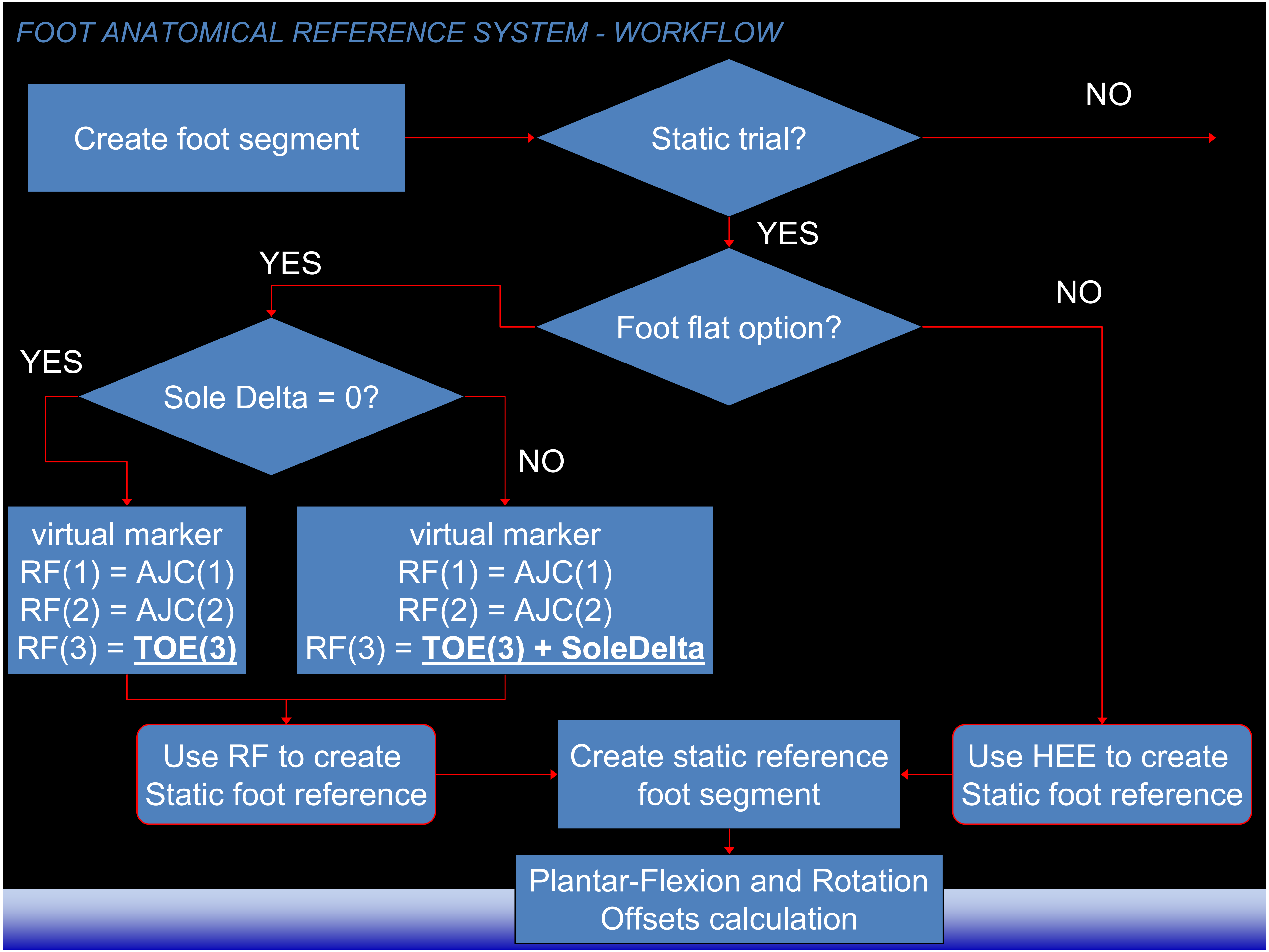
FOOT MARKERS

•***TOE***: On the second metatarsal head, on the mid-foot side of the equinus break between forefoot and mid-foot

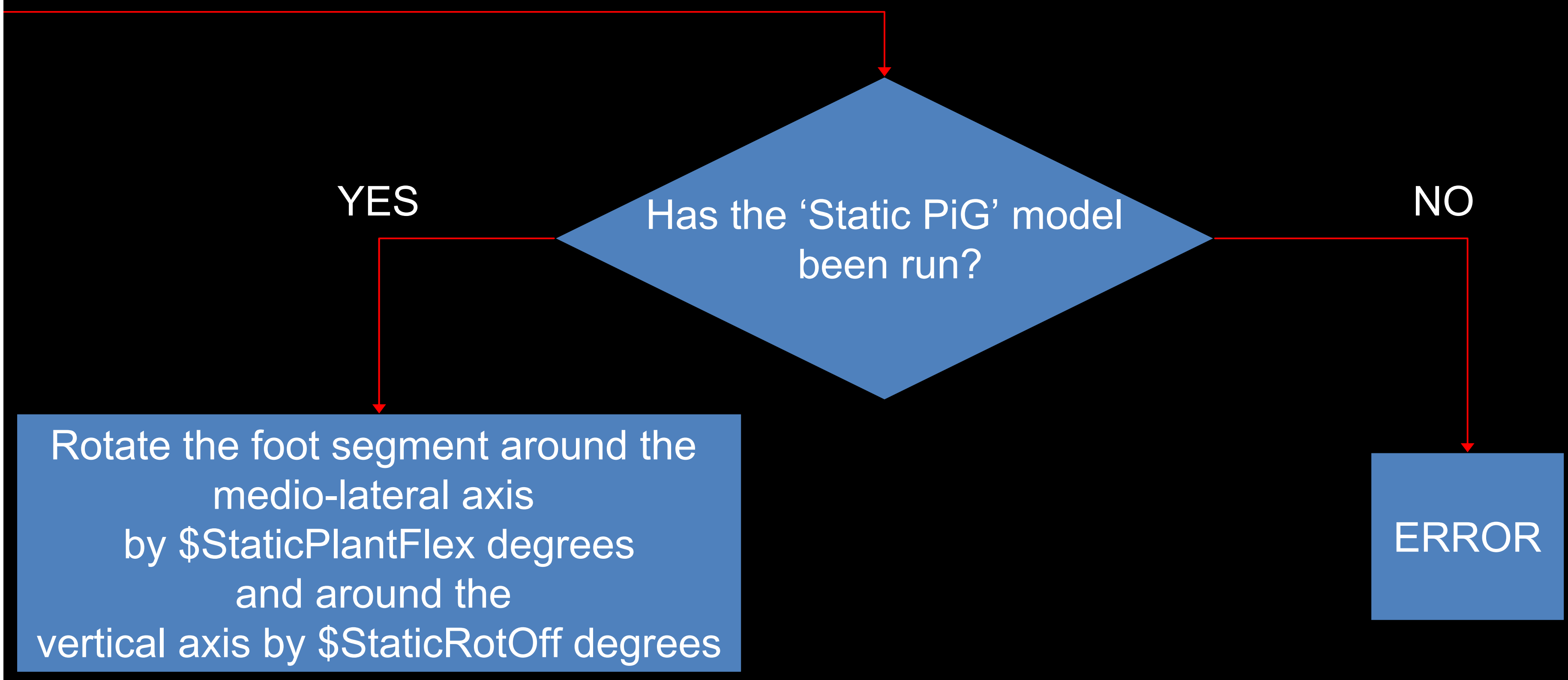
•***HEE***: On the calcaneus. The imaginary line connecting HEE and TOE should be parallel to the longitudinal axis of the foot

NOTE: The *TOE* and *HEE* markers should be at the same height from the foot plantar surface. However, for consistency, this can be achieved by setting the 'assume foot flat' option in PiG



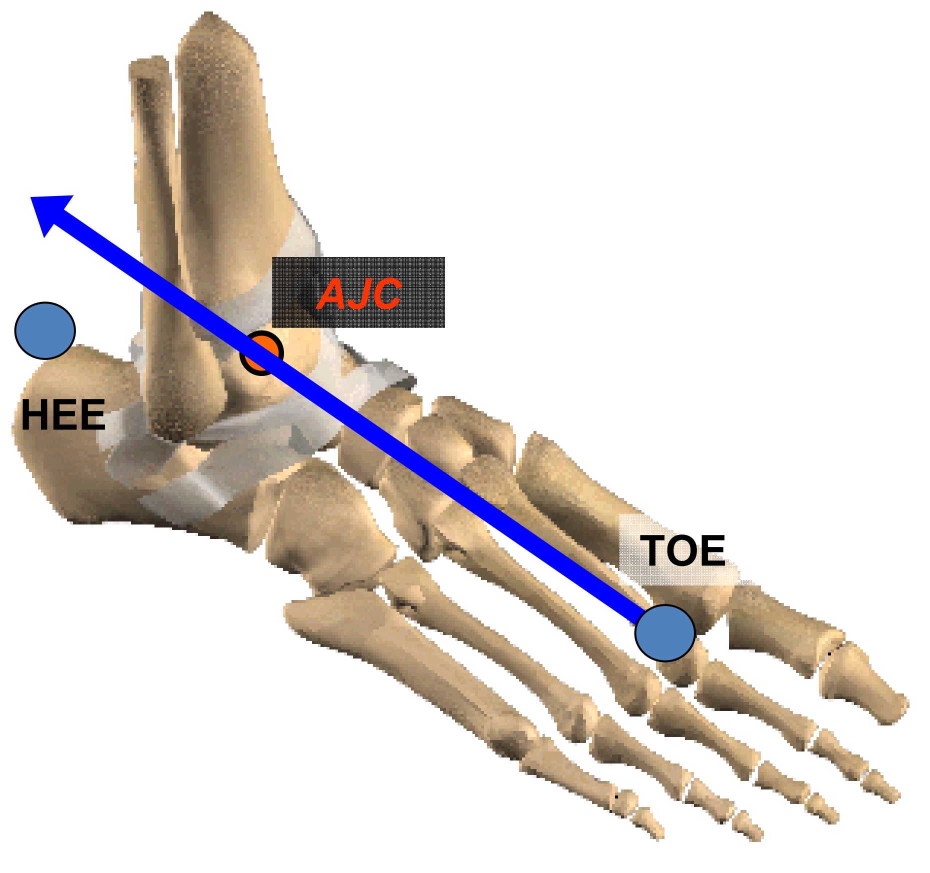

FOOT ANATOMICAL REFERENCE SYSTEM - WORKFLOW
Create foot segment
Static trial?
NO
YES
Foot flat option?
YES
NO
Sole Delta = 0?
YES
NO
virtual marker
RF(1) = AJC(1)
RF(2) = AJC(2)
RF(3) = TOE(3)
virtual marker
RF(1) = AJC(1)
RF(2) = AJC(2)
RF(3) = TOE(3) + SoleDelta
Use RF to create Static foot reference
Create static reference foot segment
Use HEE to create Static foot reference
Plantar-Flexion and Rotation Offsets calculation

FOOT ANATOMICAL REFERENCE SYSTEM - WORKFLOW



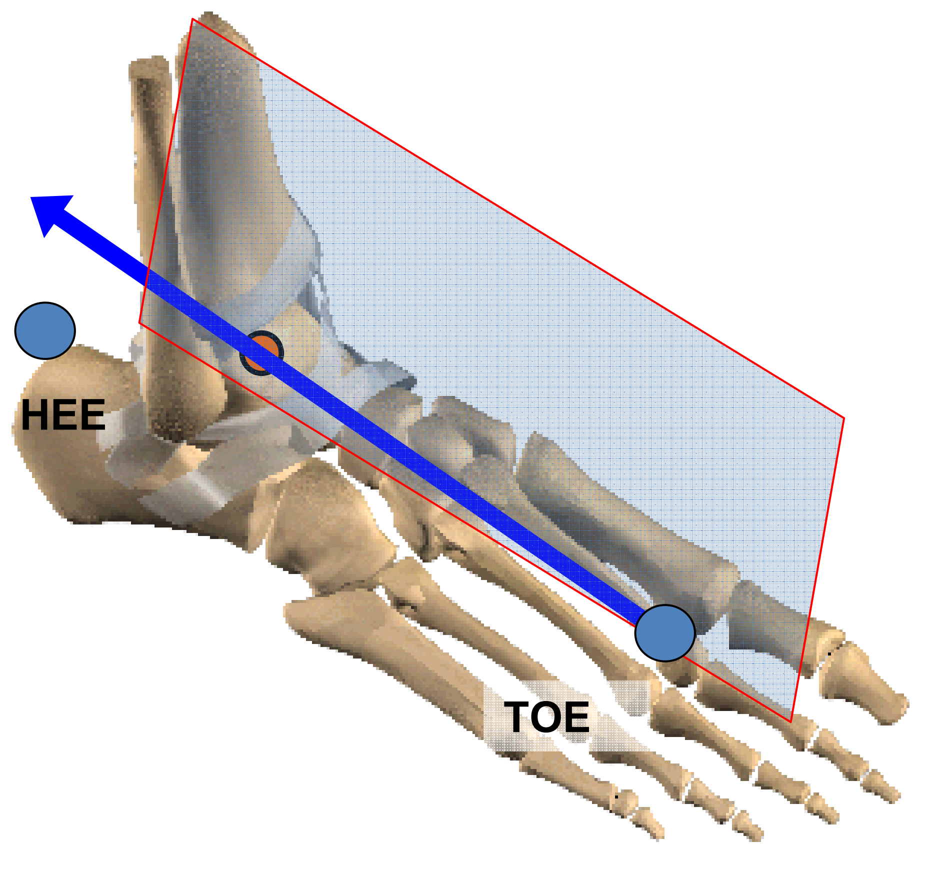
FOOT UNCORRECTED ANATOMICAL REFERENCE SYSTEM

- Origin: *TOE*
- Z Axis direction: *TOE* → *AJC*



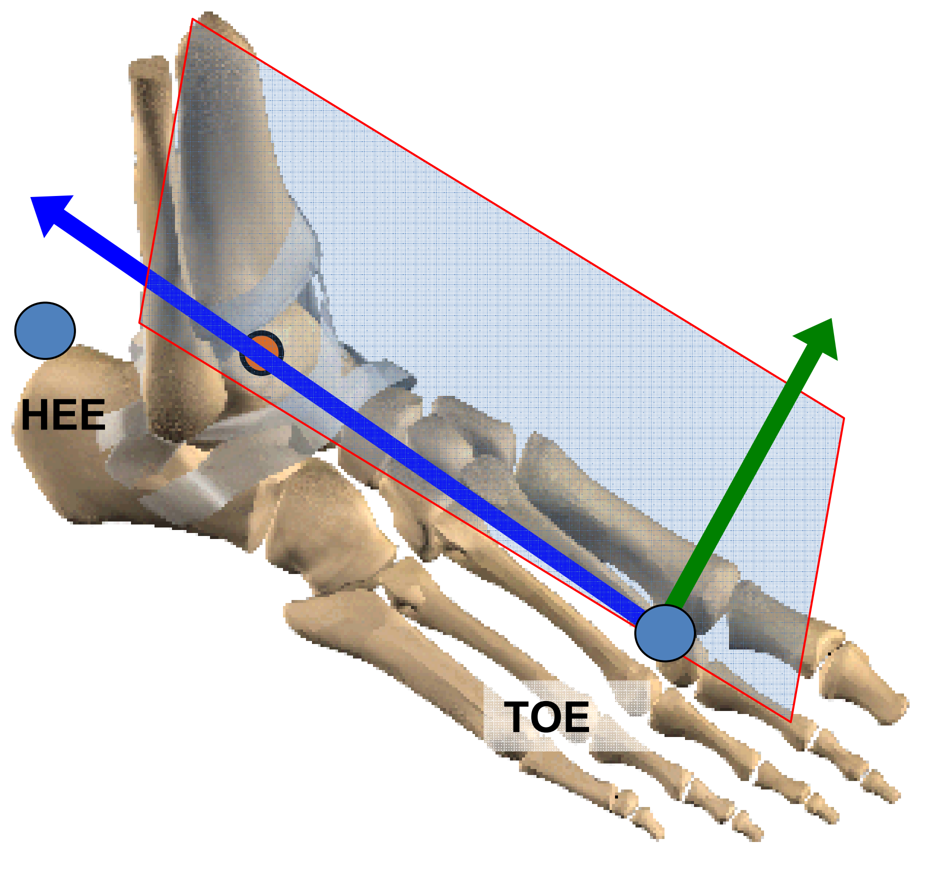
FOOT UNCORRECTED ANATOMICAL REFERENCE SYSTEM

- Origin: *TOE*
- Z Axis direction: *TOE → AJC*
- Y axis direction: perpendicular to the plane formed by *TOE, AJC, KJC*



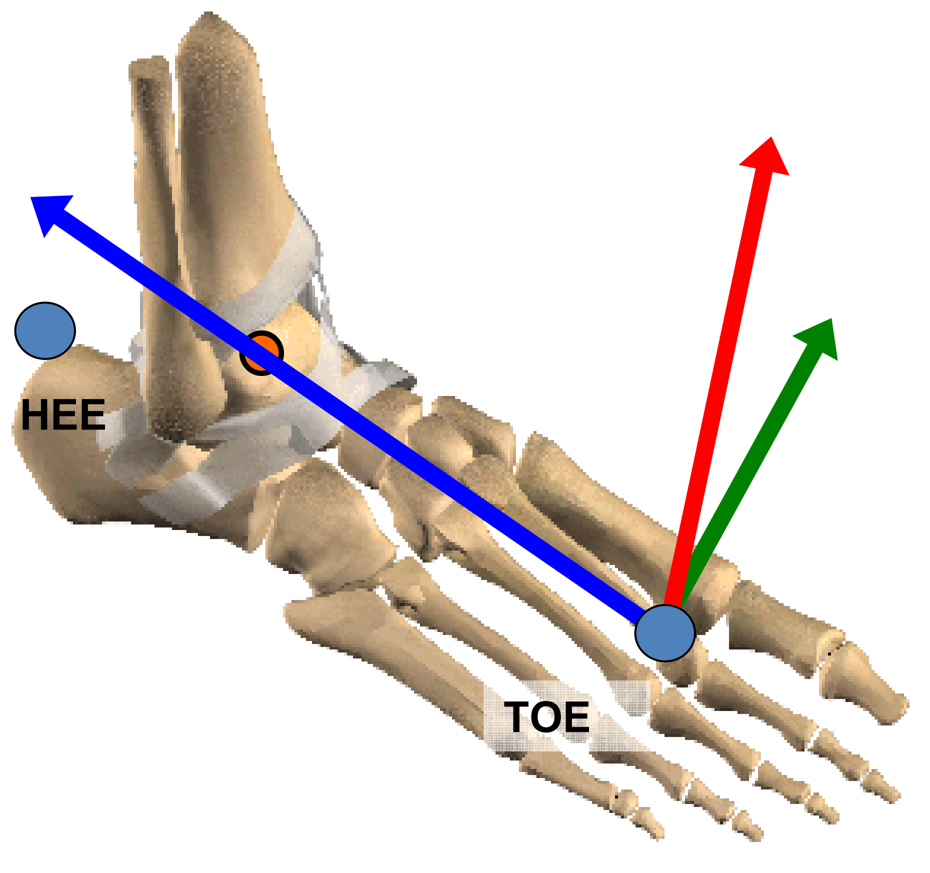
FOOT UNCORRECTED ANATOMICAL REFERENCE SYSTEM

- Origin: *TOE*
- Z Axis direction: *TOE → AJC*
- Y axis direction: perpendicular to the plane formed by *TOE, AJC, KJC*

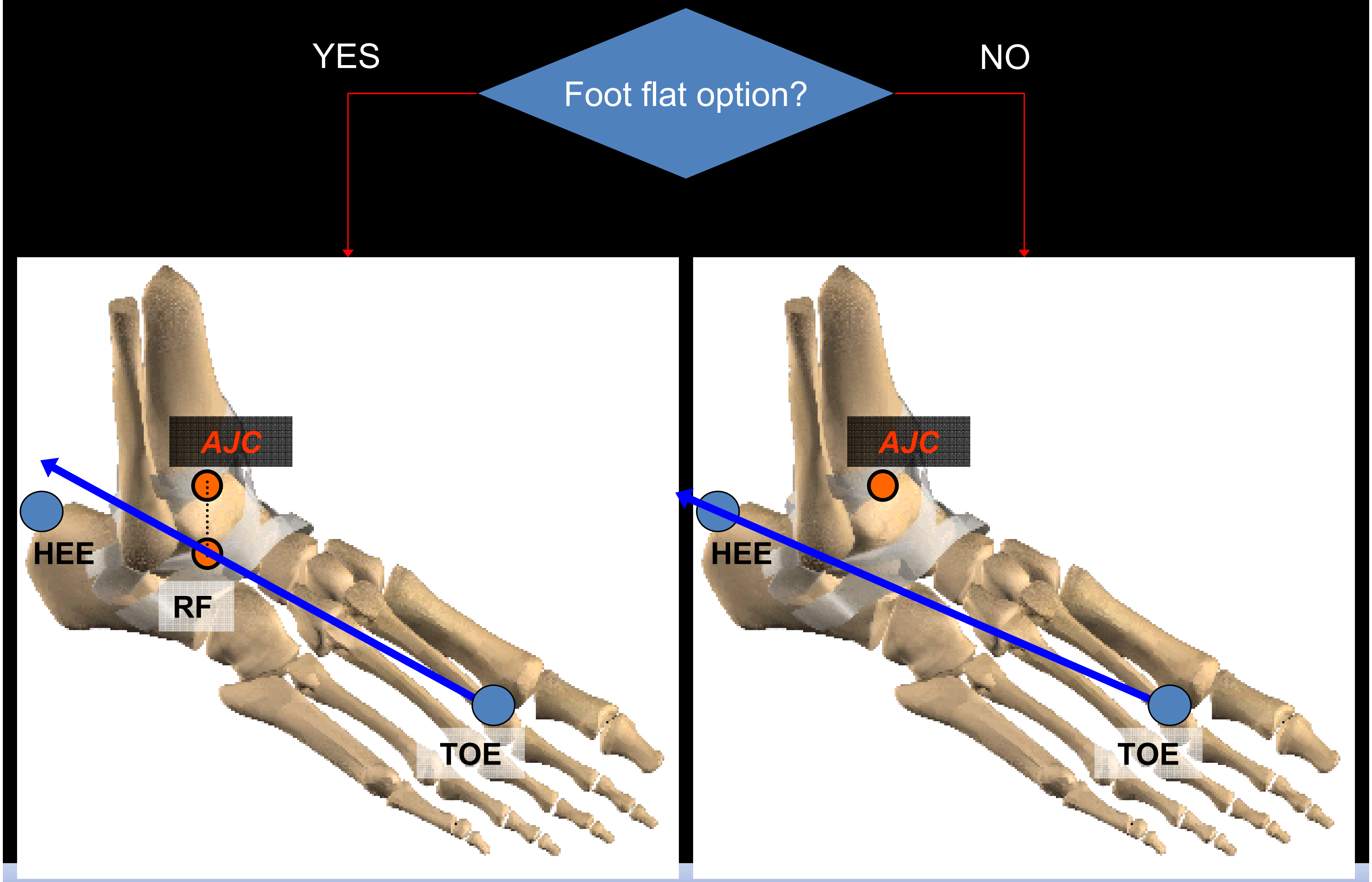


FOOT UNCORRECTED ANATOMICAL REFERENCE SYSTEM

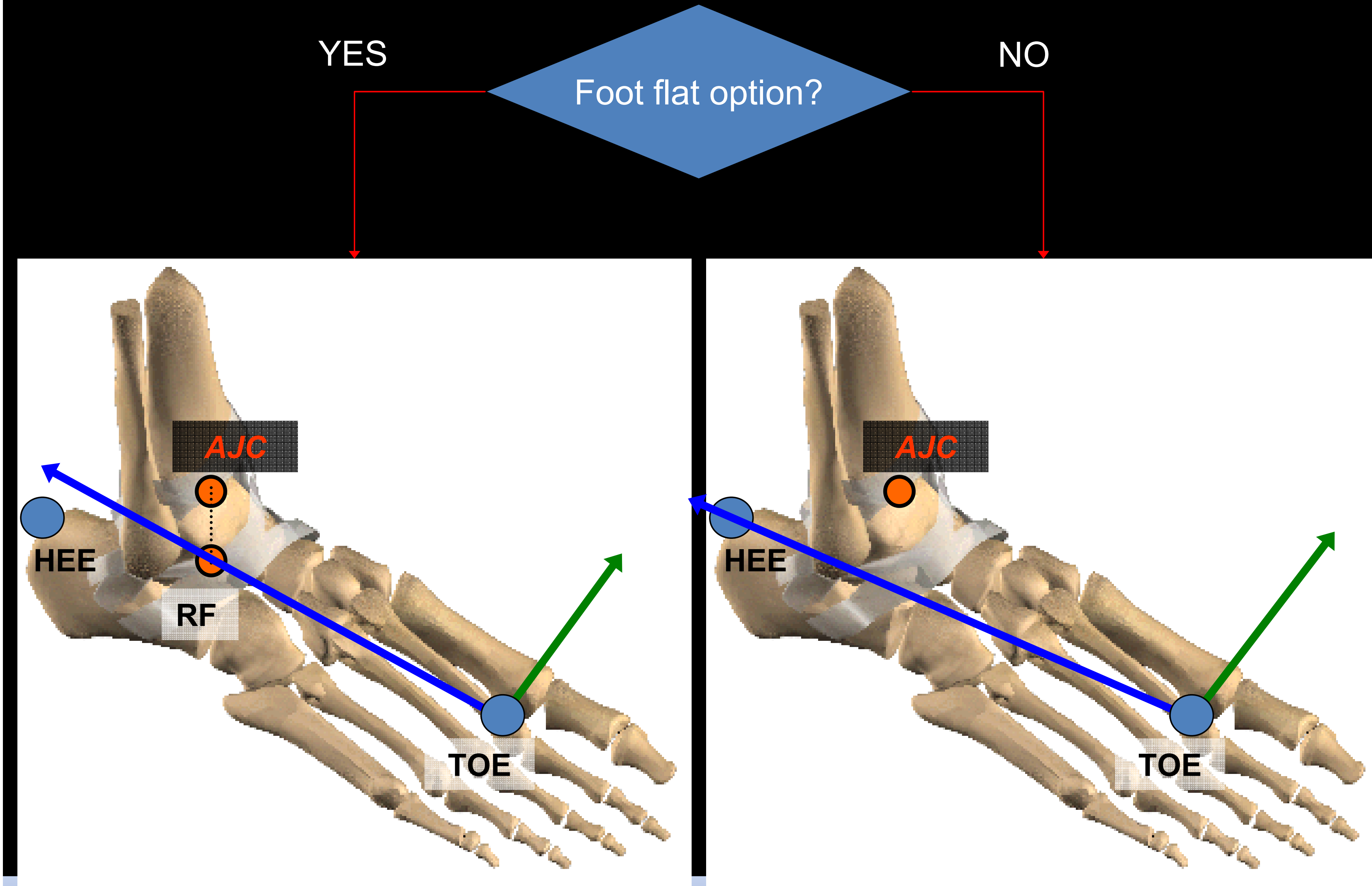
- Origin: *TOE*
- Z Axis direction: *TOE → AJC*
- Y axis direction: perpendicular to the plane formed by *TOE, AJC, KJC*
- X axis direction: cross product between Y and Z unit vectors



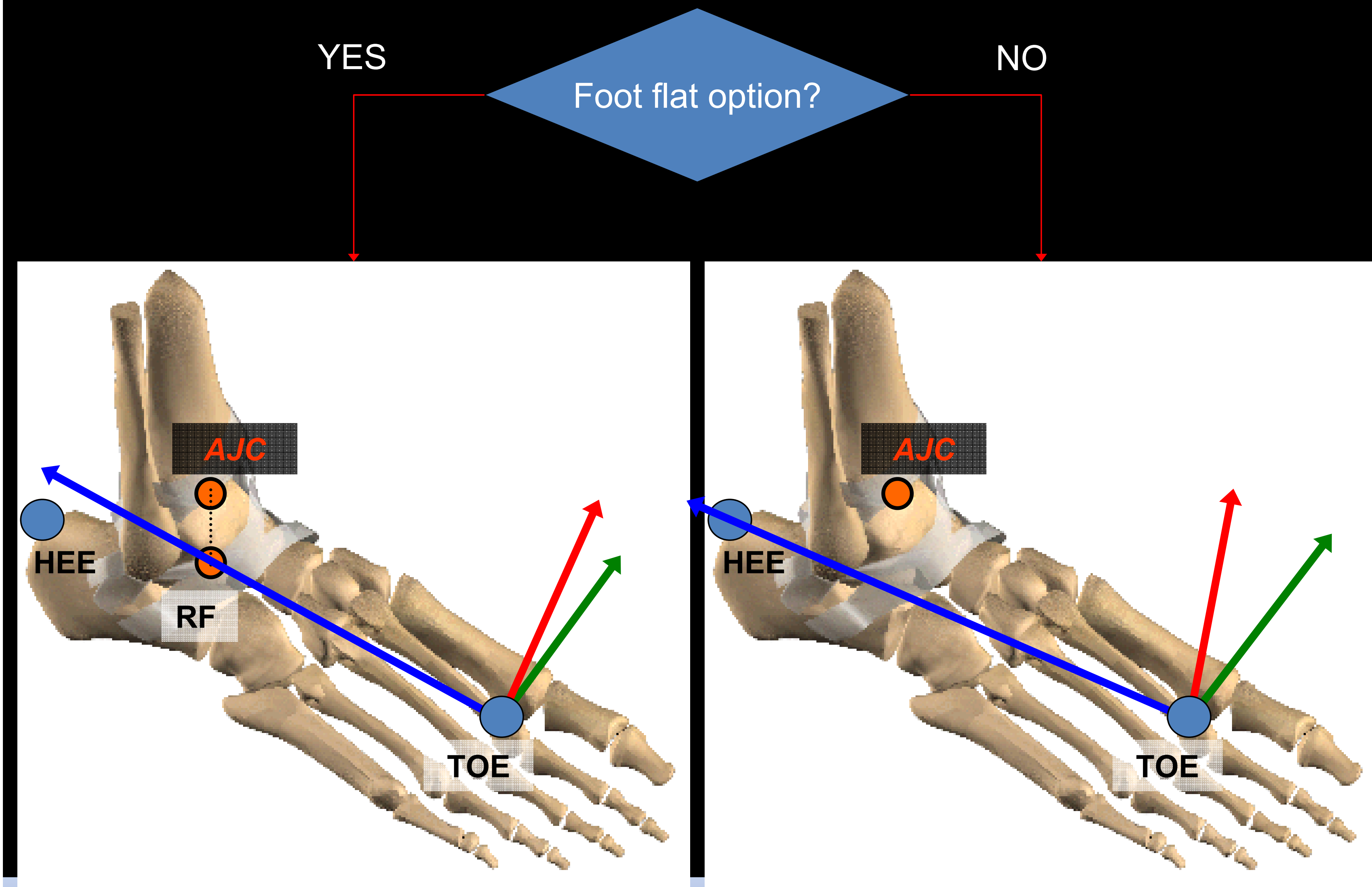
FOOT STATIC REFERENCE



FOOT STATIC REFERENCE



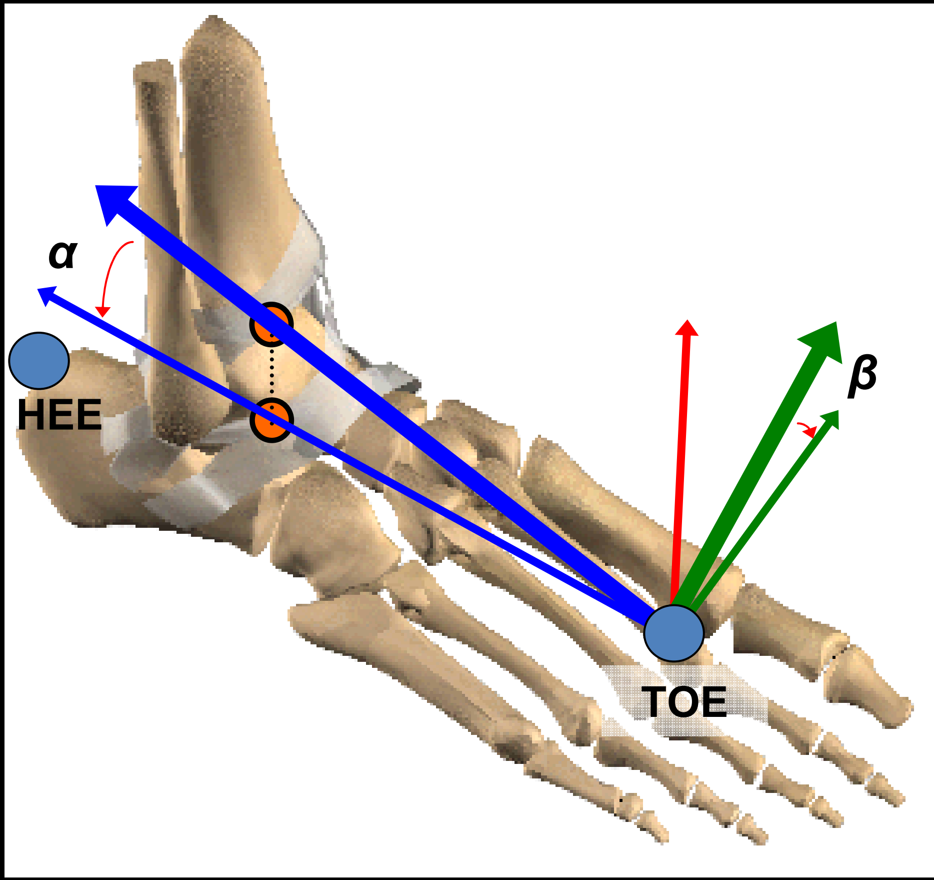
FOOT STATIC REFERENCE



For dynamic trials, the static offsets are applied to the foot anatomical reference:

α : Static Plantar-Flexion Offset

β : Static Rotation Offset



FOOT SUMMARY

- <u>Markers</u>
  - *HEE, TOE*

- <u>Anatomical reference definition</u>
  - Origin: *TOE*
  - Z Axis direction: *TOE* → *AJC*
  - Y axis direction: perpendicular to the plane formed by *TOE, AJC, KJC*
  - X axis direction: cross product between Y and Z unit vectors

- <u>If the trial is static, foot static reference definition</u>
  - Depends on foot flat option
  - Depends on the Sole Delta measurement
  - Plantar-Flexion and Rotation Offset calculation

- <u>If the trial is dynamic, the Plantar-Flexion and Rotation offsets are applied to the foot anatomical reference</u>

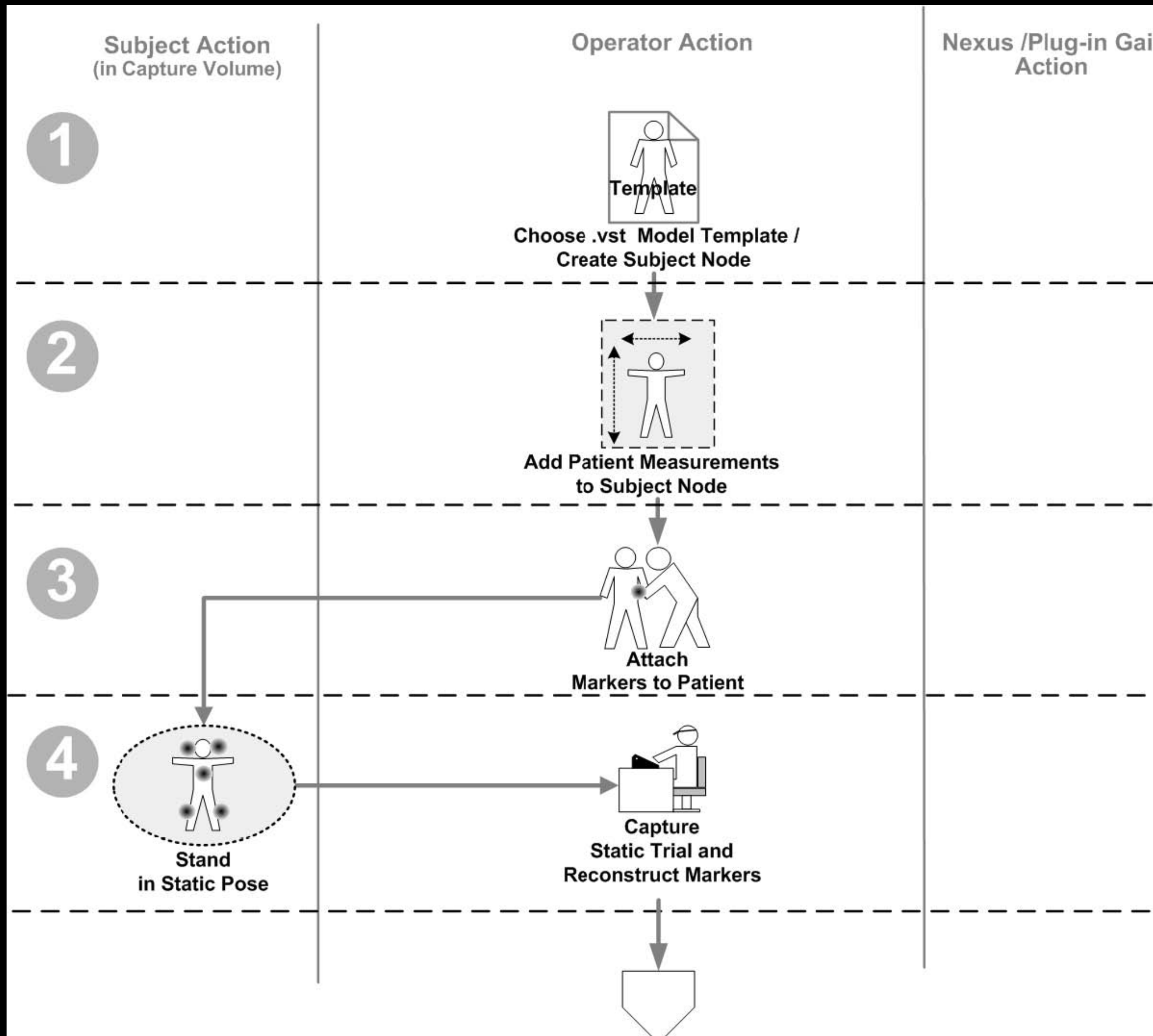
REFERENCES

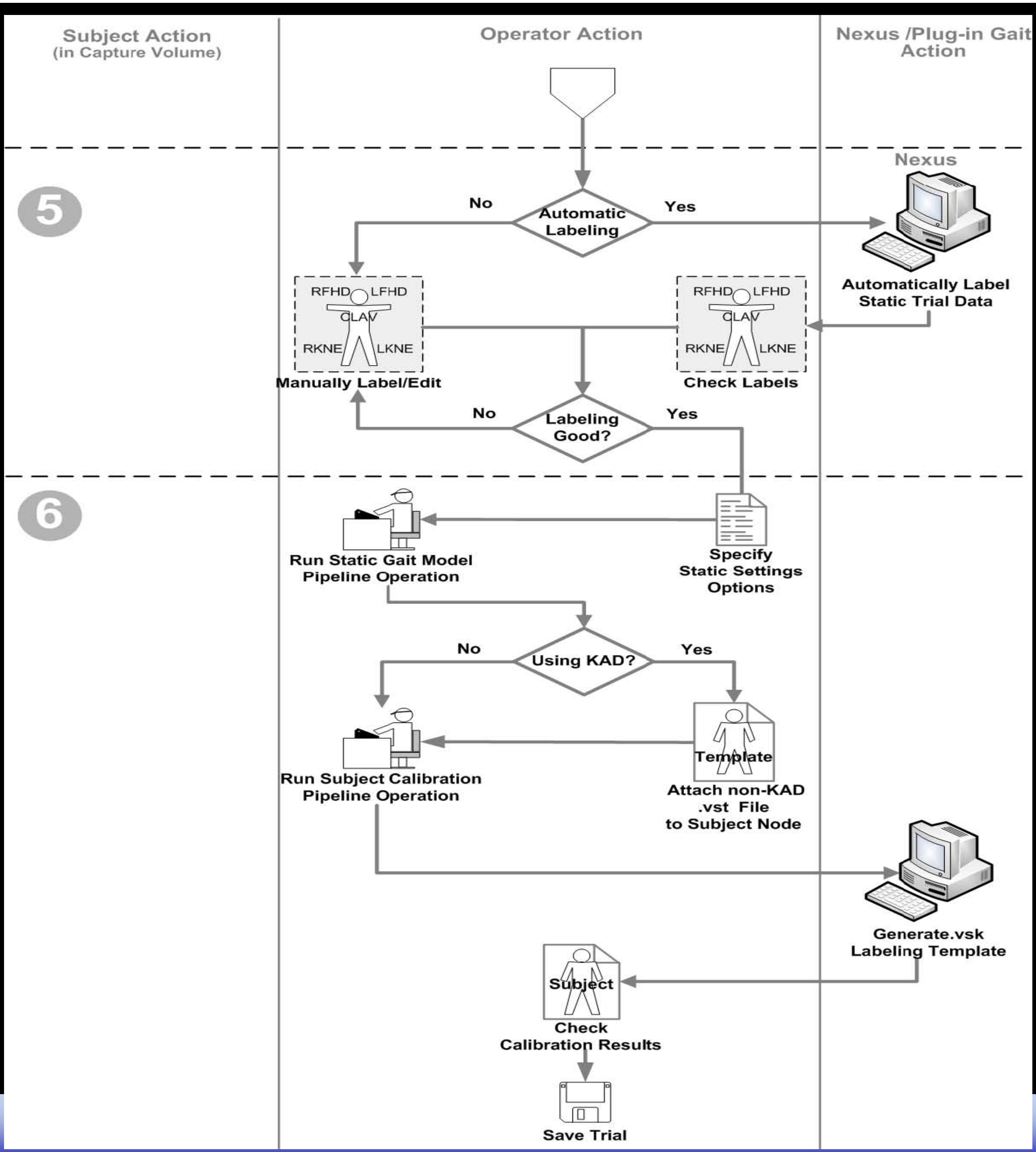
Kadaba, M.P., Ramakrishnan, H.K., Wootten, M.E, Gainey, J., Gorton, G. & Cochran, G.V.B (1989). *Repeatability of kinematic, kinetics and electromyographic data in normal adult gait*. Journal of Orthopaedic Research, 7, 849-860.

Kadaba, M.P., Ramakrishnan, H.K. & Wooten, M.E. (1990). *Lower extremity kinematics during level walking*. Journal of Orthopaedic Research, 8, 849-860.

Davis, R., Ounpuu, S., Tyburski, D. & Gage, J. (1991). *A gait analysis data collection and reduction technique*. Human Movement Sciences, 10, 575-587.

PLUG IN GAIT WORKFLOW




Subject Action
(in Capture Volume)
Operator Action
Nexus /Plug-in Gait Action
5
Nexus
No
Automatic Labeling
Yes
RFHD
LFHD
CLAV
RKNE
LKNE
Manually Label/Edit
Check Labels
Automatically Label Static Trial Data
No
Labeling Good?
Yes
6
Run Static Gait Model Pipeline Operation
Specify Static Settings Options
No
Using KAD?
Yes
Run Subject Calibration Pipeline Operation
Template
Attach non-KAD .vst File to Subject Node
Generate.vsk Labeling Template
Subject
Check Calibration Results
Save Trial