

Implementation of the Leardini Foot Model at Gillette Children's.

Foot Symposium

GCMAS Annual Meeting 2015.

- Tom Novacheck MD
- Sue Sohrweide PT



Objectives

- Introduce the multi-segment foot model used in the motion lab at GCSH
- Understanding sub-talar joint neutral (STJN) and how it is incorporated into our model
- Case study: here's how it works!
- Discussion





Available online at www.sciencedirect.com



Gait & Posture 25 (2007) 453–462



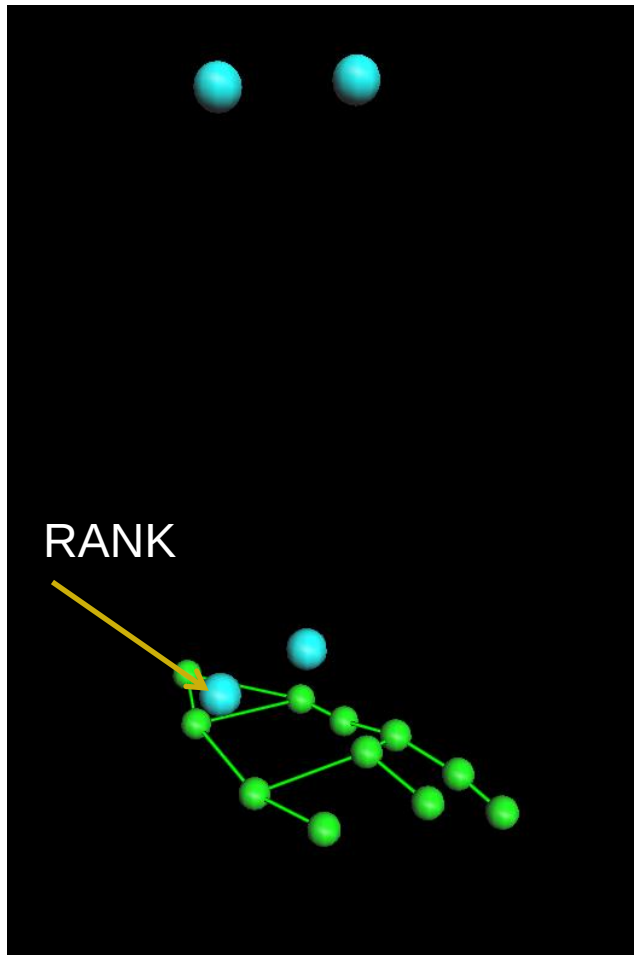
Rear-foot, mid-foot and fore-foot motion during the stance phase of gait

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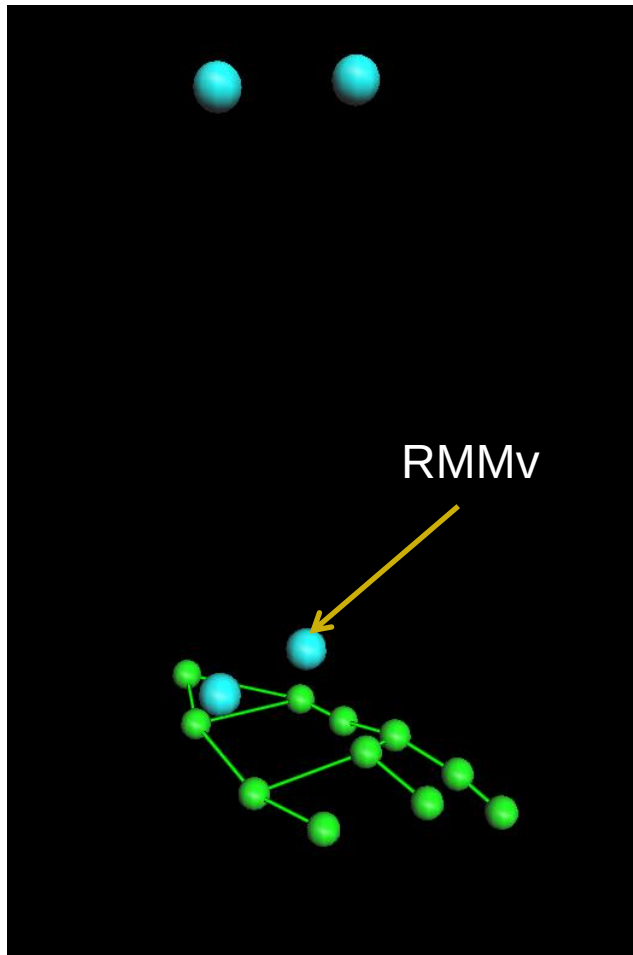
Model Review - Marker set



- Lateral Malleolus
- Virtual marker on distal apex of lateral malleolus
- Landmark is circled during VM trial



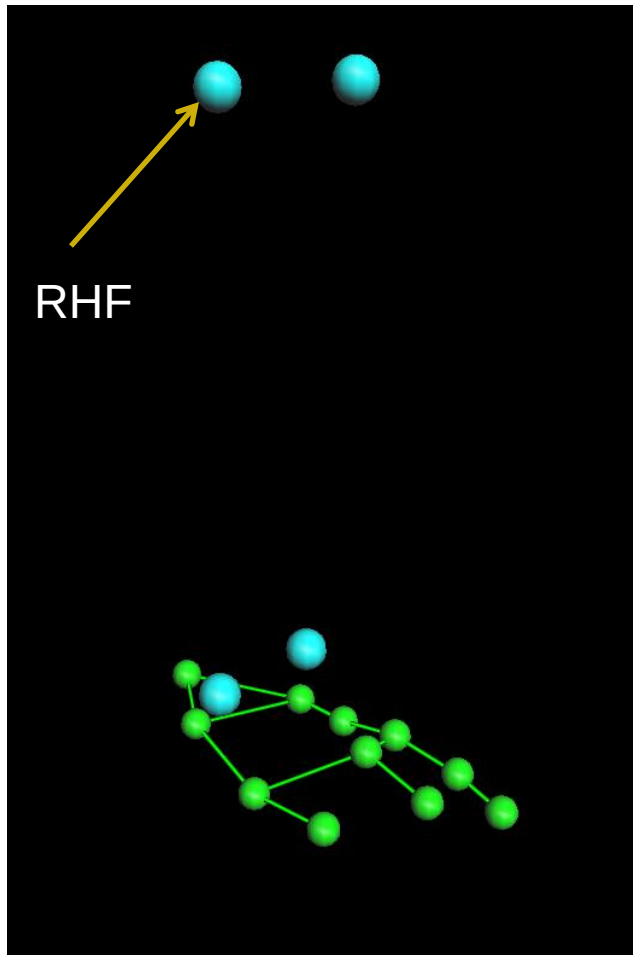
Model Review - Marker set



- Medial Malleolus
- Virtual marker on distal apex of medial malleolus
- Landmark is circled during VM trial



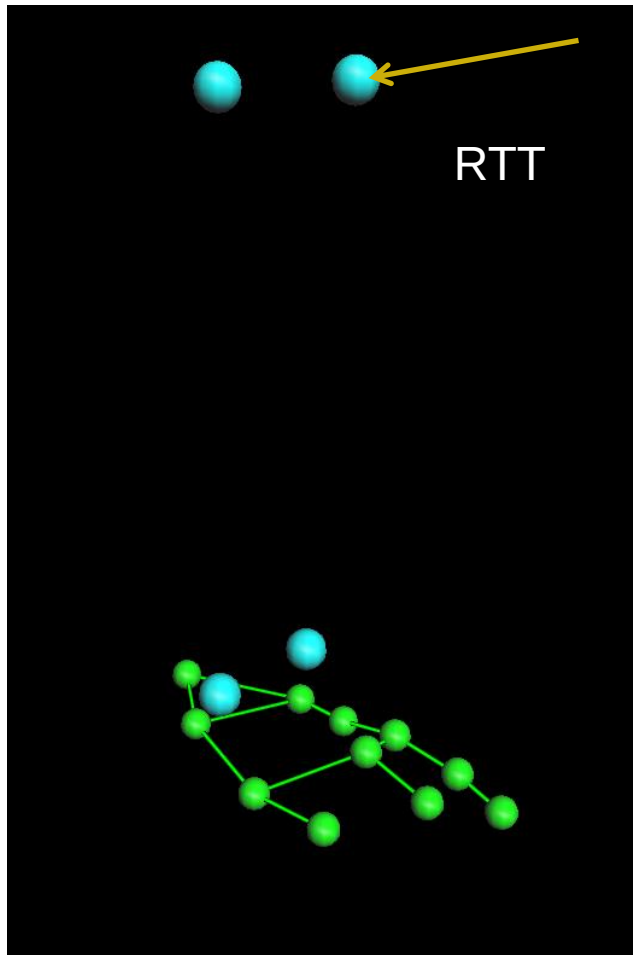
Model Review - Marker set



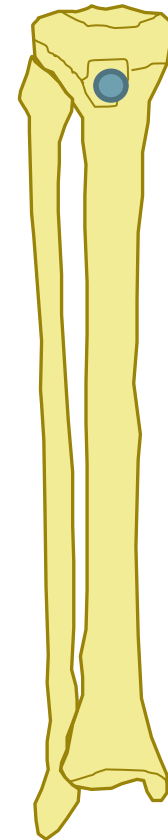
- Head of Fibula
- Virtual marker on most proximal apex of the head of the fibula
- Landmark is circled during VM trial



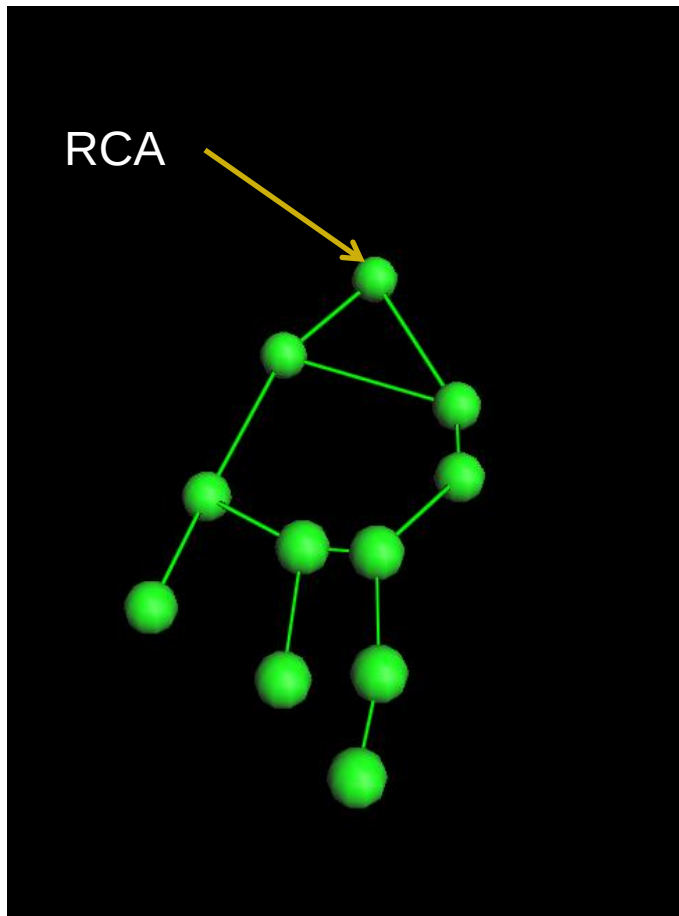
Model Review - Marker set



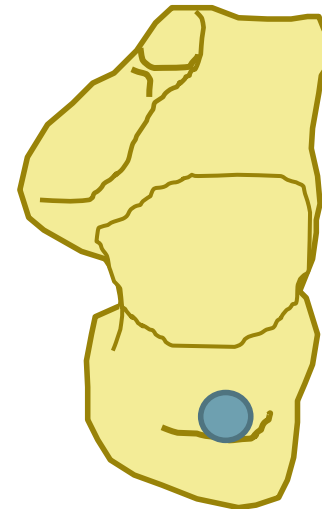
- Tibial Tuberosity
- Virtual marker placed on most anterior prominence of the tibial tuberosity
- Landmark is pointed to during VM trial



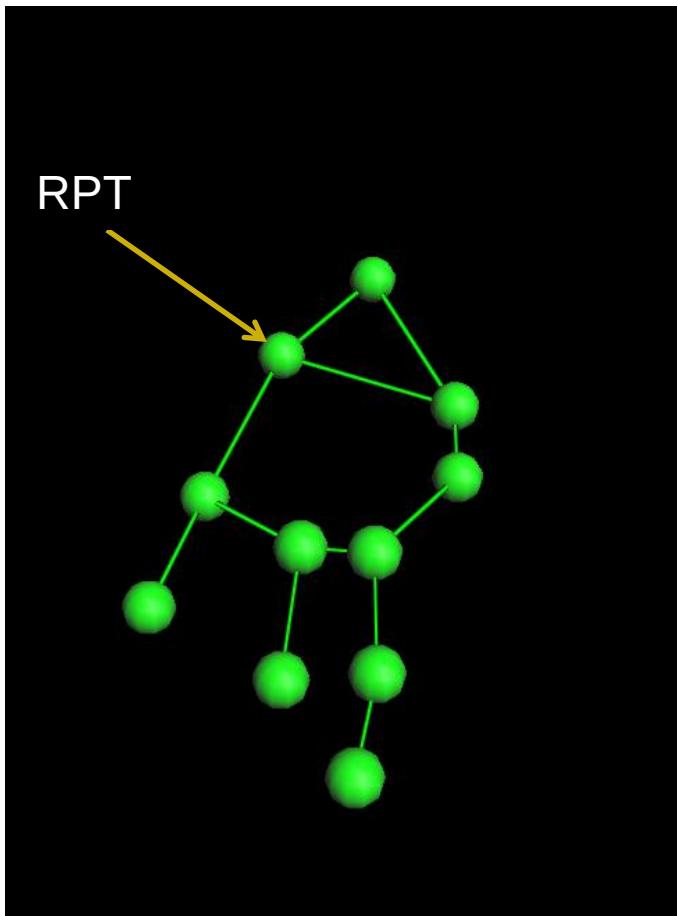
Model Review - Marker set



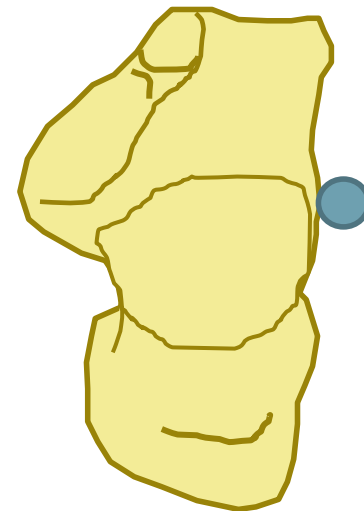
- Calcaneus
- Marker placed at Achilles' Tendon attachment
- Physical marker used



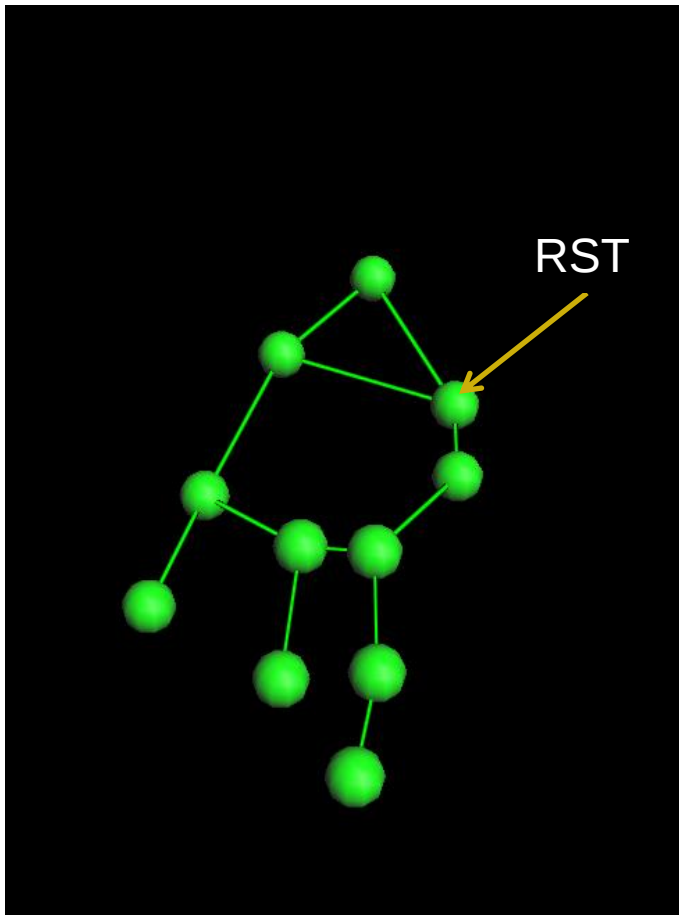
Model Review - Marker set



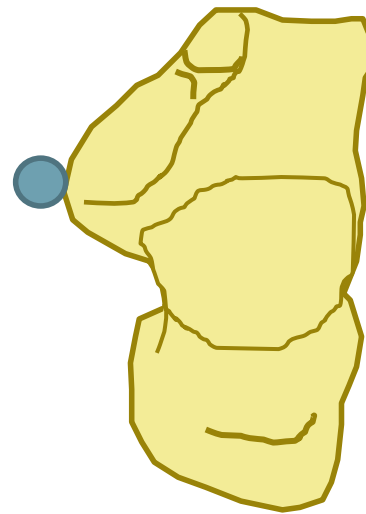
- Peroneal Tubercle
- Marker placed on at lateral apex of peroneal tubercle
- Physical marker used



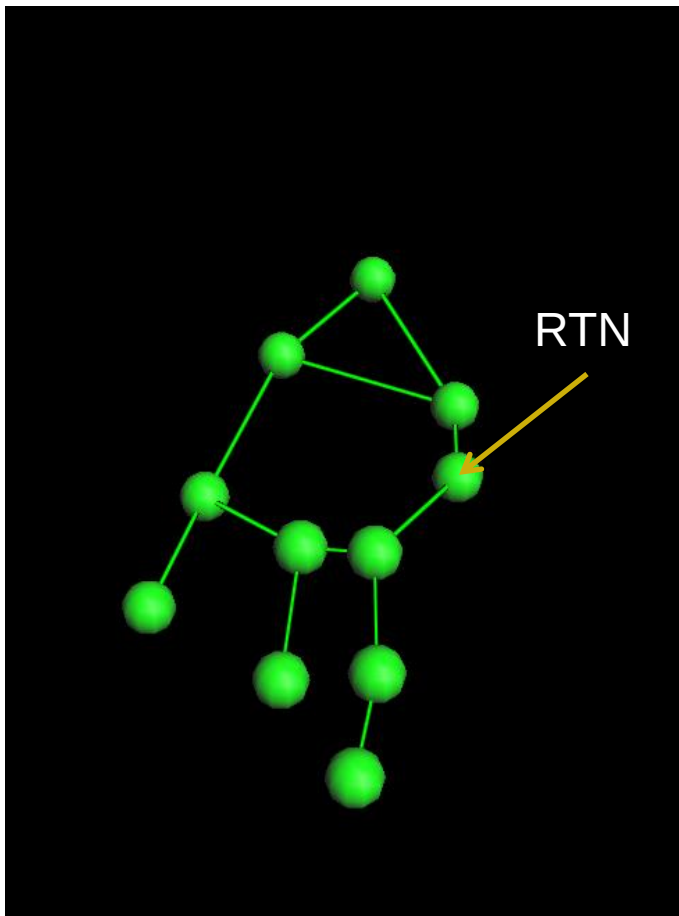
Model Review - Marker set



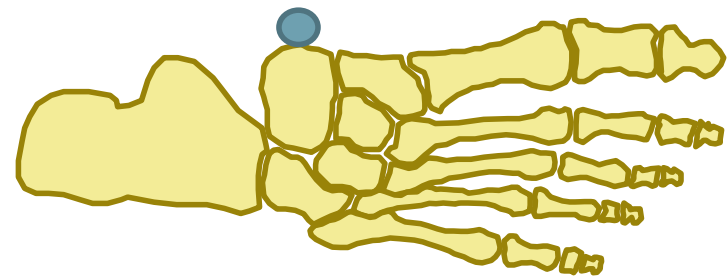
- Sustentaculum Tali
- Marker placed at most medial aspect of the sustentaculum tali
- Physical marker used



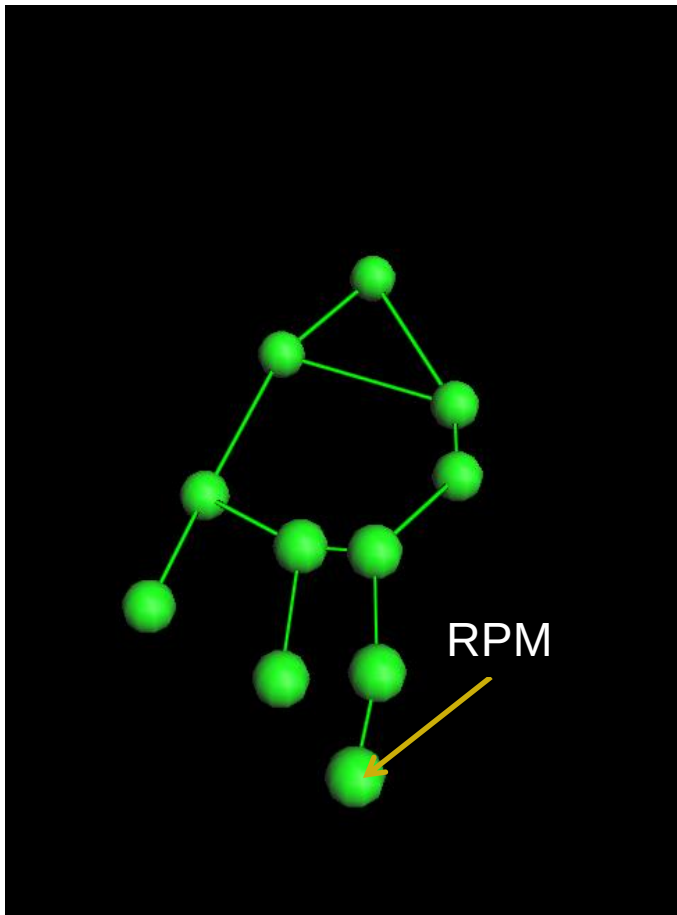
Model Review - Marker set



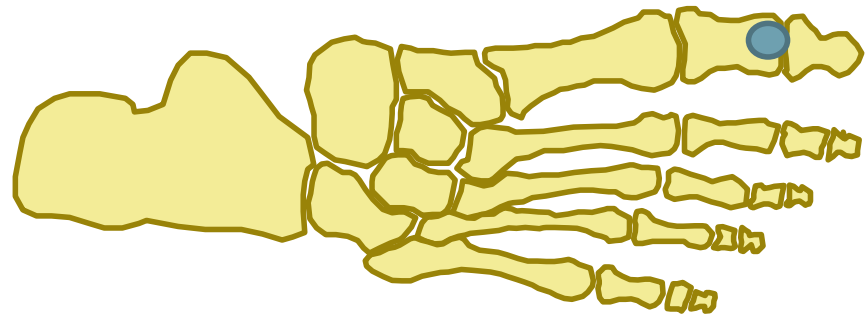
- Tuberosity of the Navicular
- Marker placed at most medial aspect of the tuberosity of the navicular
- Physical marker used



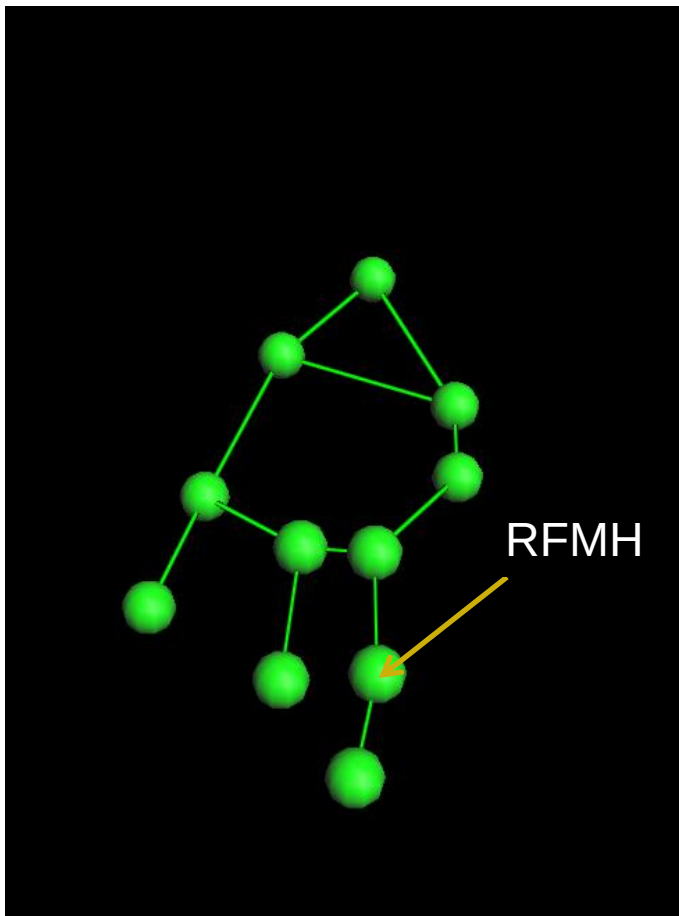
Model Review - Marker set



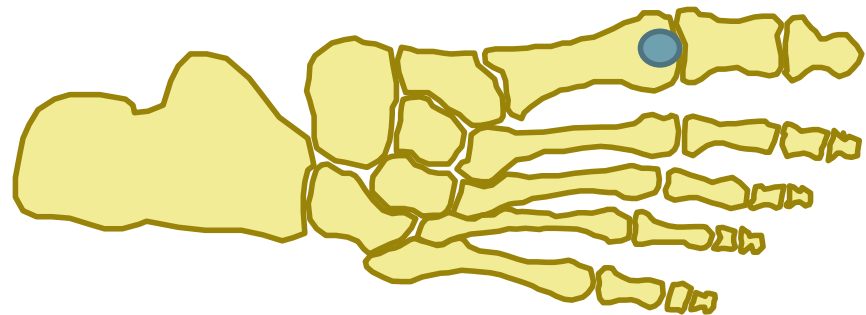
- Phalanx of the Hallux
- Marker placed at most distal and dorsal point of the head of the proximal phalanx of the hallux
- Physical marker used



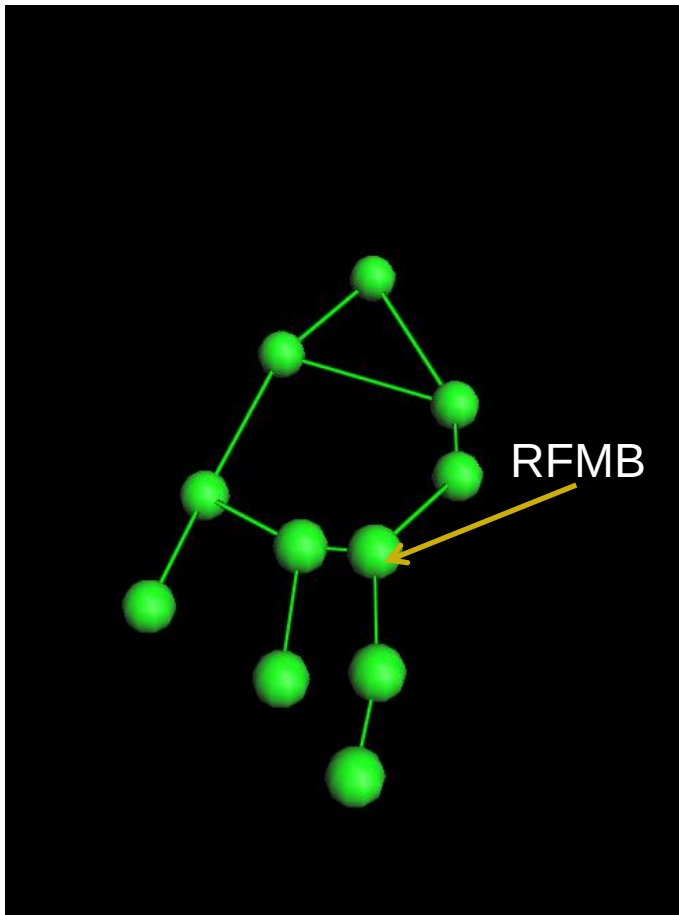
Model Review - Marker set



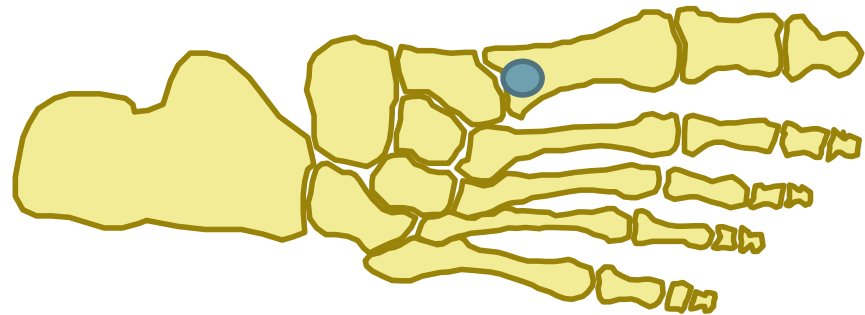
- 1st Metatarsal Head
- Marker placed on head of the 1st metatarsal, most dorsal aspect



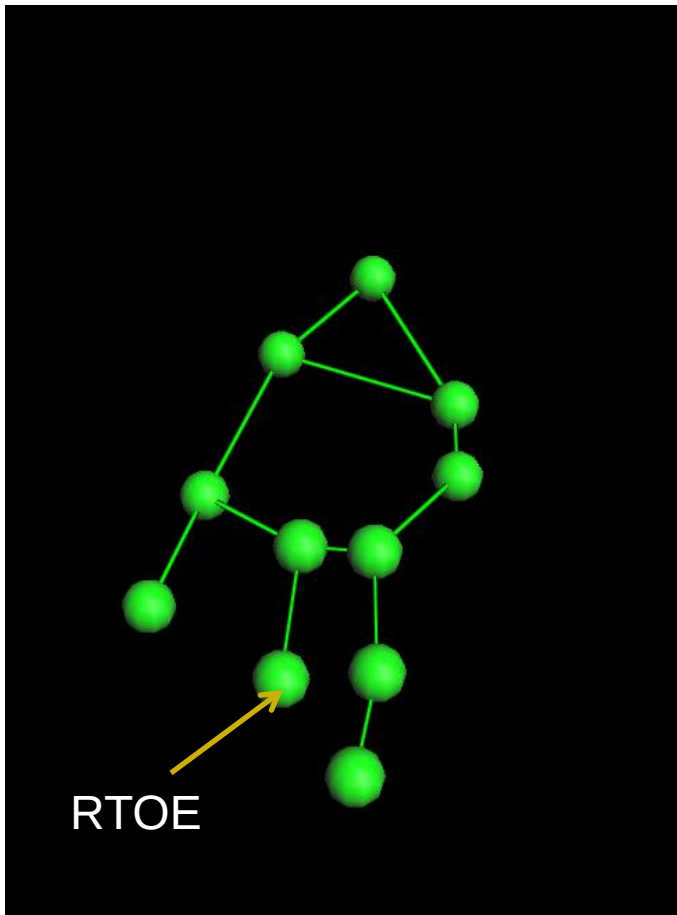
Model Review - Marker set



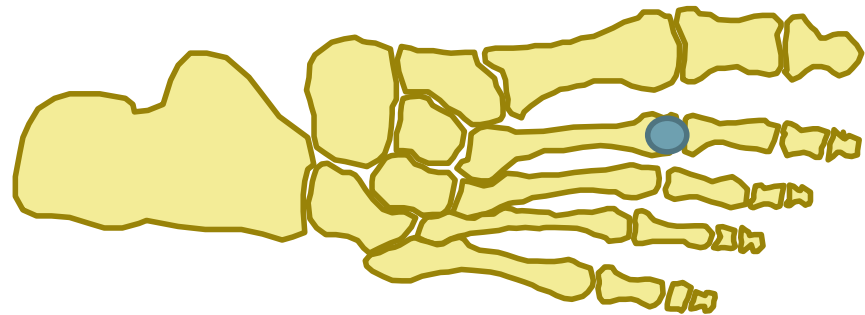
- Base of 1st Metatarsal
- Marker placed on base of the 1st metatarsal, most dorsal aspect



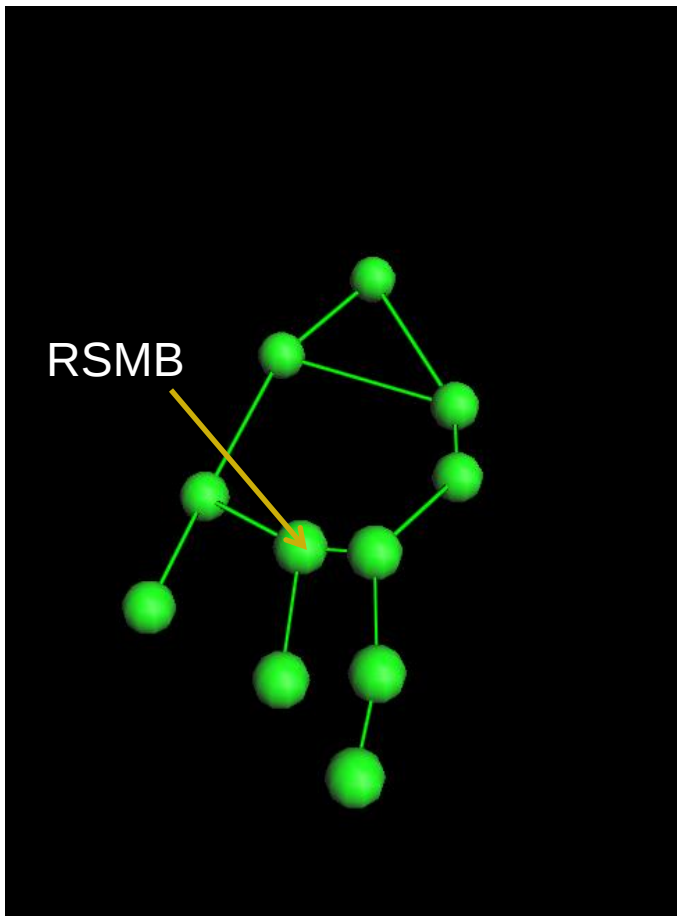
Model Review - Marker set



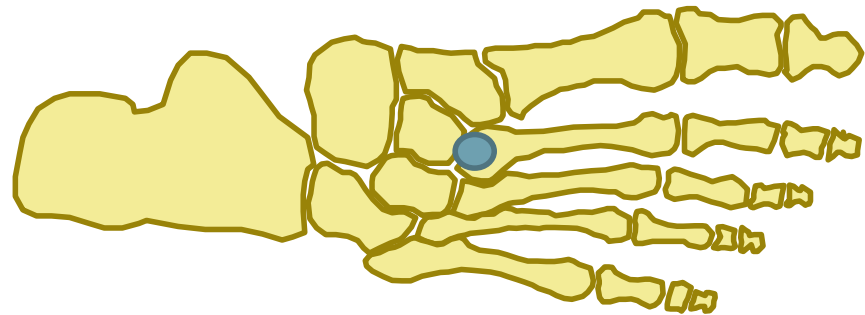
- Head of 2nd metatarsal
- Marker placed on dorsal aspect of the 2nd metatarsal head
- Physical marker used
- Doubles as “TOE” marker for standard model



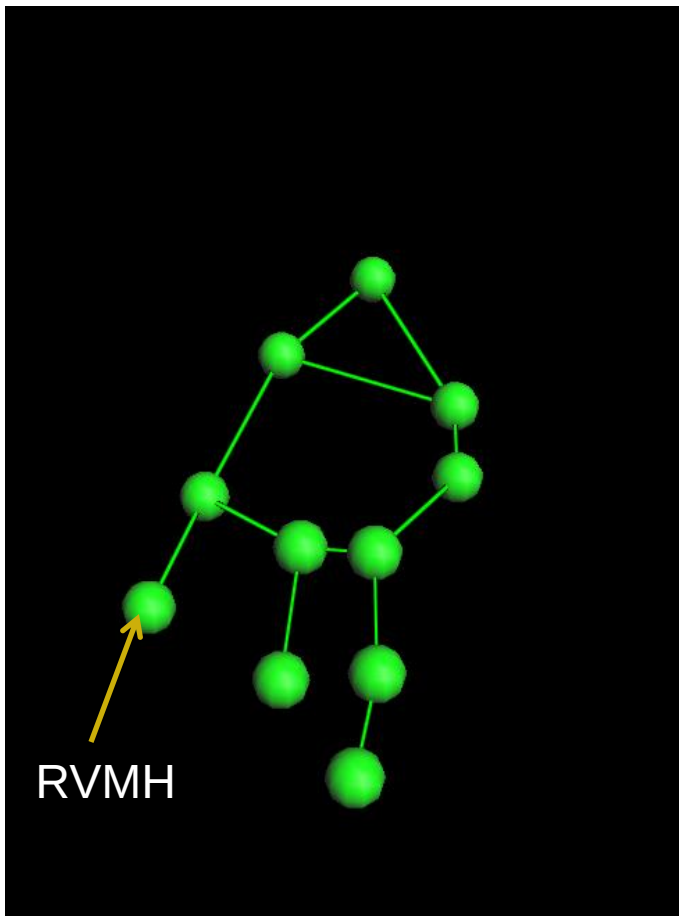
Model Review - Marker set



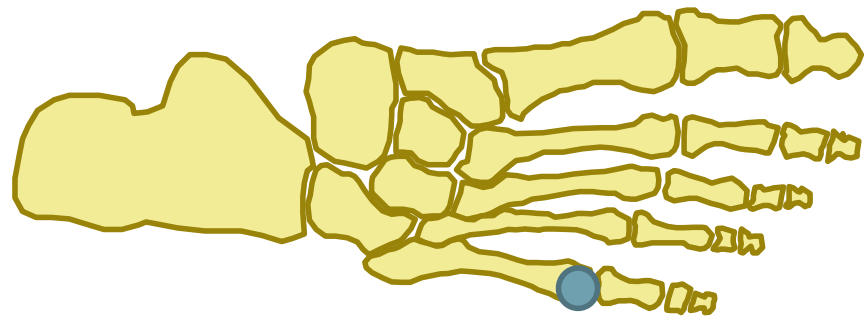
- Base of 2nd metatarsal
- Marker placed on base of the 2nd metatarsal, dorsal aspect of the 2nd metatarsal base
- Physical marker used



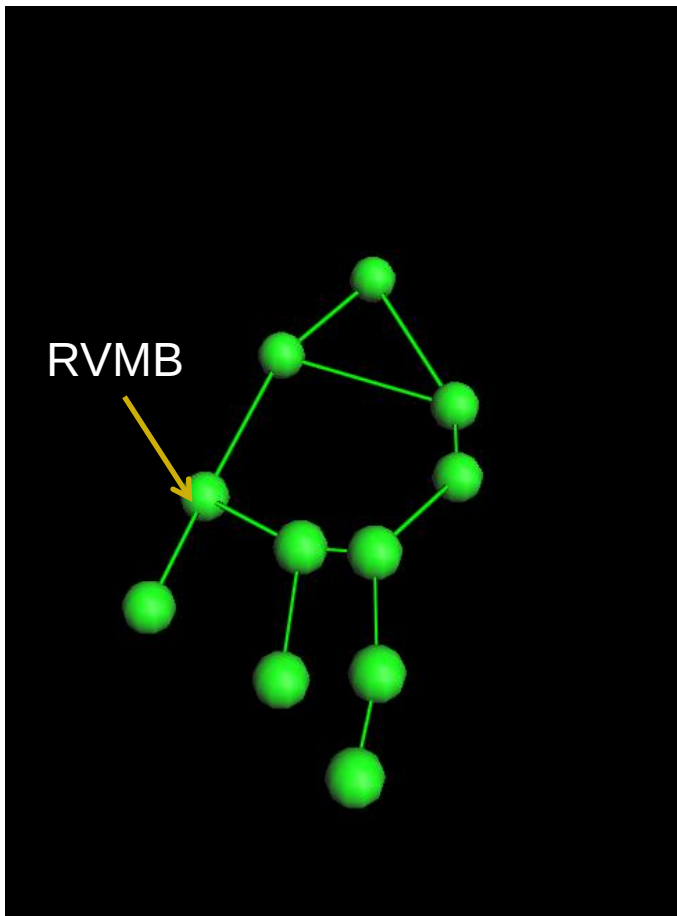
Model Review - Marker set



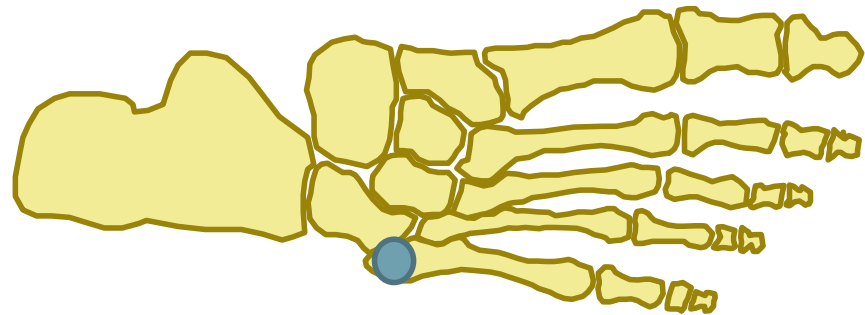
- Head of 5th metatarsal
- Marker placed on dorsal aspect of the 5th metatarsal head
- Physical marker used



Model Review - Marker set

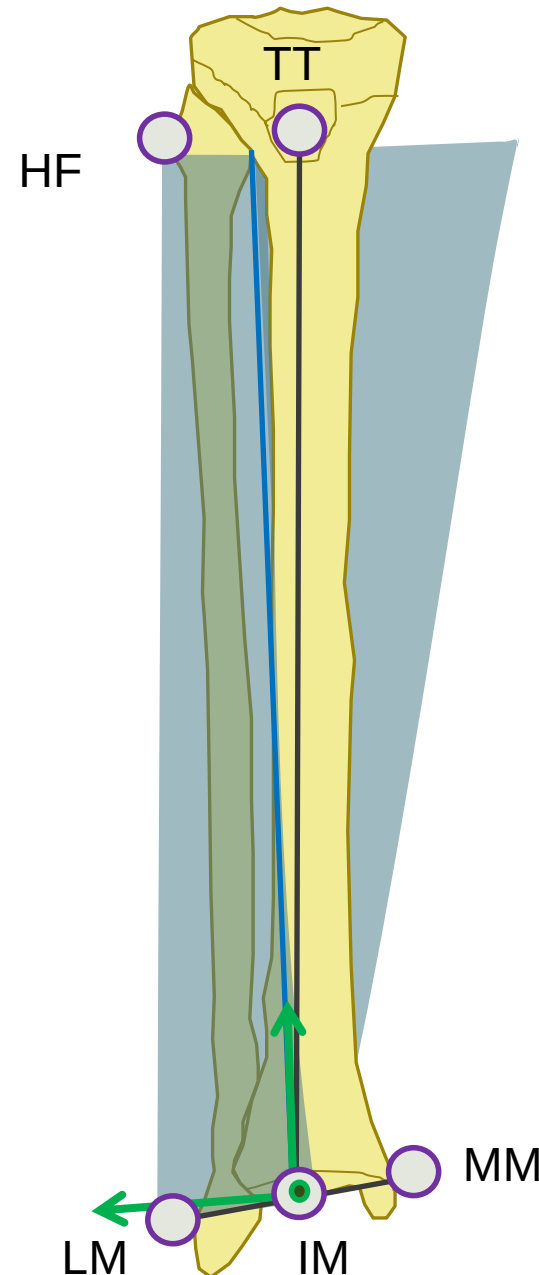


- Base of 5th metatarsal
- Marker placed on base of the 5th metatarsal, dorsal aspect of the 5th metatarsal base
- Physical marker used



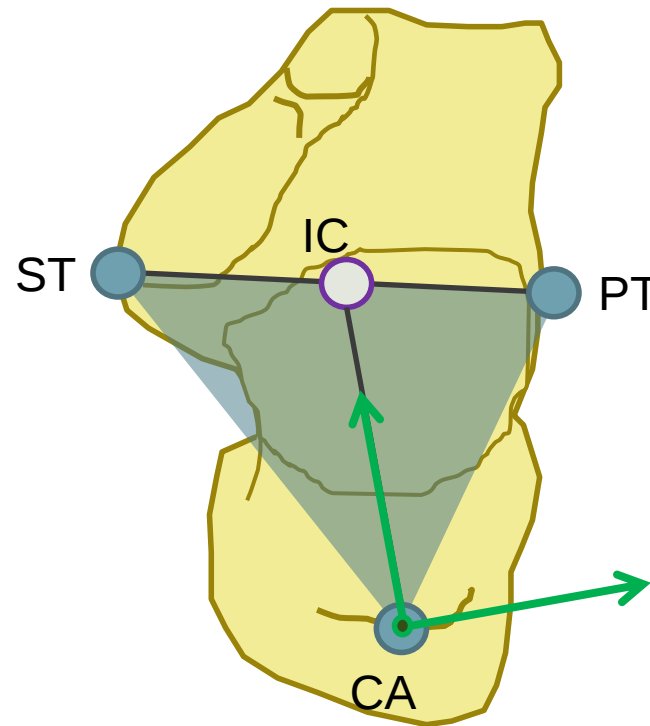
Model Review - Anatomic Reference Frames

- Shank
- IM is the point midway between MM & LM & is the origin
- LM, HF & IM lie in Frontal plane
- Y-axis is the projection of the line from IM to TT onto the frontal plane
- Z-axis is orthogonal to y-axis & lies in frontal plane.
- X-axis is orthogonal to the xz plane



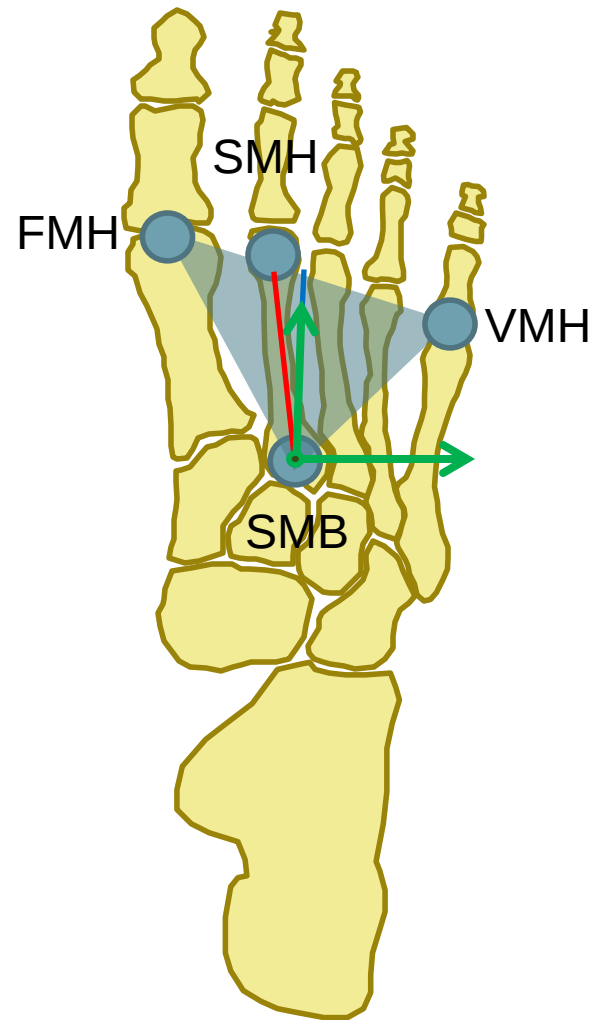
Model Review - Anatomic Reference Frames

- Calcaneus (Hind Foot)
- Origin at CA
- IC is midpoint between ST and PT
- X-axis from origin to IC
- Z-axis is perpendicular to x-axis & lies in transverse plane formed by CA, PT & ST
- Y-axis is orthogonal to the xz plane



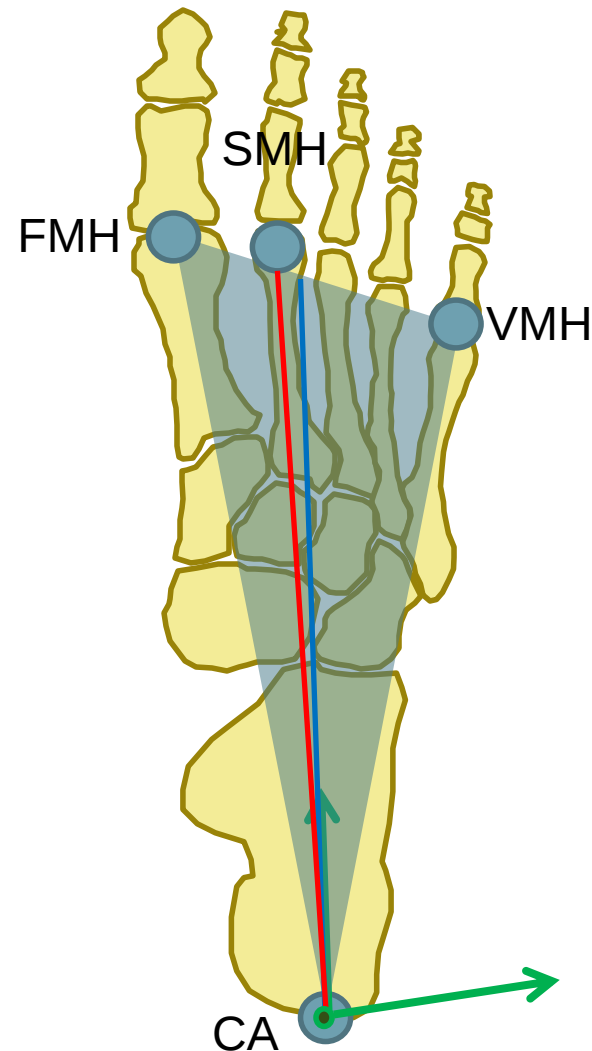
Model Review - Anatomic Reference Frames

- Metatarsus (Forefoot)
- Origin is at SMB
- Transverse plane formed by SMB, FMH & VMH
- X-axis is the projection of the line from the origin to SMH (TOE) onto the transverse plane
- Z-axis is orthogonal to the X-axis & lies in the transverse plane
- Y-axis is orthogonal to the xz plane



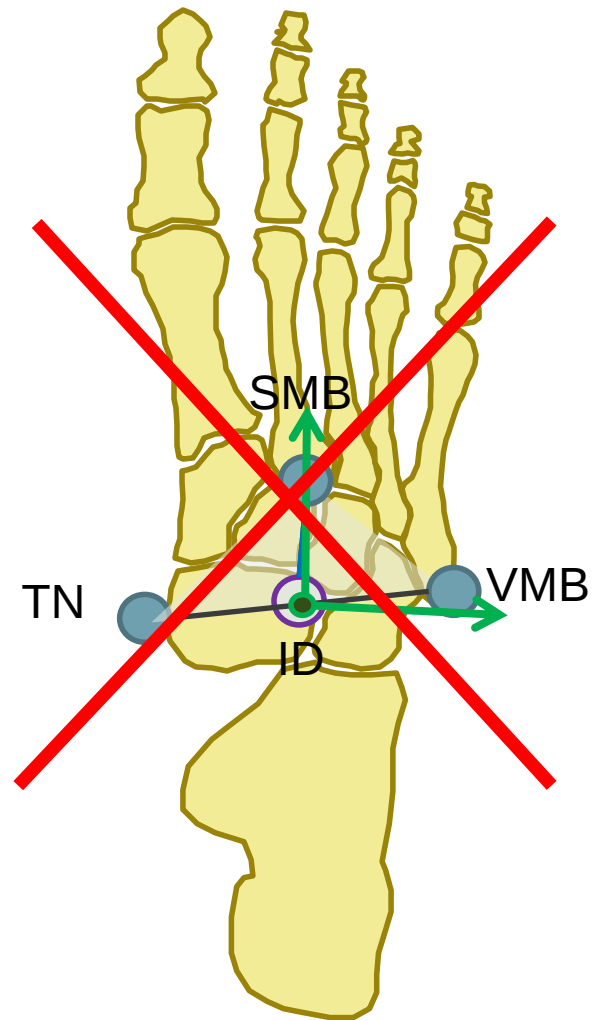
Model Review - Anatomic Reference Frames

- Single segment foot
- Origin is at CA
- Transverse plane formed by CA, FMH & VMH
- X-axis is the projection of the line from the origin to SMH onto the transverse plane
- Z-axis is orthogonal to the axis & lies in the transverse plane
- Y-axis is orthogonal to the xz plane

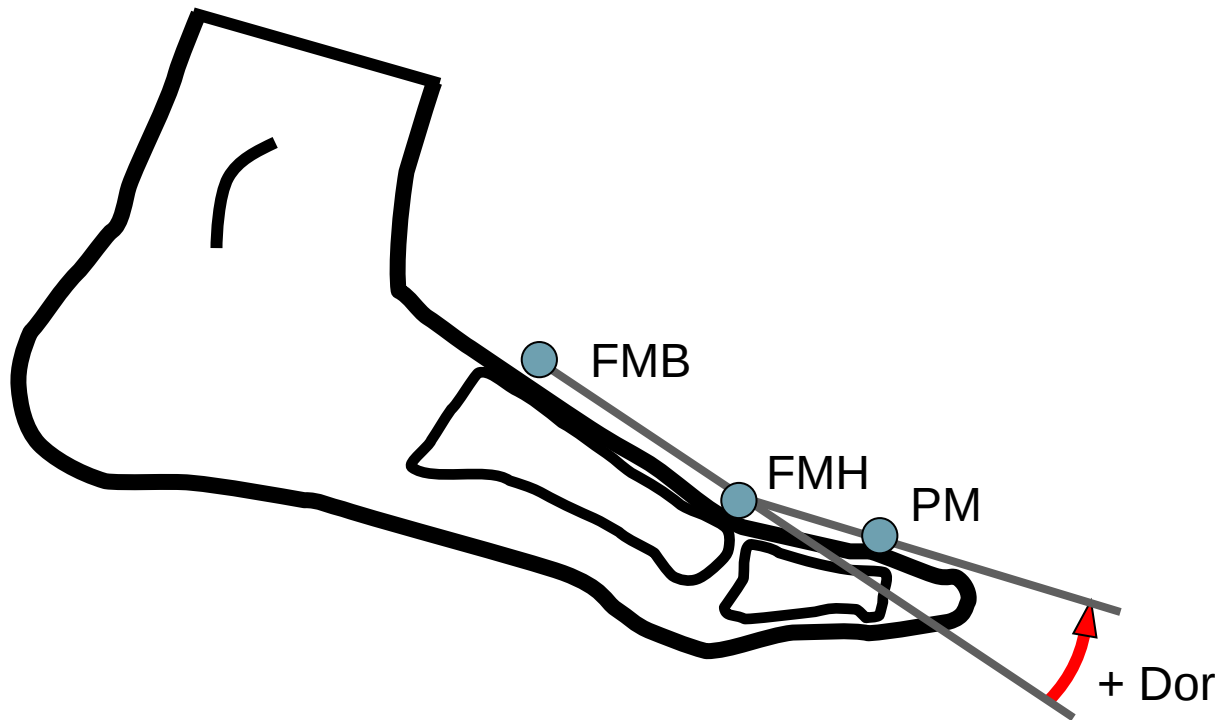


Model Review - Anatomic Reference Frames

- Midfoot
- Not used

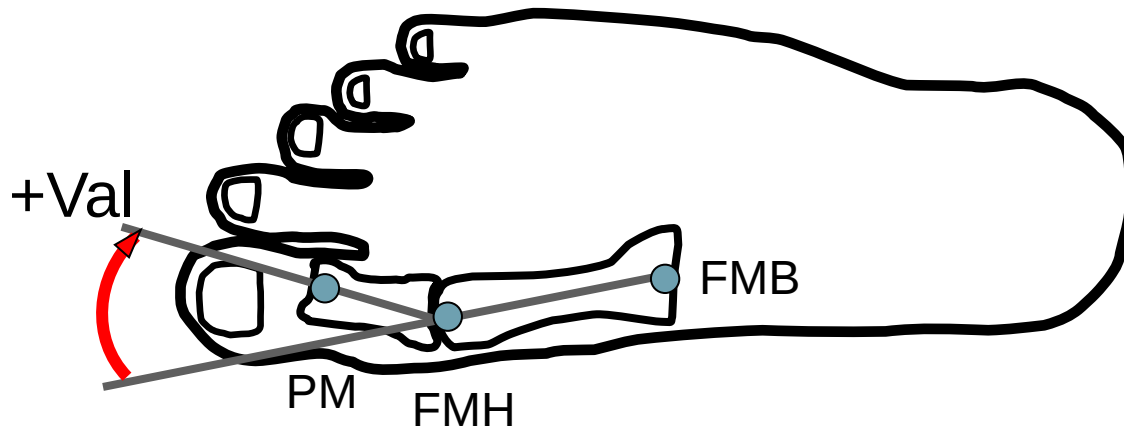


Projection Angles



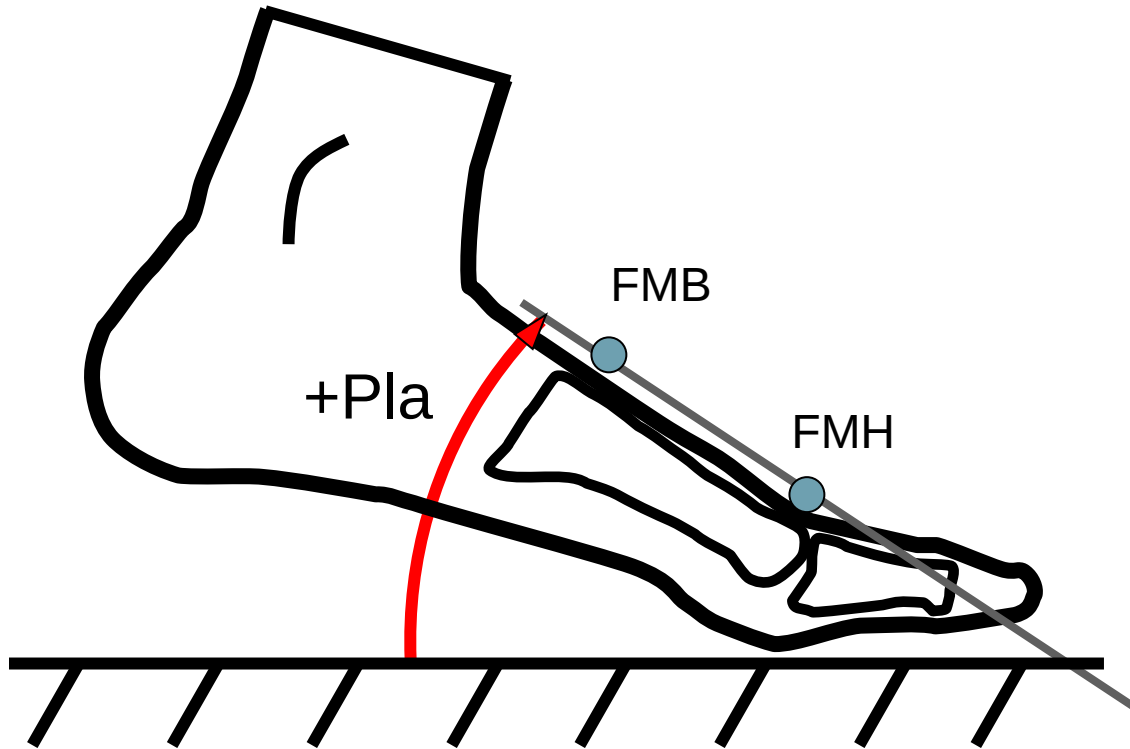
- Hallux to First Ray Sagittal Plane
- Angle between the projections of the line segments *FMH-PM* and *FMB-FMH* onto the sagittal plane of the metatarsus

Projection Angles



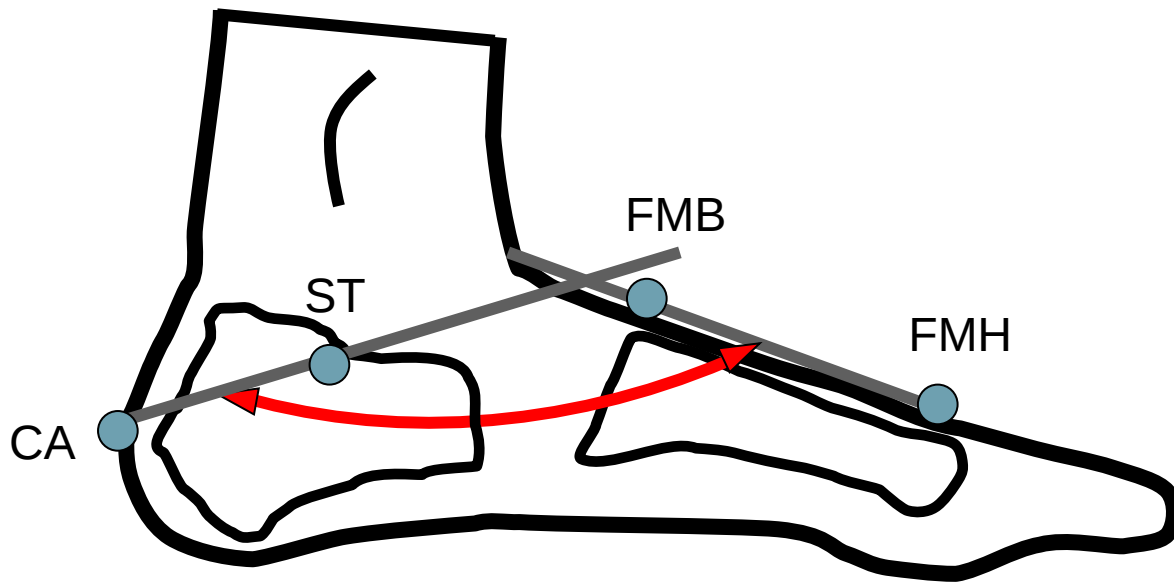
- Hallux to First Ray Transverse Plane
- Angle between the projections of the line segments *FMH-PM* and *FMB-FMH* onto the transverse plane of the metatarsus

Projection Angles



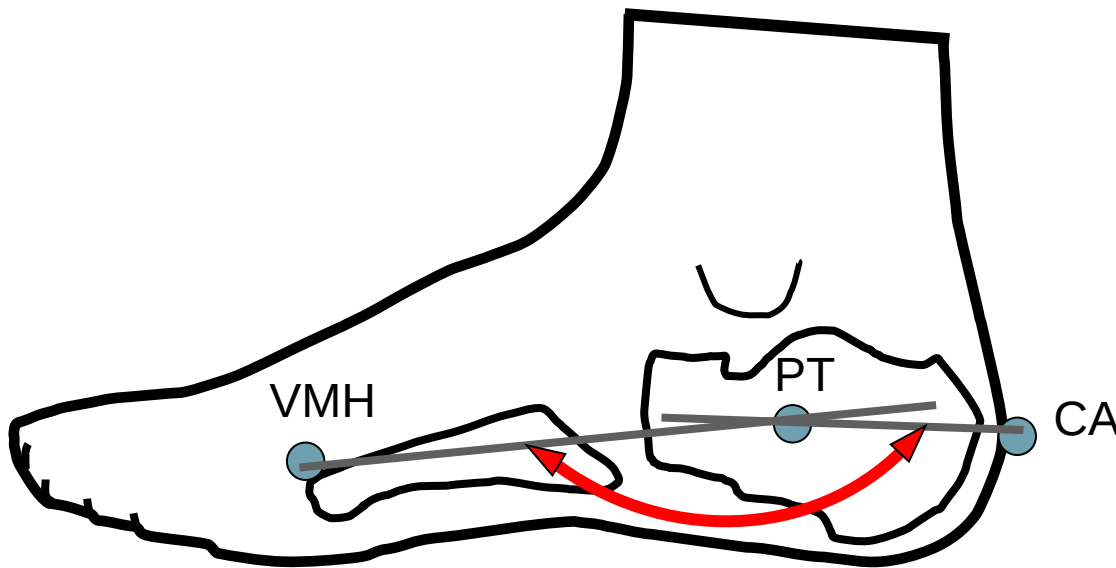
- First Ray to Ground
- Angle between the projection of the line segment *FMB-FMH* and the ground onto the plane orthogonal to the ground & containing FMB & FMH

Projection Angles



- Medial Longitudinal Arch
- Angle between the projections of the line segments *FMB-FMH* & *CA-ST* onto the sagittal plane of the *foot*

Projection Angles



- Lateral Longitudinal Arch
- Angle between the projections of the line segments *VMH-PT* & *CA-PT* onto the sagittal plane of the foot

Offset Angles & the Foot Model - History

- Leardini's Model subtracts weight bearing offset angles from the raw inter-segmental Euler angle kinematics
- This scheme masks foot deformity
- Foot model was changed so that offset angles were collected with the foot positioned in STJN instead of WB
- This can distort sagittal plane results and STJN has no meaning in this plane
- In the coronal & transverse planes we are interested in the STJN position, but subtracting STJN offsets from the raw Euler angle kinematics can also distort the results

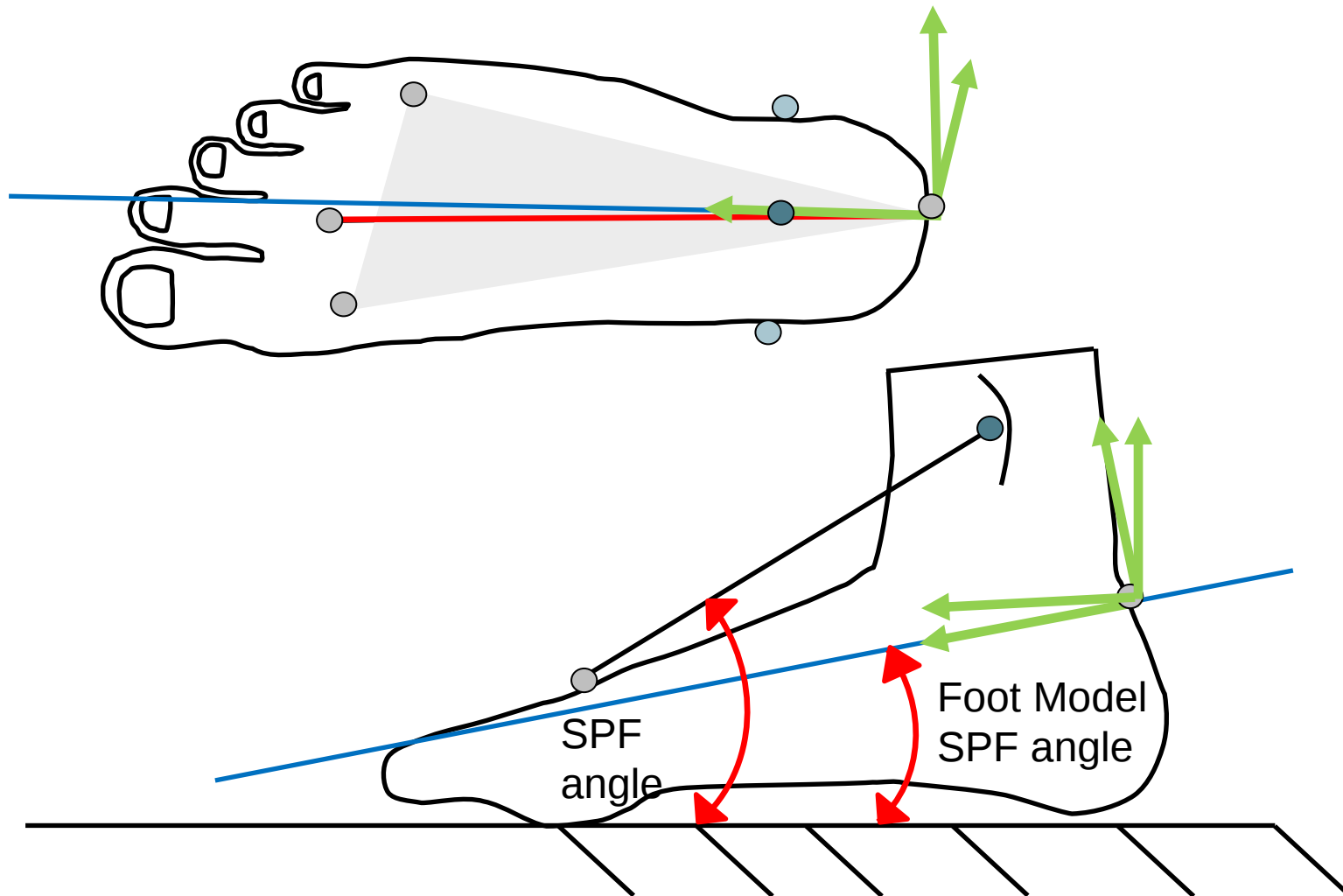
What's a Foot Modeler to do?

- We value the extra meaning we get from knowing the STJN offset angles
- We don't like the confusion that subtracting STJN offsets can create
- We decided to report the data in a different way....

Single Segment Foot Sagittal Plane Kinematics

- Sagittal plane kinematics are often quite different for Conventional and Leardini Single Segment foot models
- Clinicians would like better agreement between models
- Most of the differences can be accounted for by closely examining how the “*Static Plantar Flexion Angle Offsets*” are handled.
- Next slide show how the SPF angle for each is calculated
- Look at some example plots

Static Plantarflexion Angles: Conventional & Leardini Single Segment Foot



One more thing...

- The Tuberosity of the Navicular marker (TN) is not needed to plot the model outputs that we currently plot
- The TN marker is used in the original Leardini model to help track the midfoot
- With collapsed arch feet the TN marker is the most difficult to track (sometimes impossible)
- We don't need it, so we don't apply the TN marker anymore.

Foot evaluation: STJN



Subtalar joint neutral (STJN) position

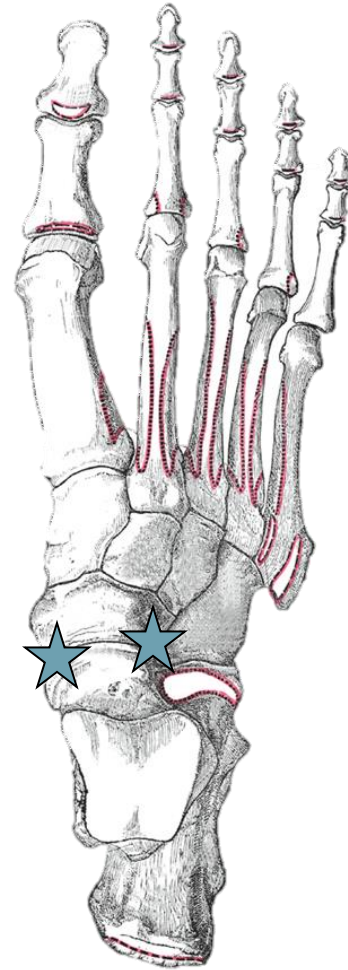
- What is neutral?
- How is it determined?
- Why is it important?

What is Sub-talar Neutral?

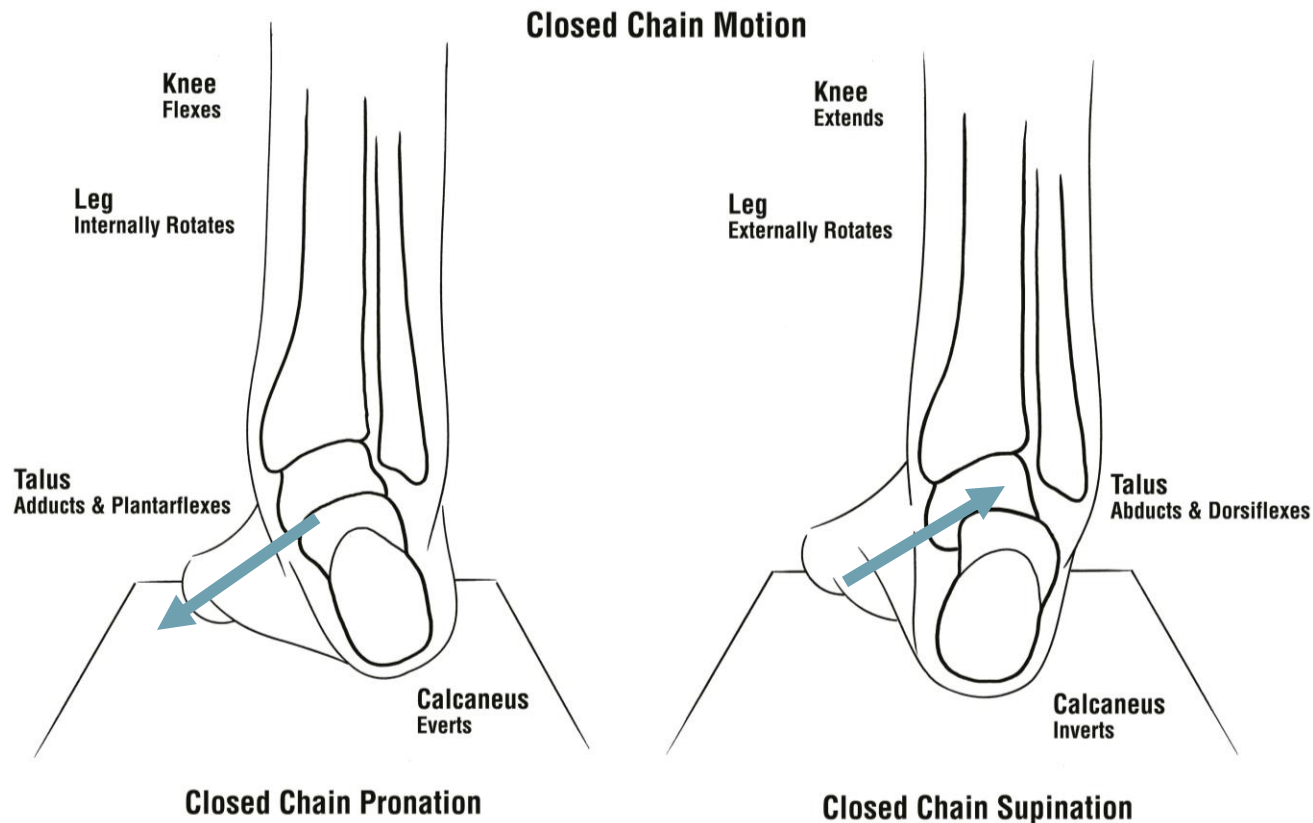
- A term originally defined by Root as the position from which the sub-talar joint can be maximally pronated or supinated and, therefore, the position from which it can function optimally
- The position of the sub-talar joint where it is neither pronated nor supinated

How is Sub-talar Joint Neutral Determined?

- Anatomical landmarks are used to assure accurate palpation of the head of the talus and the navicular
- Palpation is done at the articulation between the head of the talus and the navicular



Palpation of the head of the talus takes advantage of the fact that the talus will **plantar flex** and **adduct** when the STJ is pronated, and will **dorsiflex** and **abduct** when the STJ is supinated





STJN Evaluation

- Includes

- Description of rear foot position relative to shank (vertical, varus, valgus)
- Description of forefoot position relative to rear foot (neutral, varus, valgus, abducted, adducted)
- Description of arch height
- Description of range of motion in the rear foot, midfoot and 1st metatarsal-phalangeal joint
- Presence of a bunion deformity

	FOOT POSITION	
	L	R
FOOT NON-WEIGHTBEARING		
Subtalar neutral		
★ Hindfoot position	_____	_____
★ Hindfoot motion	_____	_____
eversion		
inversion	_____	_____
★ Arch	_____	_____
★ Midfoot motion	_____	_____
★ Forefoot position 1	_____	_____
★ Forefoot position 2	_____	_____
★ Bunion def.	_____	_____
★ 1st MTP DF	_____	_____
FOOT WEIGHTBEARING		
Hindfoot position	_____	_____
Midfoot position	_____	_____
Forefoot position 1	_____	_____
Forefoot position 2	_____	_____

Compensation: A change in the structural alignment or position of the foot to neutralize the effect of an abnormal force resulting in a deviation in structural alignment or position of another part. This can be normal or abnormal

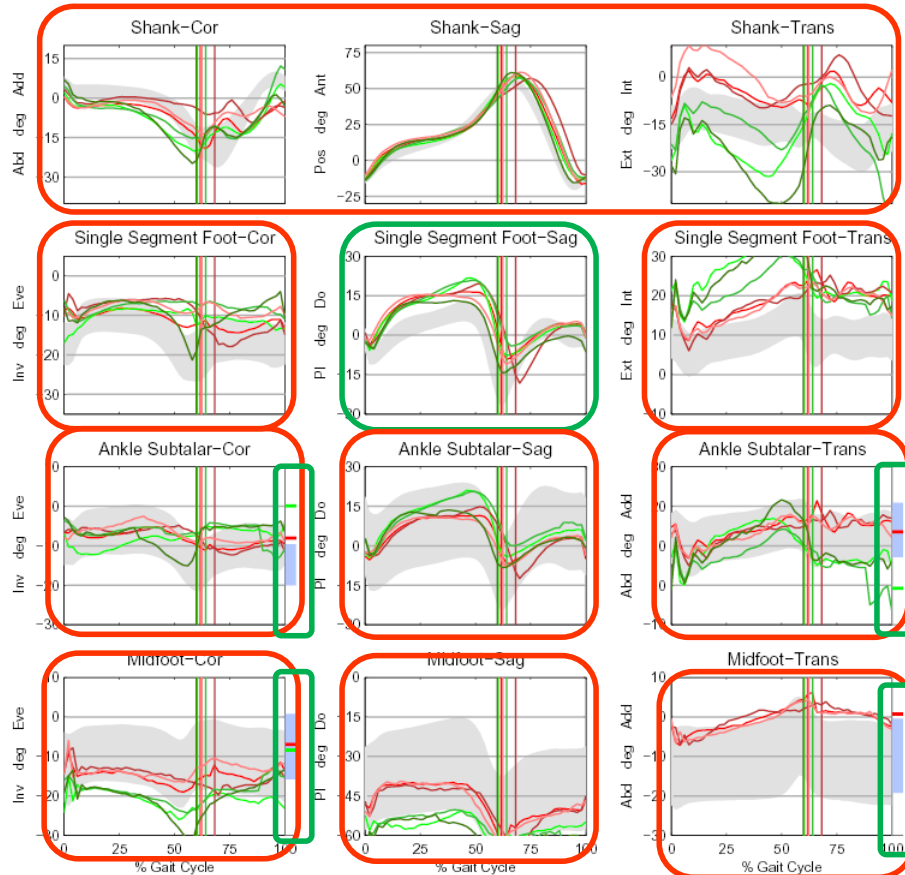


Why use STJN to determine static foot alignment?

- “If you don’t know where you started, how do you know how far you have come”!
- Establishing a meaningful kinematic reference is important when evaluating data obtained from multi-segment foot models. For patients with foot deformity, using WB static offset angles can mask both the fixed and compensatory components of foot deformity.
- The STJN static position provides a reference that is both standardized and clinically meaningful, correlating well with our current physical exam of the foot



Current Foot Kinematics Plots

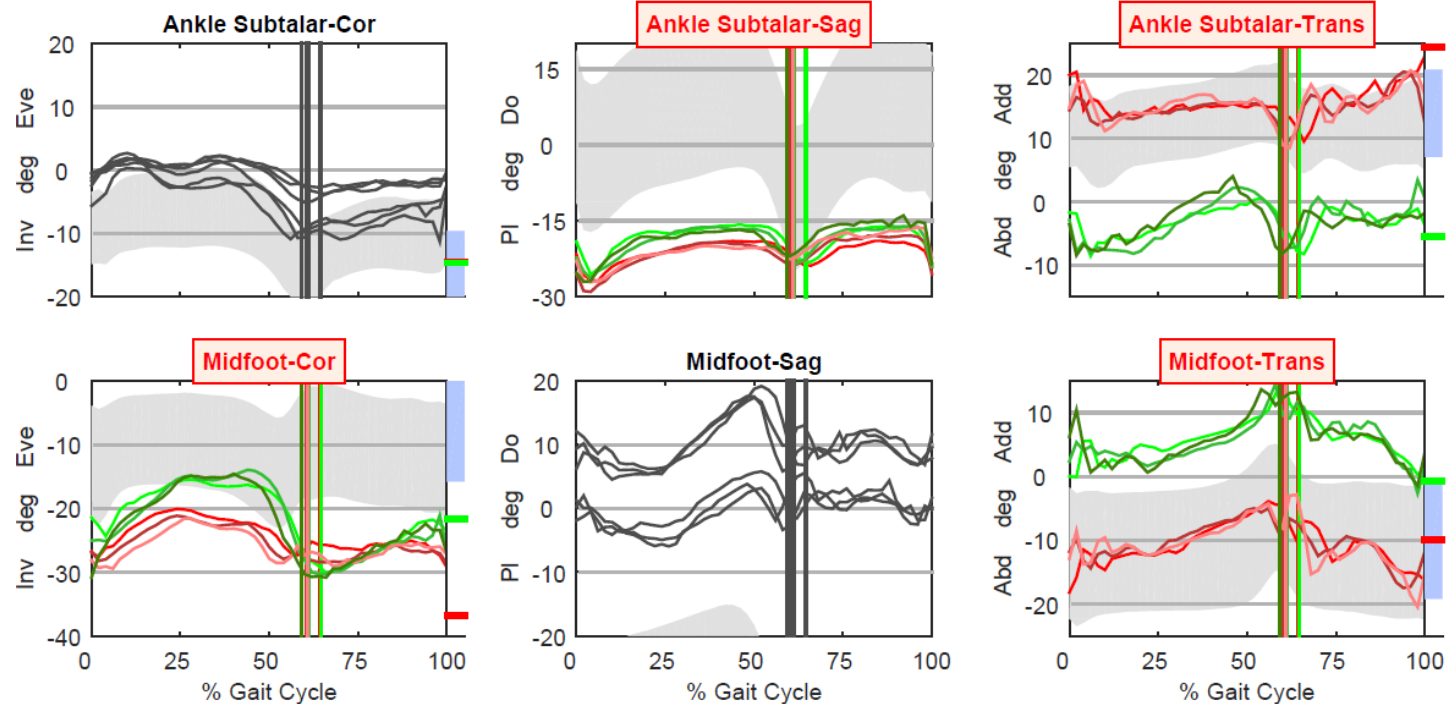


Left: 52 53 54 Right: 52 53 54

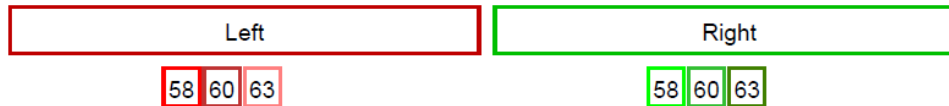
Coronal Plane STJN Offsets			Subtalar Joint Neutral Control		Transverse Plane STJN Offsets		
	Left	Right				Left	Right
Ankle	-8.0	0.1	—	Left STJN	—	13.6	-0.8
Midfoot	-6.9	-8.3	—	Right STJN	—	0.8	14.9

- Here are the Shank Plots
- No offsets subtracted ...
- ...except the SPF angle from SSF sagittal plane kinematics
- STJN offset angles reported next to coronal & transverse plane Ankle Subtalar and Midfoot plots
- Blue error band reports STJN offsets from control data set
- STJN offset also reported in tabular form at bottom of page
- Terminology differences compared to Leardini

Current Foot Kinematic Plots



Plots with red highlighted titles have scales adjusted to fit the data's range



Coronal Plane STJN Offsets		
	Left	Right
Ankle	-14.6	-14.7
Midfoot	-36.8	-21.7

Subtalar Joint Neutral Control		
—	Left STJN	Right STJN

Transverse Plane STJN Offsets		
	Left	Right
Ankle	24.4	-5.5
Midfoot	-9.9	-0.7

Case study

If the shoe
doesn't fit, must
we change the
foot?

Gloria Steinham



Case study

- 9+2 year old female (pre-op)
- CP, spastic diplegia
- Born 15 weeks prematurely with birth weight 1 lb. 12 oz.
- Previous treatments included BOTOX (gastrocnemius, hamstrings, EHL), serial casting
- c/o tripping and falling, occasional foot pain
- concern about her foot deformities, function as an adult
- Ongoing and regular PT
- No current orthoses
- FAQ 9 (walks outside the home for community distances, easily gets around on level ground, curbs, uneven terrain but has difficulty or requires minimal assistance/supervision with running, climbing, and/or stairs with some difficulty keeping up with peers)

Video

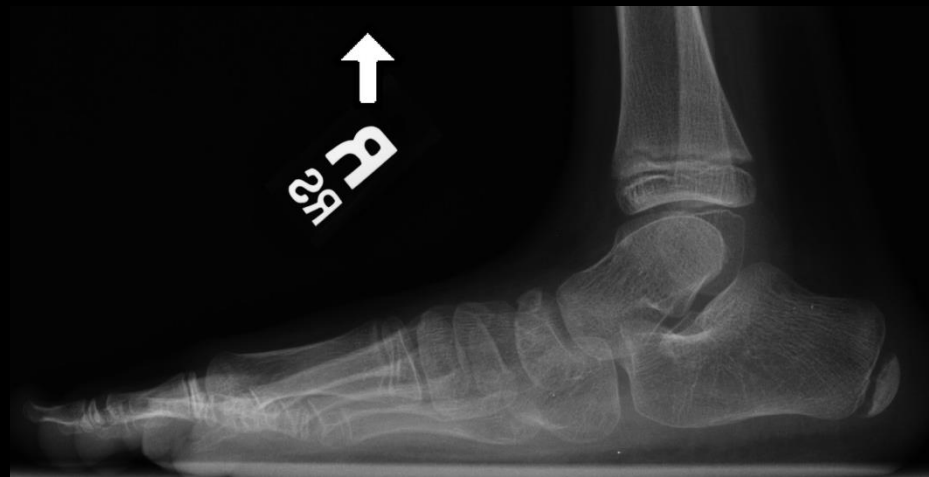


Pre-op physical exam

	FOOT POSITION	
	L	R
FOOT NON-WEIGHTBEARING		
Subtalar neutral	Yes	Yes
Hindfoot position	VER	VER
Hindfoot motion		
eversion	RES	RES
inversion	TYP	TYP
Arch	Low	Low
Midfoot motion	HYP	HYP
Forefoot position 1	VAR/SEV	VAR/MOD
Forefoot position 2	NEU	ADD/MIL
Bunion def.	Yes	Yes
1st MTP DF	RES	RES
FOOT WEIGHTBEARING		
Hindfoot position	VAL/MOD	VAL/MOD
Midfoot position	Planus	Planus
Forefoot position 1	TYP	TYP
Forefoot position 2	ABD/MIL	TYP

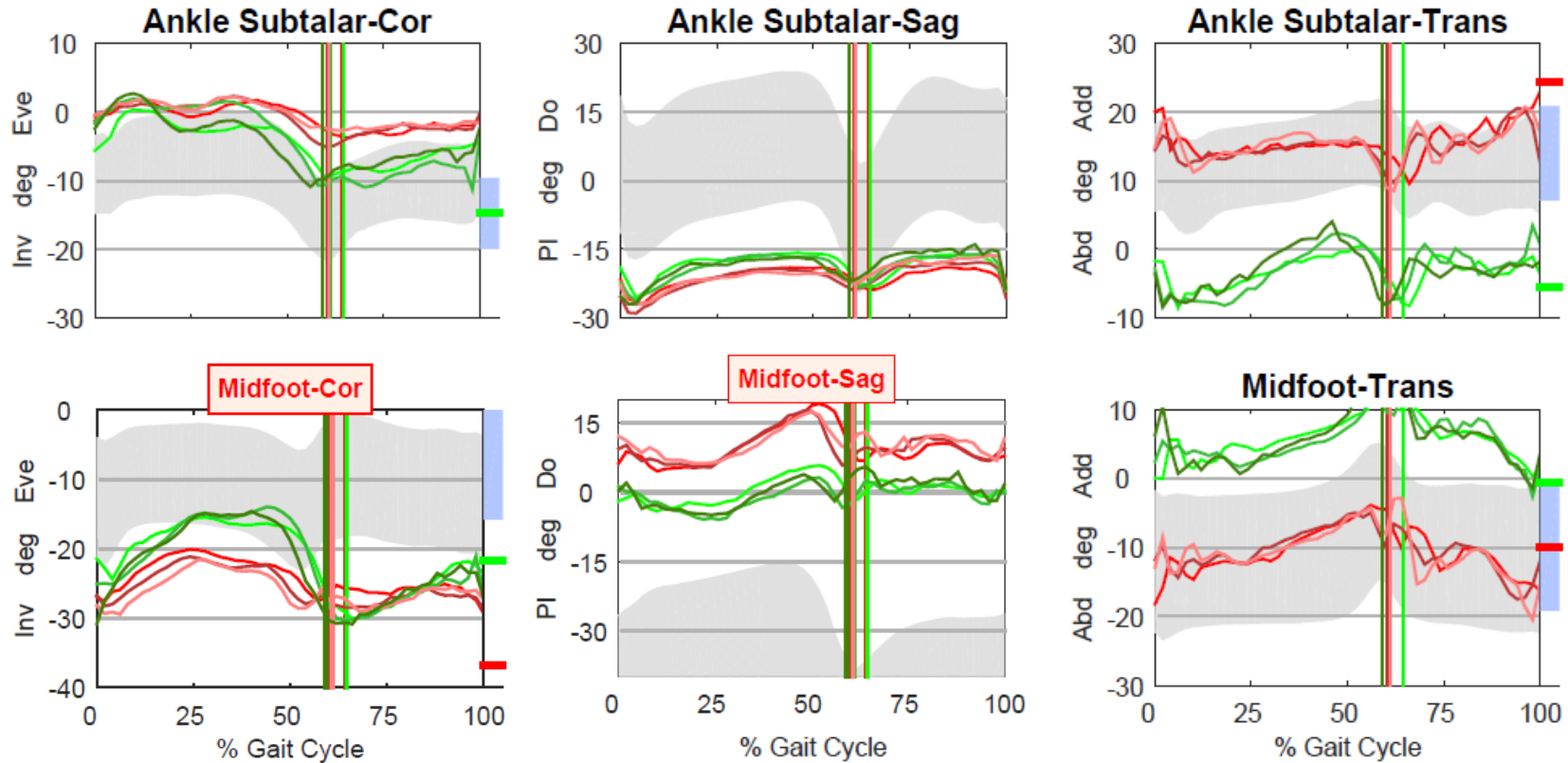


Pre-op





Pre-op multi segment foot kinematics



Coronal Plane STJN Offsets

	Left	Right
Ankle	-14.6	-14.7
Midfoot	-36.8	-21.7

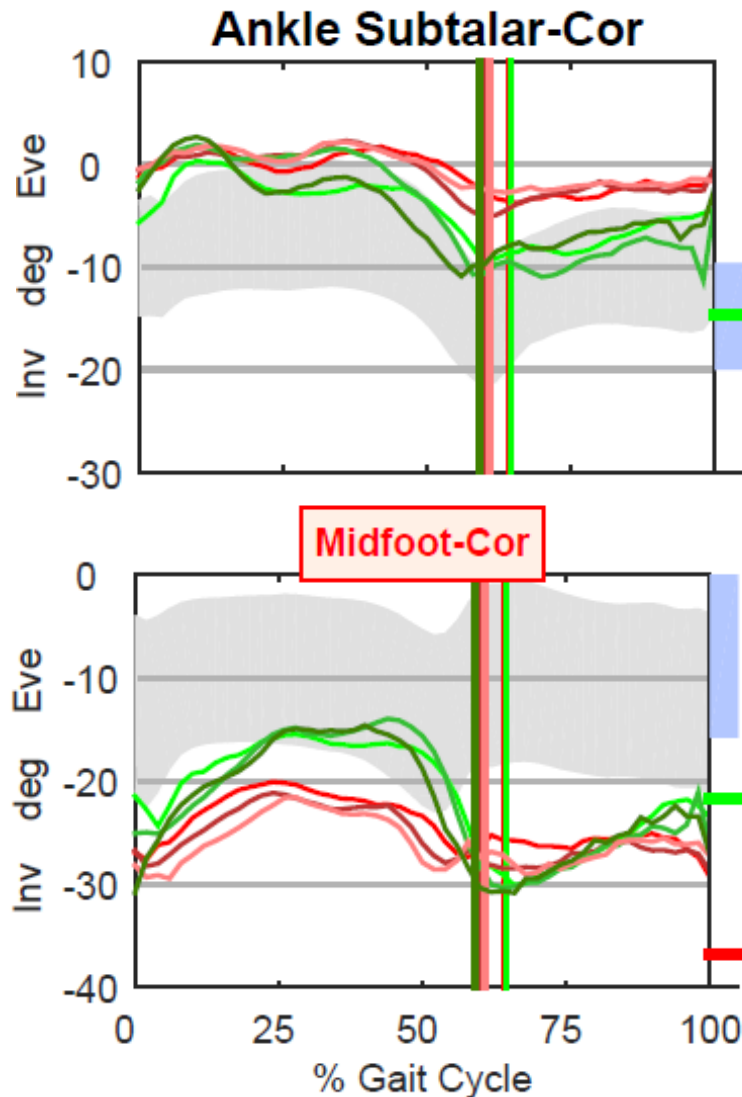
Subtalar Joint Neutral Control

— Left STJN
 — Right STJN

Transverse Plane STJN Offsets

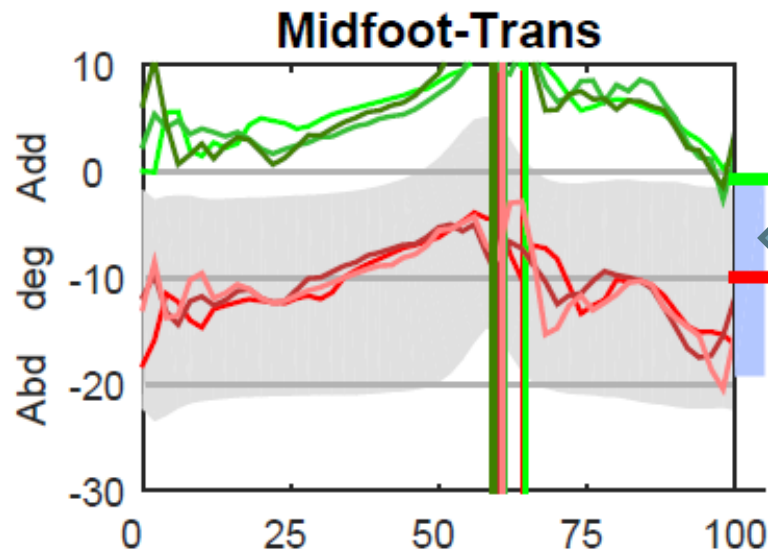
	Left	Right
Ankle	24.4	-5.5
Midfoot	-9.9	-0.7

Pre-op multi segment foot kinematics



	L	R
FOOT NON-WEIGHTBEARING		
Subtalar neutral	Yes	Yes
Hindfoot position	VER	VER
Hindfoot motion		
eversion	RES	RES
inversion	TYP	TYP
Arch	Low	Low
Midfoot motion	HYP	HYP
Forefoot position 1	VAR/SEV	VAR/MOD
FOOT WEIGHTBEARING		
Hindfoot position	VAL/MOD	VAL/MOD
Midfoot position	Planus	Planus
Forefoot position 1	TYP	TYP
Forefoot position 2	ABD/MIL	TYP

Pre-op multi segment foot kinematics



FOOT NON-WEIGHTBEARING

Subtalar neutral	Yes	Yes
Hindfoot position	VER	VER
Hindfoot motion		
eversion	RES	RES
inversion	TYP	TYP
Arch	Low	Low
Midfoot motion	HYP	HYP
Forefoot position 1	VAR/SEV	VAR/MOD
Forefoot position 2	NEU	ADD/MIL

FOOT WEIGHTBEARING

Hindfoot position	VAL/MOD	VAL/MOD
Midfoot position	Planus	Planus
Forefoot position 1	TYP	TYP
Forefoot position 2	ABD/MIL	TYP

Pre-op multi segment foot

ANKLE SUBTALAR

Dorsiflexion

knee 90

10

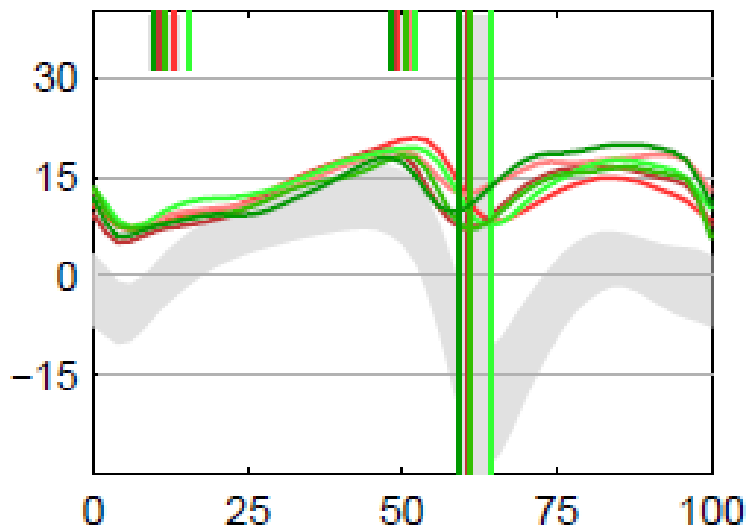
20

knee 0

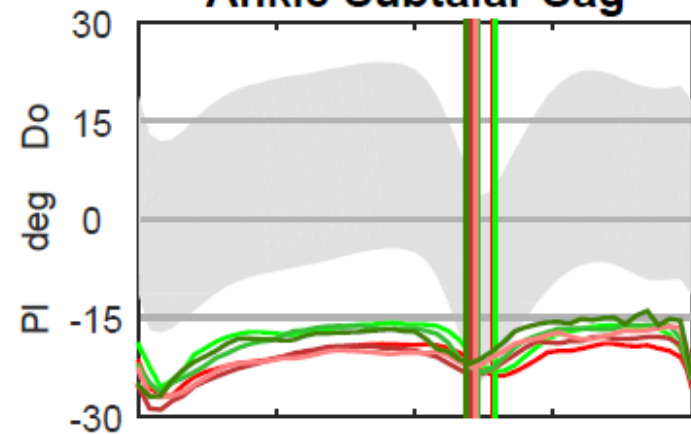
5

10

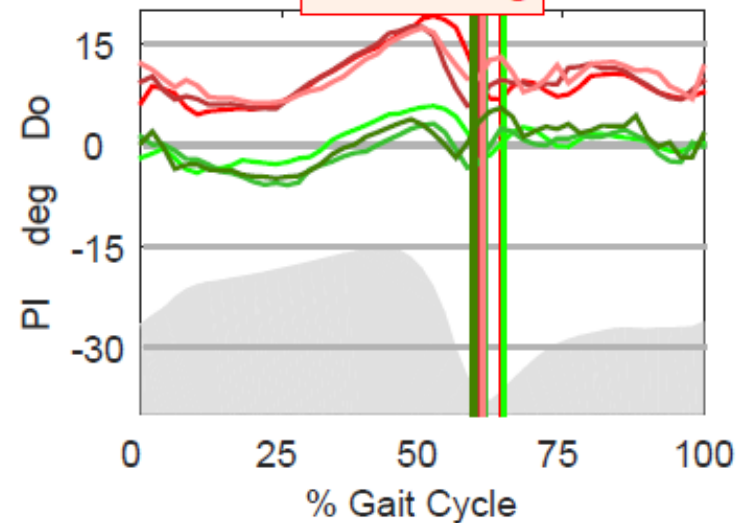
Ankle Dorsi/Plantar



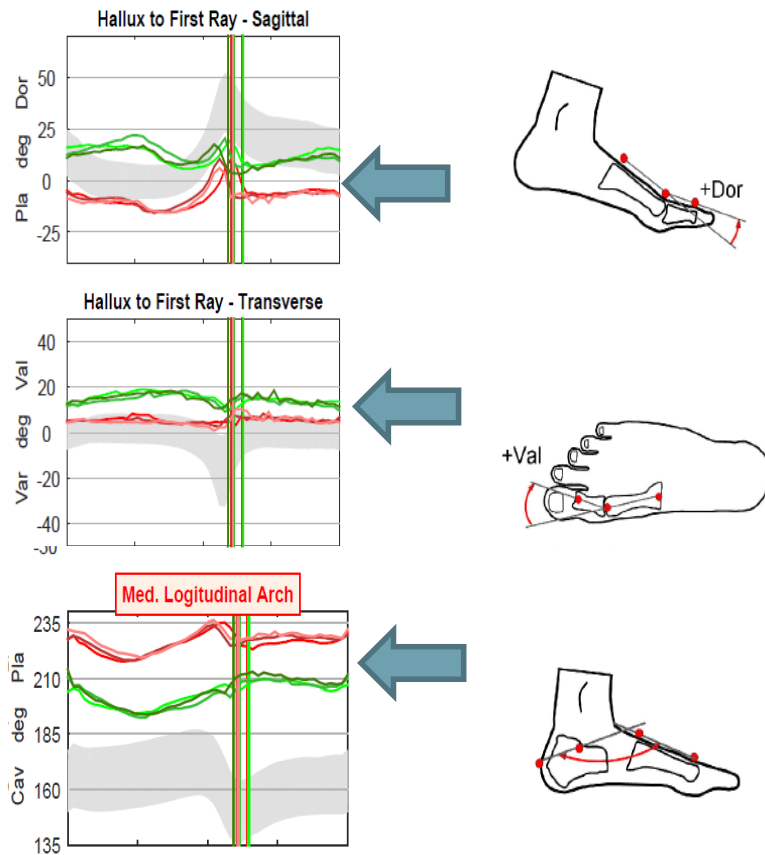
Ankle Subtalar-Sag



Midfoot-Sag



Projection angles



	FOOT POSITION	
	L	R
FOOT NON-WEIGHTBEARING		
Subtalar neutral	Yes	Yes
Hindfoot position	VER	VER
Hindfoot motion		
eversion	RES	RES
inversion	TYP	TYP
Arch	Low	Low
Midfoot motion	HYP	HYP
Forefoot position 1	VAR/SEV	VAR/MOD
Forefoot position 2	NEU	ADD/MIL
Bunion def.	Yes	Yes
1st MTP DF	RES	RES
FOOT WEIGHTBEARING		
Hindfoot position	VAL/MOD	VAL/MOD
Midfoot position	Planus	Planus
Forefoot position 1	TYP	TYP
Forefoot position 2	ABD/MIL	TYP

Assessment and SEMLS

- Problem list

- B femoral anteversion
- L external tibial torsion
- B foot deformity NWB
 - B midfoot instability
 - B forefoot varus
 - B hallux valgus
- B foot deformity WB
 - B hind foot valgus
 - B planus
 - B hallux valgus

- Solution list

- B FDO
- L TDO
- B os calcis lengthening
- B 1st cuneiform plantar flexion osteotomy

Case study

- 10+7 years old
- 1 year post SEMLS
- Family reports “extreme satisfaction” with results from surgery
 - Minimal foot pain
 - Able to stand on tip toes
 - Improved running and climbing abilities
 - Better control descending stairs
 - No longer trips or falls
- FAQ 10 (walks, runs, climbs without difficulty and is typically able to keep up with peers) (initially 9)
- GDI average 94 (initially 84)

PE

Pre op

	FOOT POSITION	
	L	R
FOOT NON-WEIGHTBEARING		
Subtalar neutral	Yes	Yes
Hindfoot position	VER	VER
Hindfoot motion		
eversion	RES	RES
inversion	TYP	TYP
Arch	Low	Low
Midfoot motion	HYP	HYP
Forefoot position 1	VAR/SEV	VAR/MOD
Forefoot position 2	NEU	ADD/MIL
Bunion def.	Yes	Yes
1st MTP DF	RES	RES
FOOT WEIGHTBEARING		
Hindfoot position	VAL/MOD	VAL/MOD
Midfoot position	Planus	Planus
Forefoot position 1	TYP	TYP
Forefoot position 2	ABD/MIL	TYP

Post op

	FOOT POSITION	
	L	R
FOOT NON-WEIGHTBEARING		
Subtalar neutral	Yes	Yes
Hindfoot position	VER	VER
Hindfoot motion		
eversion	TYP	TYP
inversion	TYP	TYP
Arch	Low	TYP
Midfoot motion	TYP	TYP
Forefoot position 1	NEU	NEU
Forefoot position 2	NEU	NEU
Bunion def.	Yes	Yes
1st MTP DF	RES	TYP
FOOT WEIGHTBEARING		
Hindfoot position	VAL/MIL	TYP
Midfoot position	Planus	TYP
Forefoot position 1	VAL/MIL	VAL/MIL
Forefoot position 2	ABD/MIL	TYP

Video

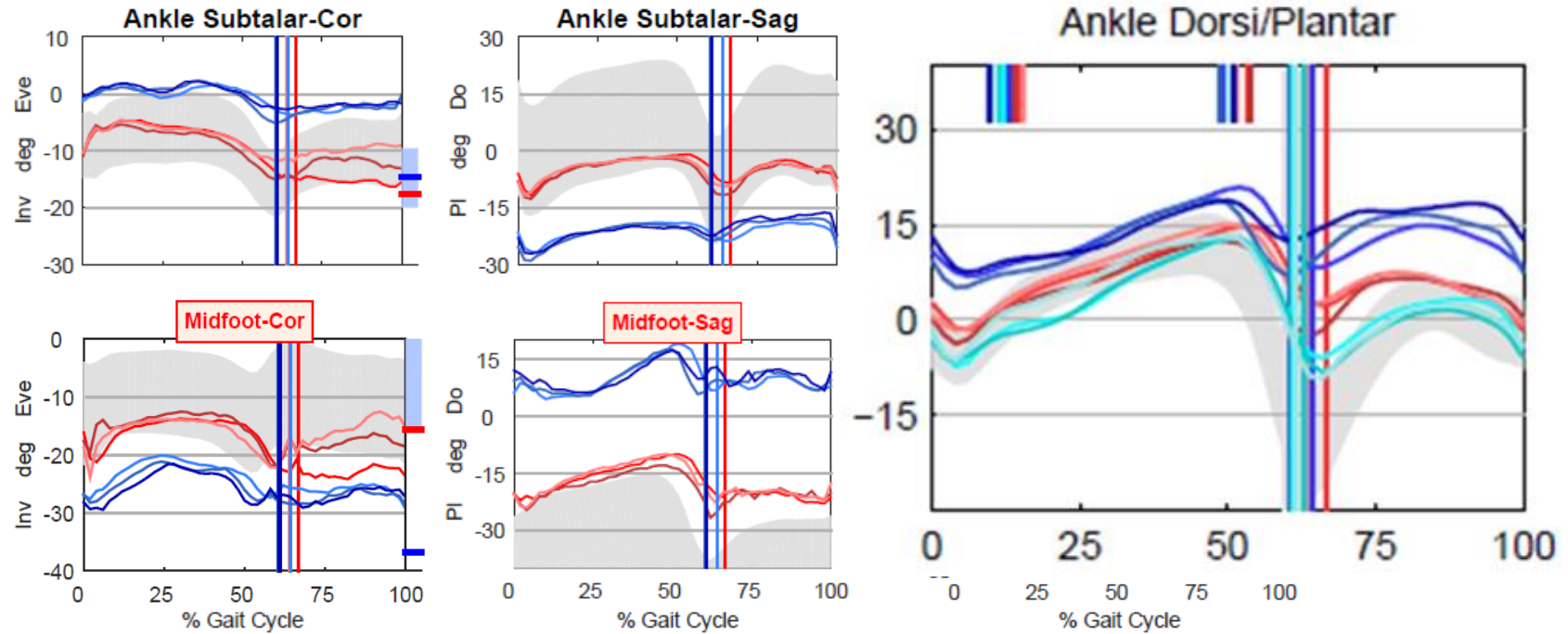
Pre op



Post op



Pre/post multi segment **left** foot kinematics



12/30/2014

8/12/2013

83 85 86

58 60 63

Subtalar Joint Neutral Control

12/30/2014
8/12/2013

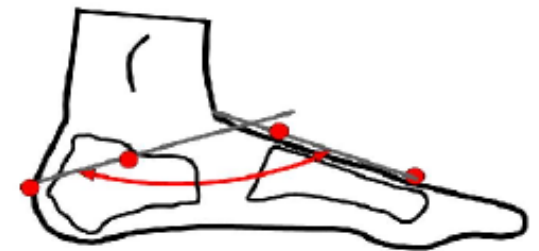
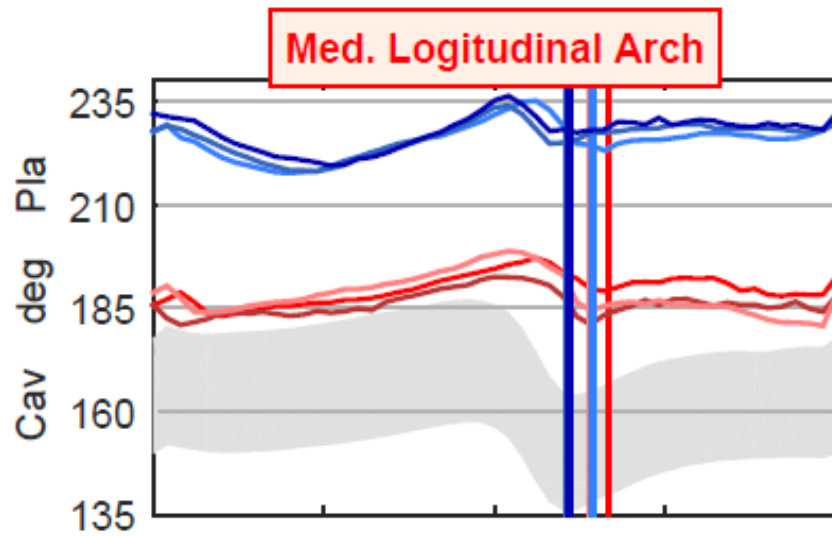
Coronal Plane STJN Offsets

	12/30/2014	8/12/2013
Ankle	-17.6	-14.6
Midfoot	-15.7	-36.8

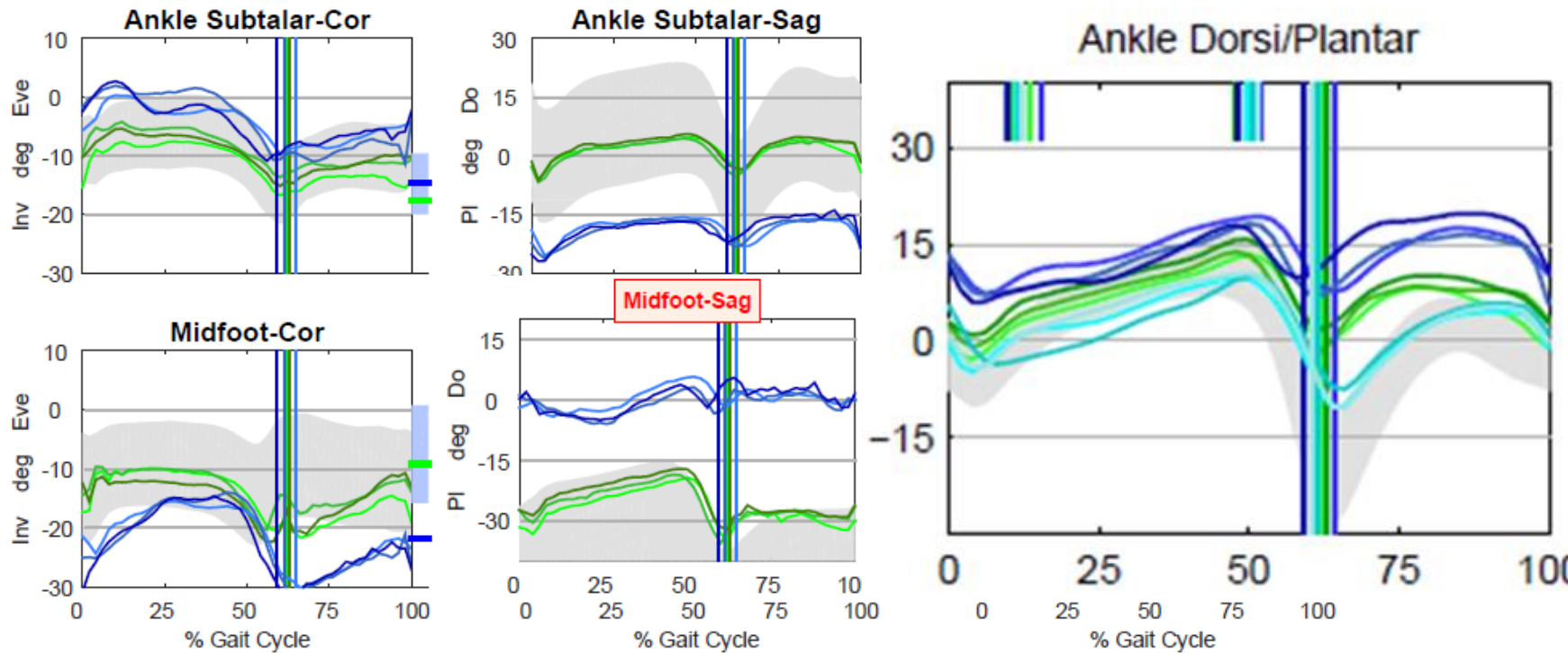
Transverse Plane STJN Offsets

	12/30/2014	8/12/2013
Ankle	2.3	24.4
Midfoot	-0.5	-9.9

Pre/post left planar projections



Pre/post multi segment **right** foot kinematics



12/30/2014

8/12/2013

83 85 86

58 60 63

Subtalar Joint Neutral Control

12/30/2014

8/12/2013

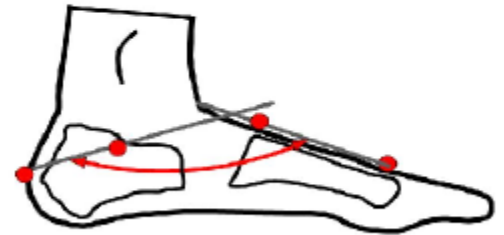
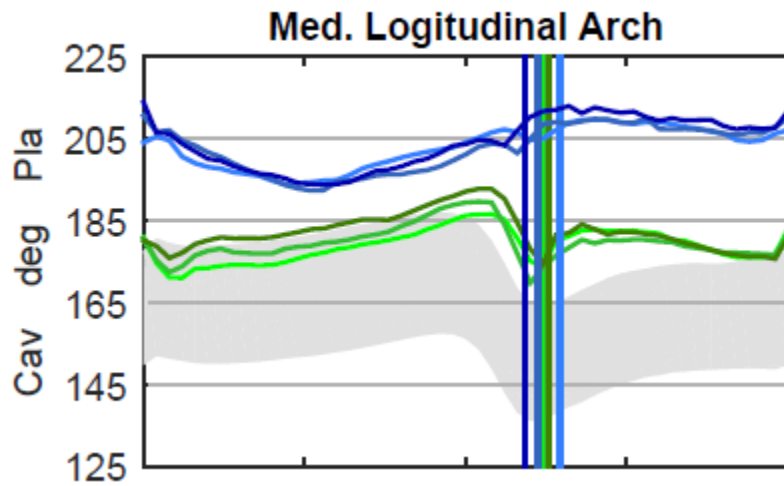
Coronal Plane STJN Offsets

	12/30/2014	8/12/2013
Ankle	-17.7	-14.7
Midfoot	-9.2	-21.7

Transverse Plane STJN Offsets

	12/30/2014	8/12/2013
Ankle	10.6	-5.5
Midfoot	-5.0	-0.7

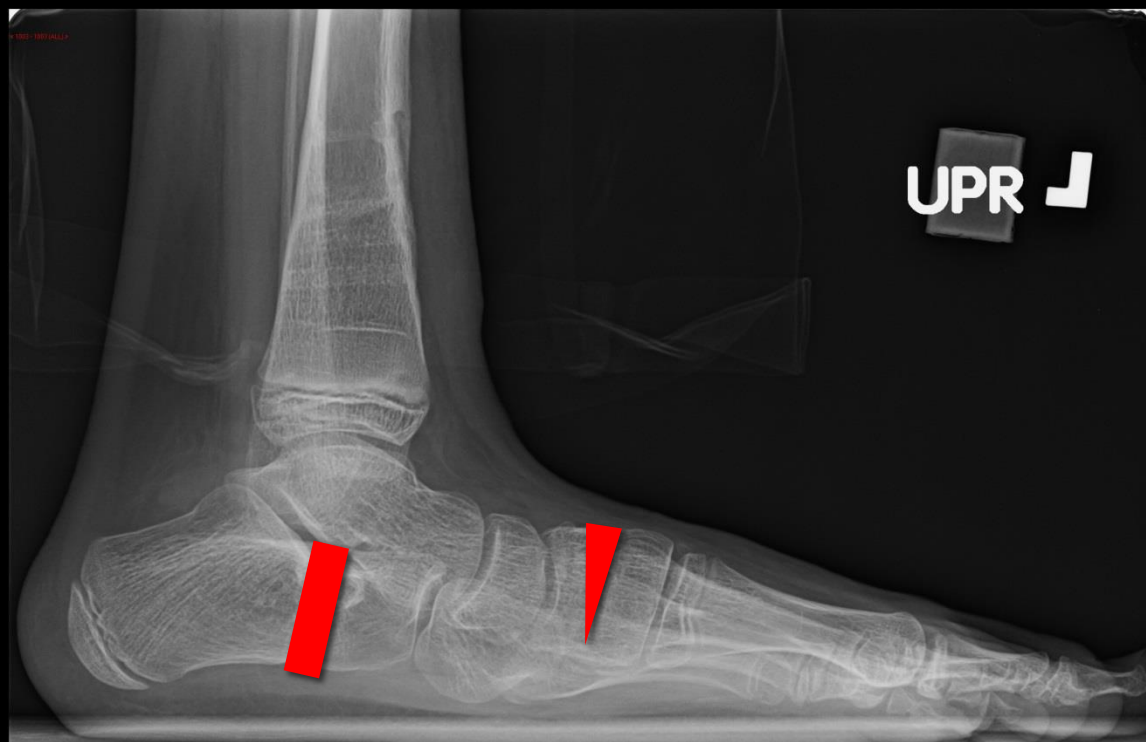
Pre/post right planar projections

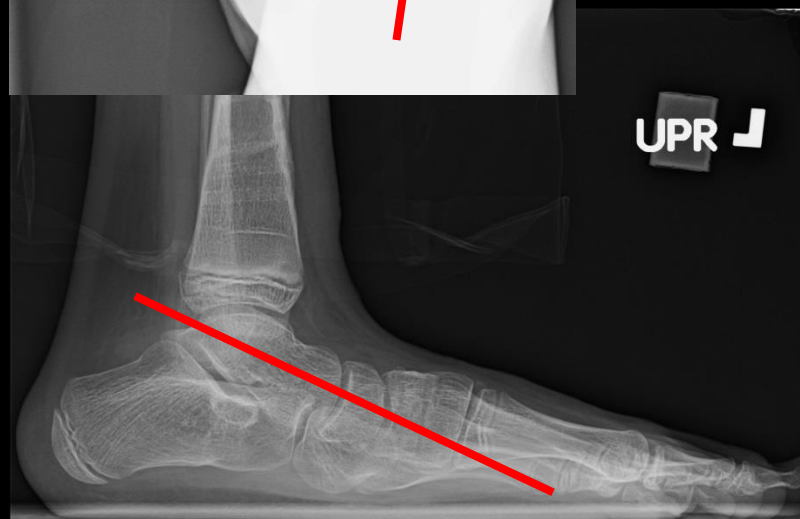
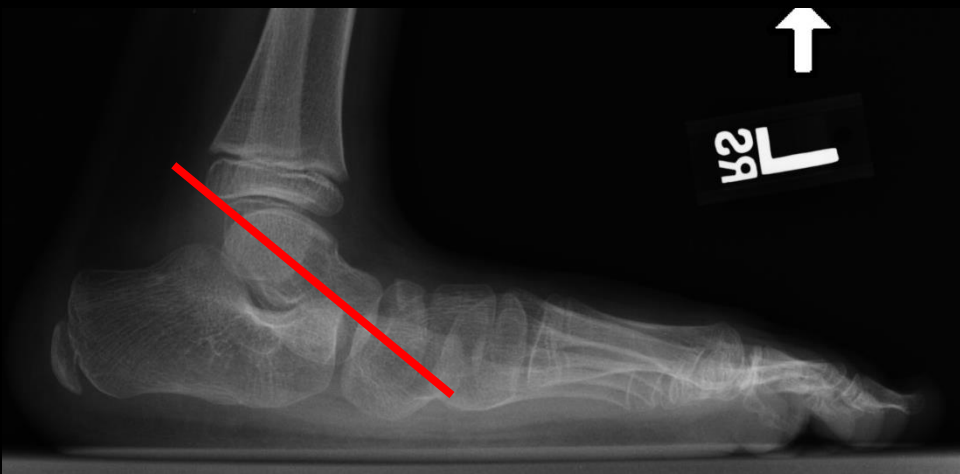




Post op x-rays







So, how did the data help?

- Confirmed impression based on
 - clinical appearance
 - physical examination
 - NWB
 - WB
- Documented postoperative improvement/confirms surgical result
- Usually gastrocnemius recession is required, but not performed in this case based on intraoperative findings

Clinical implementation

- Choice of model
 - Decision to maintain focus on NWB foot alignment and compensatory movements in WB position by gathering static data in subtalar joint neutral (STJN) position
 - Data collection pre
 - Data collection pre/post
 - Determination of zero offset
 - Determination of method for data output to incorporate both zero offset position and STJN position
 - Interpretation
 - Problem list
- 2007
 - Immediate
 - 200 cases
 - 40 cases
 - 2013
 - 2013
 - Ongoing
 - Future

Limitations of current model

- Clinical interpretation

What do we hope for the future?

- How much deformity can be managed with orthoses?
- How much deformity can be managed with osteotomy?
 - Os calcis lengthening alone
 - Os calcis lengthening + 1st cuneiform plantar flexion osteotomy
 - Triple C
- How much deformity is too much to manage with osteotomy and fusion is required?

Thank you

