Development of 3D Model-based Morphometric Method for Assessment of Human Weight-bearing Joint

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Introduction

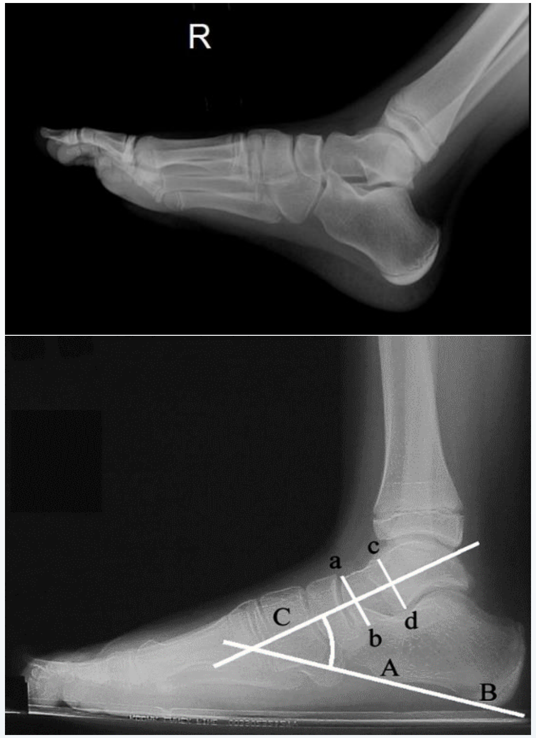
- Clinical measurement in the foot pathology requires **accurate** and **robust** measurement

- Among weight-bearing joints, the ankle has a complex structure which can derive errors in diagnosis using conventional medical images
  - During performing 2D X-ray based conventional measurement

- To assess 3D posture of the foot, several methods have been proposed using 3D medical images (CT, MRI)
  - Different from measurement methods based on a 2D image (X-ray)
  - Usually measure the angle referring anatomical landmarks on the surface of bone or skin

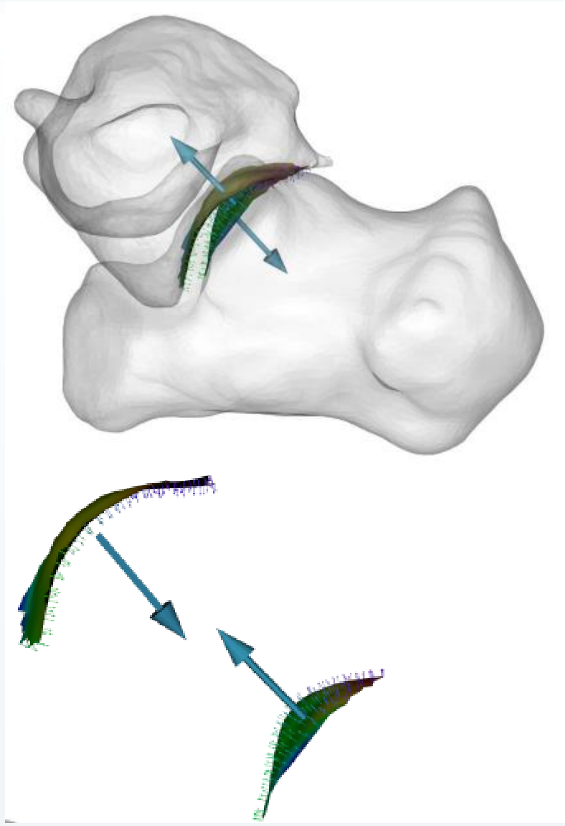
Goal

Conventional Method



Angles measured
from 2D radiographs

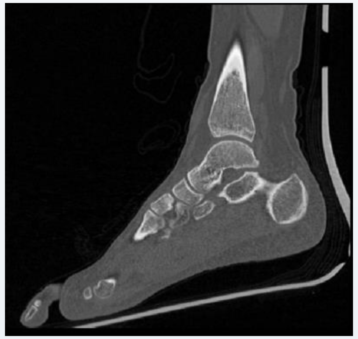
Proposed Method

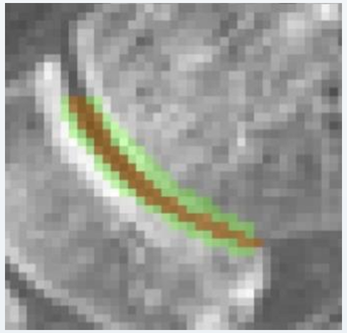


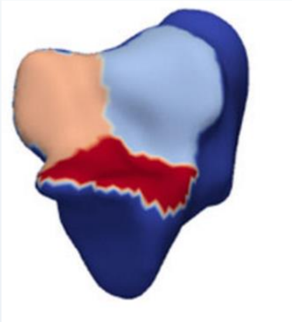
Angles measured
based on 3D structures

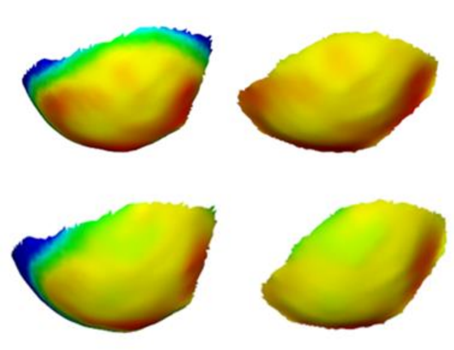
Overall Method

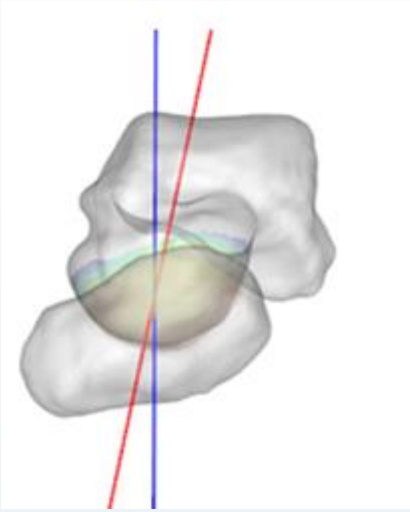
	Segmentation	Modeling	Articular surface definition	Measurement & Visualization
Raw image data	(Semi-)auto segmentation	Region mapping		Distance map
	Segmented image volume	Model to image mapping	Model to model mapping	Angle between vectors
		3D surface model	Articular surface	Posture assessment











Problems

- Issues raised for the project
  - Difficulties in segmentation due to the fuzzy structure of the bone from the image
  - Difficulties in consistent designation of articular surface due to variety of the bone shape among subjects
  - Difficulties in consistent measurement of the angle between bones due to various appearance of foot structure in patient images

→ Our approaches for obtaining robust measurements

  - Using the articular surface encoded in a 3D foot bone model
  - Algorithms for the standardization

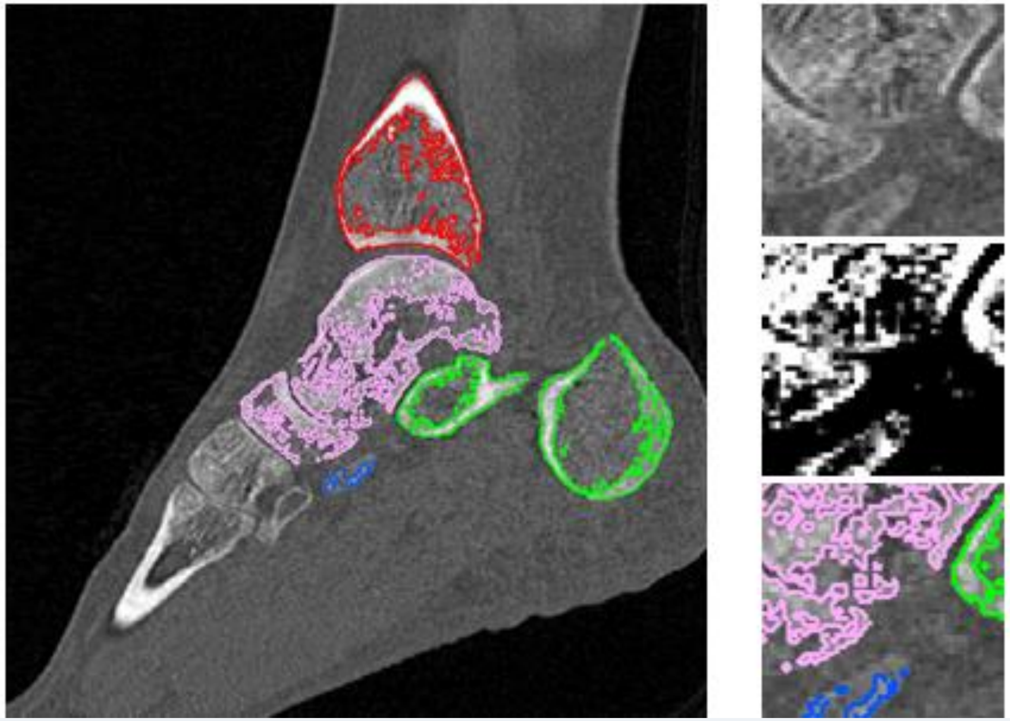
Contents

- Segmentation technique for joint space
- Patient-specific modeling
- Model-based 3D foot posture measurement
- Global frame of reference generation

Joint space segmentation

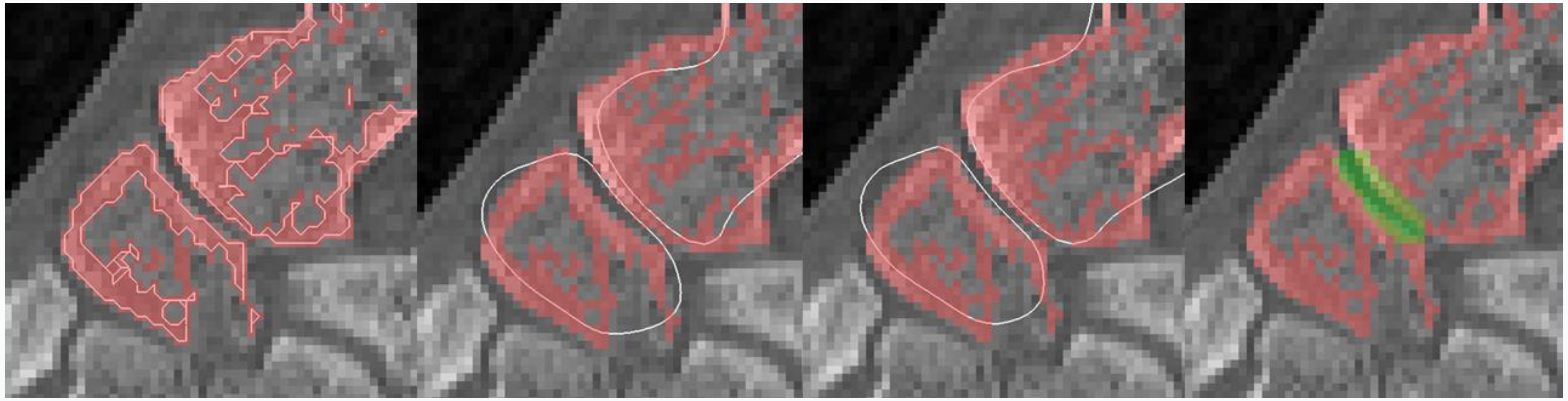
- Difficulties in segmentation of foot bone from the image
  - Vague boundary between bones
  - Hard to separate bones especially in weight-bearing image caused by narrowing

- Our solution
  - Tight bound ROI
    - Designate a joint space on a template model of the foot bone
    - Deform whole structure of the foot joint to a target image
    - Detect the region which should been separated
  - Joint space extraction
    - Approximate a joint space based on the probabilistic model
    - MAP-MRF labeling method

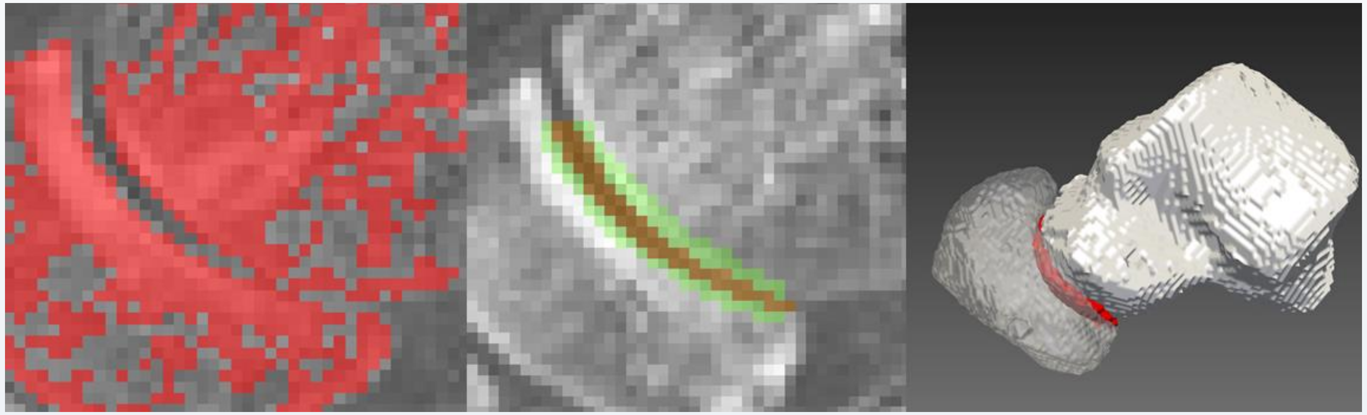


Joint space segmentation

Tight bound ROI generation



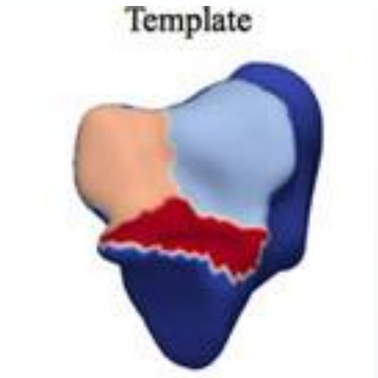
Joint space extraction using MRFs



E. Park, T. Kim, and J. Park, "Template-based automatic extraction of the joint space of foot bones from CT scan," SPIE medical imaging, 2016

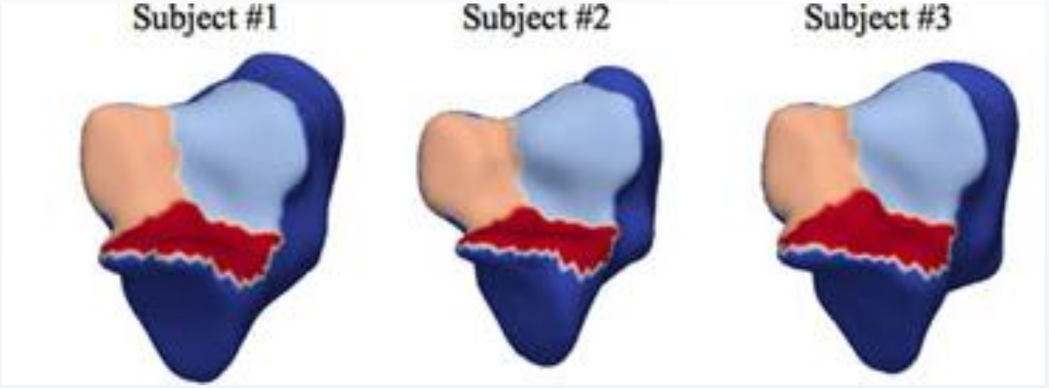
Patient-specific modeling

- Difficulties in region mapping for articular surface
  - Hard to transfer the designated region uniformly from one model to another



- Our solution: Deformable modeling technique
  - Construct a template model based on generic shape of the target
  - Encode an articular surface region on the template model
  - Perform non-rigid template-to-image registration to individual subject
    - *Maintain point correspondence on the mesh model*
    - *Minimize model distortion*

  → *Patient-specific model including anatomical information*



J. Kim, S. Seo, D. Lee, and J. Park, "Template-based landmark and region mapping of bone," Journal of Foot and Ankle Research, 2014

J. Kim, M. d. C. Valdes-Hernandez, N. A. Royle, and J. Park, "Hippocampal Shape modeling based on a Progressive Template Surface Deformation and Its Verification," IEEE Transactions on Medical Imaging, Vol. 34, No. 6, pp. 1242-1261, June 2015

Patient-specific modeling

- Template initialization
  - Align model to segmented image using ICP algorithm
  - Set multi-level neighborhood and Laplacian coordinate

- Non-rigid model deformation
  - Progressive model deformation
  - $E(V') = \sum_{i-1}^{n} \| \alpha_i (L(v_i') - \delta_i) \|^2 + \sum_{i=1}^{n} \| b_i - v_i \|^2$
    - V': set of the optimal vertex coordinate (v_i')
    - δ_i : Laplacian coordinate of each vertex (v_i)
    - b_i : Desired position where v_i will be placed after each iteration

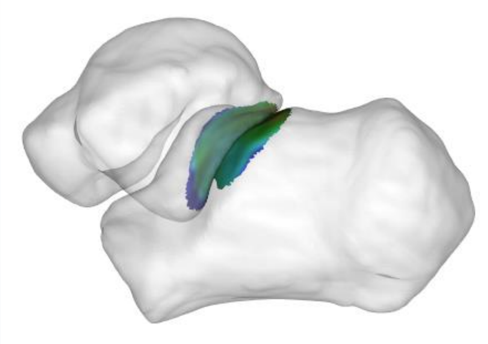
- Local shape detail restoration
  - Set minimum neighbor count
  - Rotation-and Scale Invariant (RSI) Transformation

J. Kim, M. d. C. Valdes-Hernandez, N. A. Royle, and J. Park, "Hippocampal Shape modeling based on a Progressive Template Surface Deformation and Its Verification," IEEE Transactions on Medical Imaging, Vol. 34, No. 6, pp. 1242-1261, June 2015

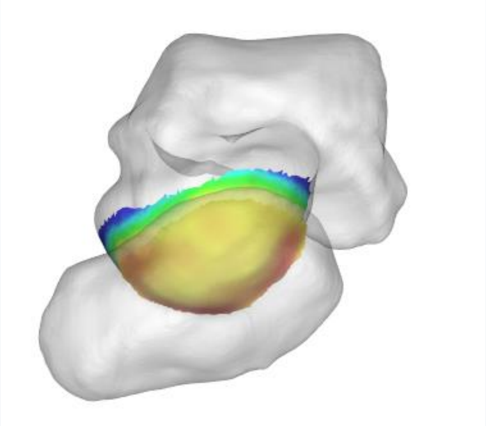
Model-based 3D foot posture measurement

- Measurement of the posture using an articular surface in a patient-specific foot bone model

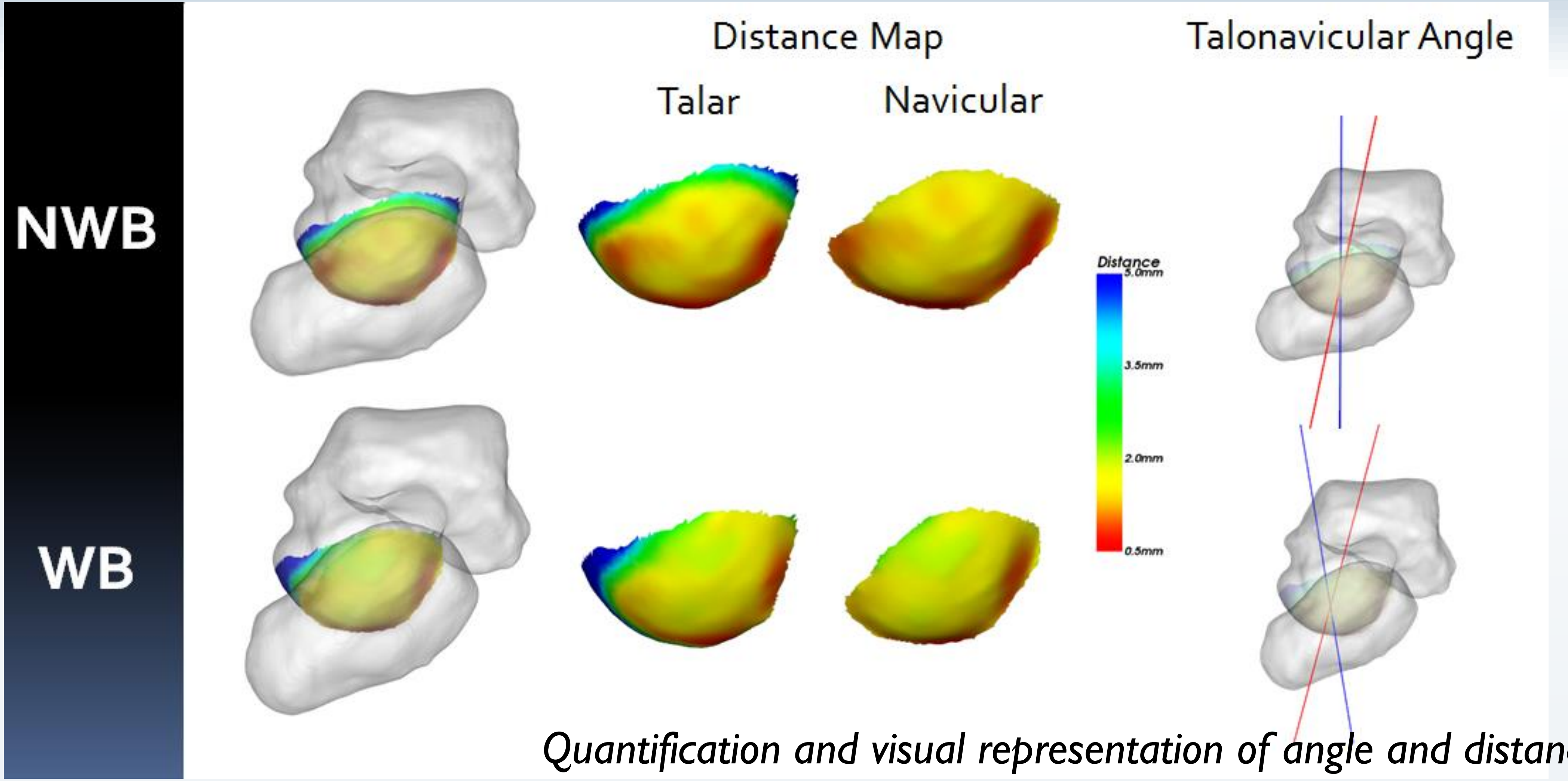
- Measurement method
  - Talus → Calcaneus
    - Angle from local reference axis of Talus to local reference axis of Calcaneus
    - → Reported in 2D projection angles based on the global reference
    - Distance map between Talus and Calcaneus



  - Talus → Navicular
    - Angle from local reference axis of Talus to local reference axis of Navicular
    - → Reported in 2D projection angles based on the global reference
    - Distance map between Talus and Navicular



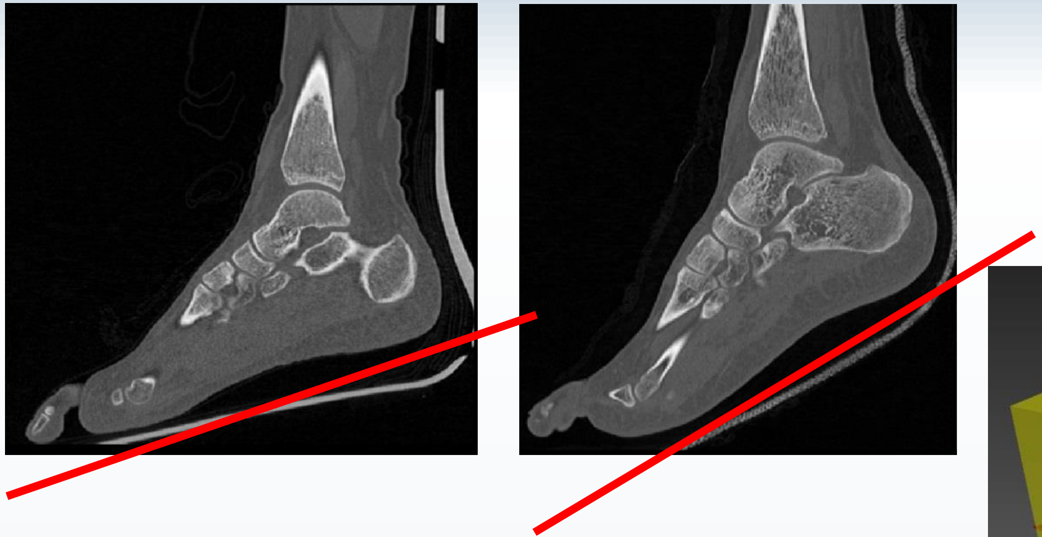
Model-based 3D foot posture measurement

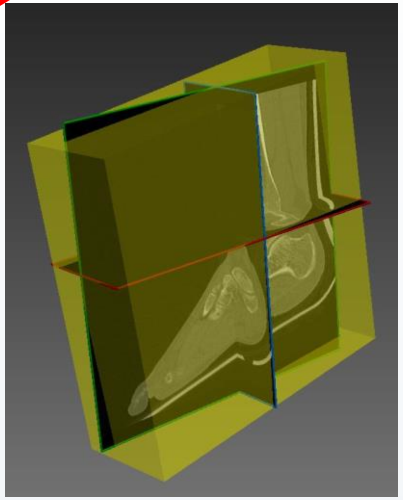


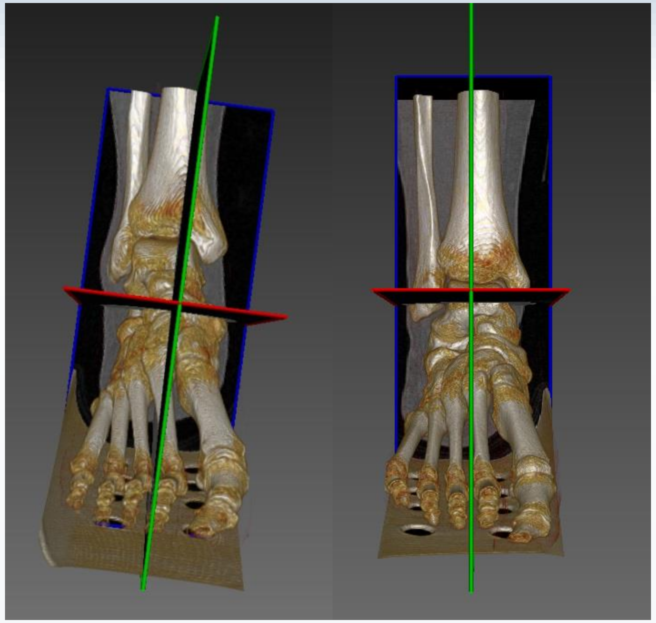
Quantification and visual representation of angle and distance

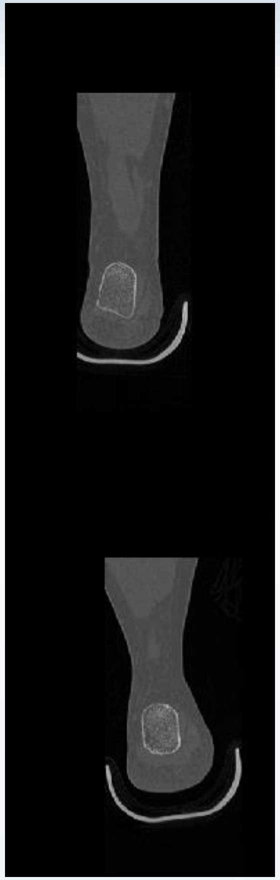
D. Lee, T. Kim, S. Seo, E. Kim, W. Lee, K. L. Wapner, and J. Park, “3D Computational Position Analysis based on the Articular Surface of Tarsal Bone: A Preliminary Study”, 2015 AOFAS Annual Meeting

Global frame of reference generation





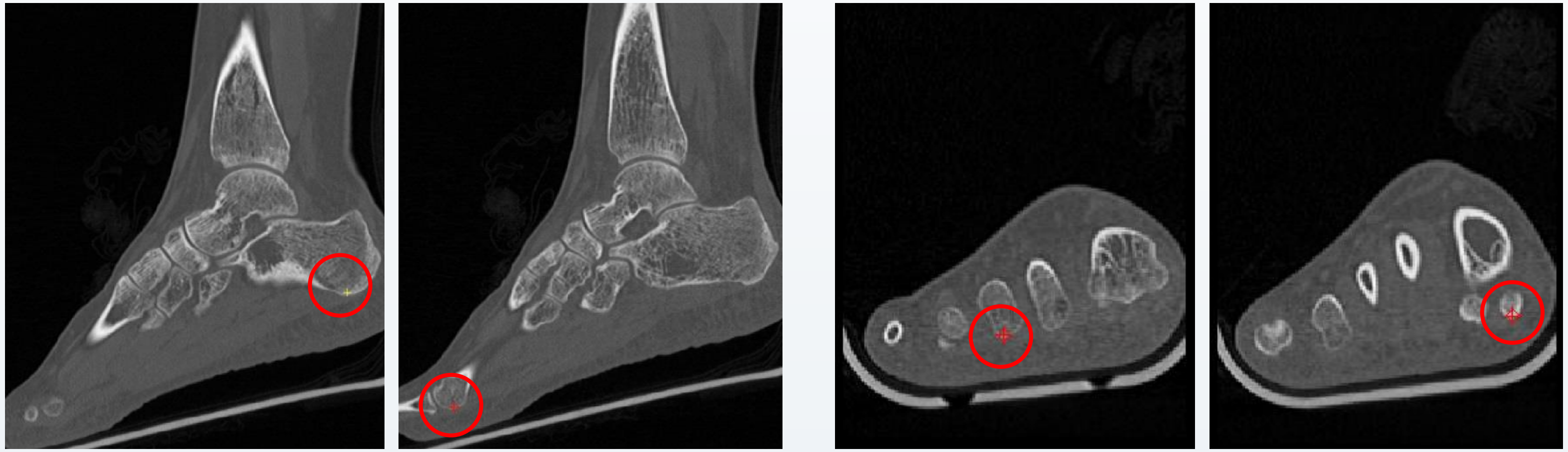


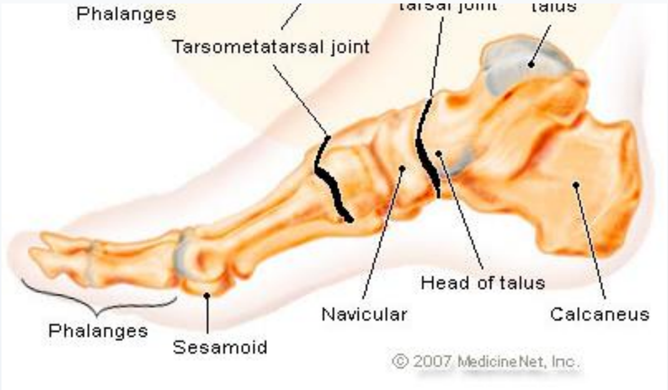


- Problem: Inconsistency in the frame of reference from the image
  - Direction of the foot may be varied
    - Movement of patient
    - Imaging circumstance (device, cast, …)

Global frame of reference generation

- Our solution
  - Global reference axis based on extracted anatomical landmarks from selected foot bones
    - Represent a ground that the foot is stepping on
    - 1st axis: lowest point of Calcaneus → lowest point of 3rd Metatarsal
    - 2nd axis: lowest point of 3rd Metatarsal → lowest point of Sesamoid
    - 3rd axis: 1st axis × 2nd axis





Global frame of reference generation

- Result
  - Aligned foot structures based on generated global frame of reference

T. Kim and J. Park, "Reliable measurement of 3D foot bone angles based on the frame-of-reference derived from the sole of the foot," SPIE medical imaging, 2016

Conclusion

- Measurement based on the articular surface
  - 3D measurement of *angle, narrowing, coverage* between bones

- TODO
  - Verification of proposed method with comparison among
    - Articular surface-based method and anatomical point-based method
    - Manual designation and automatic designation of the anatomical landmarks
  - Clinical analysis on various subjects using quantified posture

→ By using proposed methods, we can capture 3D posture of the foot bone and quantify <u>inter-patient or inter-posture</u> differences using standardized measurement process

THANK YOU ☺