Statistical Shape Model of Infant Femurs and the Relationship with the Severity of Hip Dysplasia

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Overview

Hip Dysplasia

Statistical Shape Modeling

Objectives

Methodology

Preliminary Results

Future Work

Hip Dysplasia in Infants

Developmental Dysplasia of the Hip (DDH)

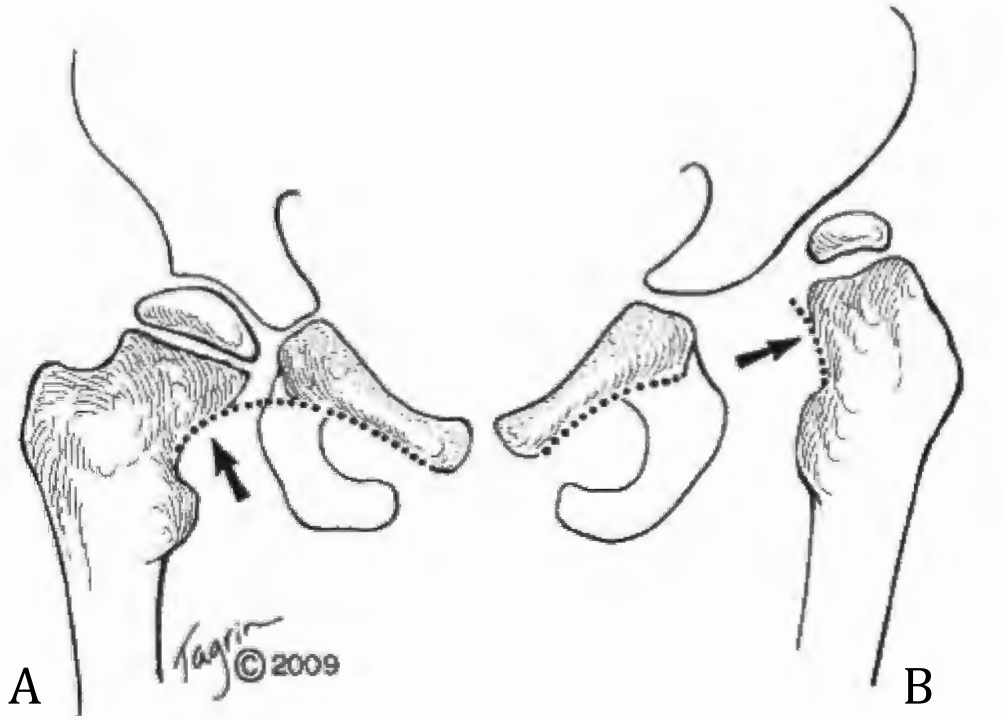
- Hip disorder

Abnormal development, instability, or misalignment

- Subluxation or dislocations

Risk factors

- Family history
- Breech delivery
- Being born female



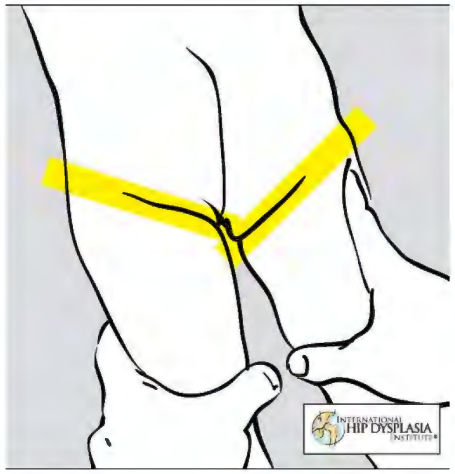
Normal hip (A) and a dislocated hip (B) (Holmes, 2012)

Clinical Evaluations

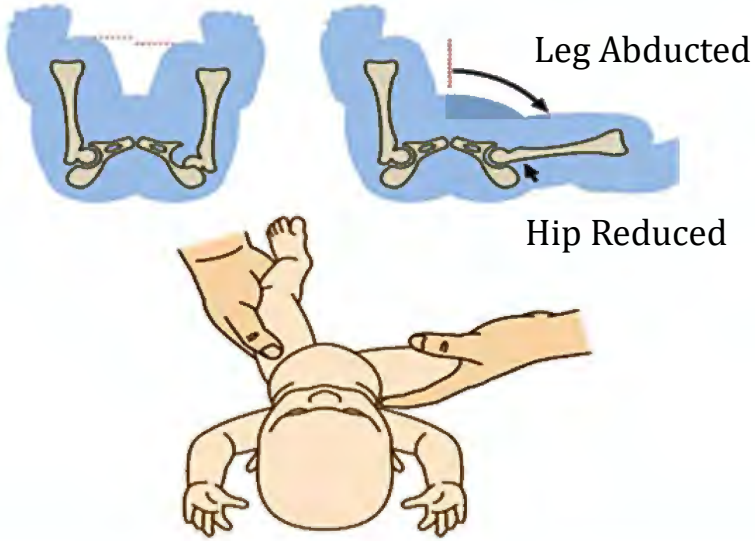
Routine examinations of newborns

General inspection

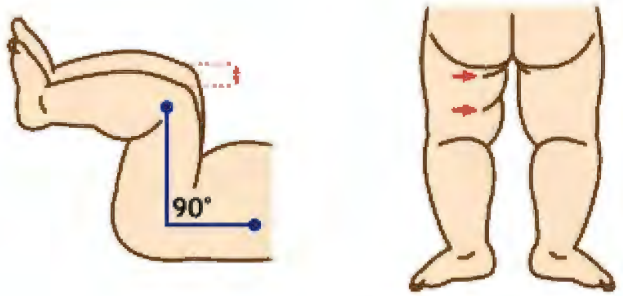
- Asymmetric gluteal folds
- Limited abduction
- A positive “clunk” felt on the Ortolani maneuver (Riccabona and Gassner, 2014)



International Hip Dysplasia Institute



Ortolani maneuver (Bracken et al., 2012)



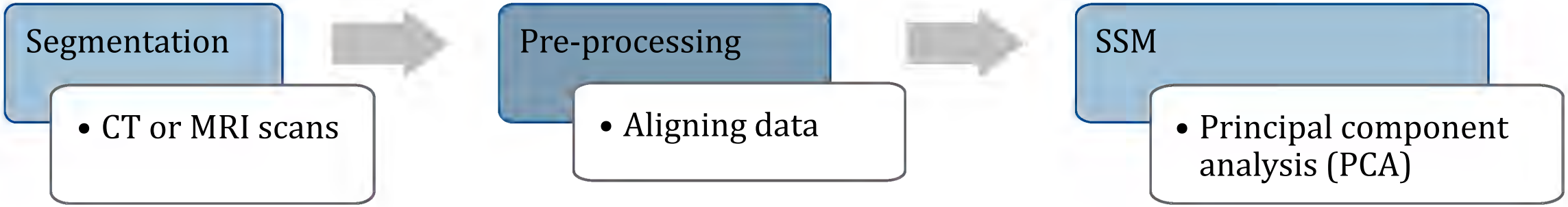
(Bracken et al., 2012)

Statistical Shape Modeling (SSM)

A way to convert image data to meaningful information (Davies et al., 2008)

- Use statistical models to learn patterns of variability (i.e., dominant features or modes) in a class of objects (i.e., femurs)

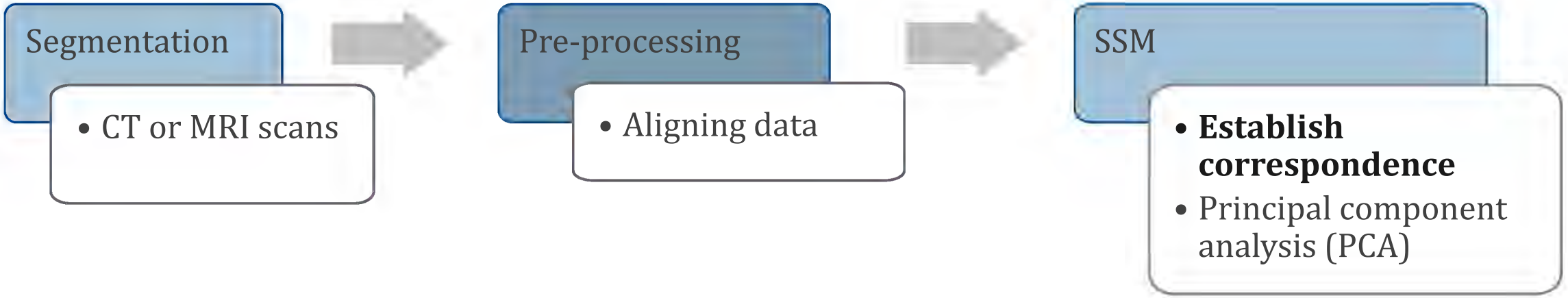
Assumes each shape is a deformed version of a reference shape (Zheng et al., 2017)



Particle-based SSM

Locations of correspondence particles are optimized to represent anatomically equivalent locations on each shape

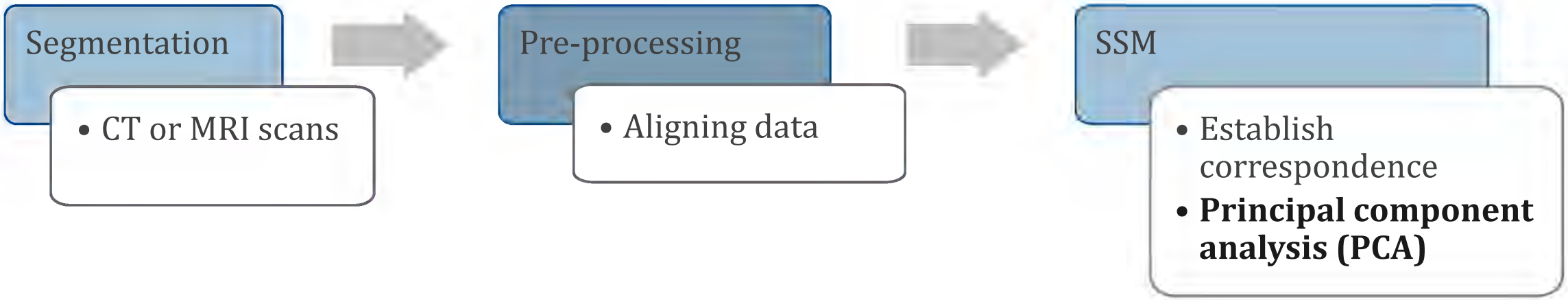
Particles are tracked over a set of shapes to objectively create a mean shape



Particle-based SSM

Principal component analysis (PCA) allows for the distillation of the shape variation into specific modes

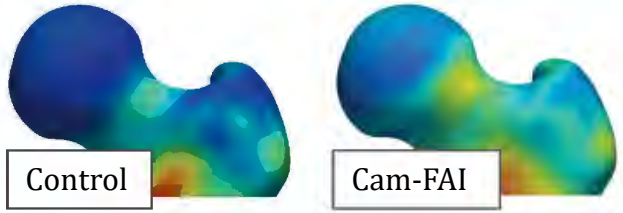
- Variation captured in modes can be used to understand the overall shape variation within the population



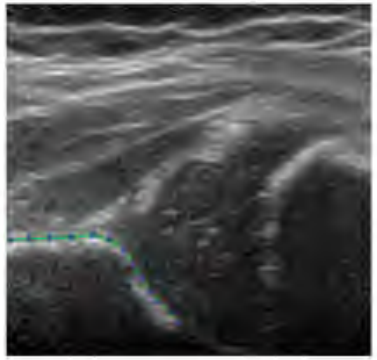
SSM- Applications

Automatic segmentation of brain structures (Shen et al., 2001)

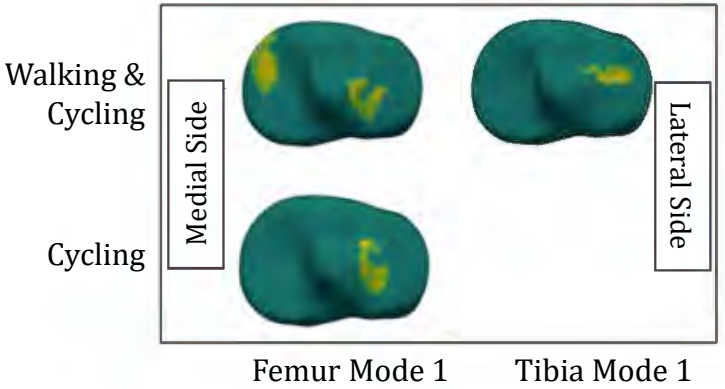
Facial recognition (Drira et al, 2013)



Cortical bone thickness variations (Atkins et al., 2016)



Predicting hip dysplasia development (Bonsel et al., 2022)



Changes in cartilage during walking and cycling (Gatti et al., 2022)

Objectives

1. Quantify the anatomy of the infant femur using shape models
2. Assess the relationship between the variations in femur shape with the severity of hip dysplasia

Padua Collection

Postmortem infant specimens

Compiled and classified by Ortolani

- Includes both normal and dysplastic hips

University of Padua, Italy

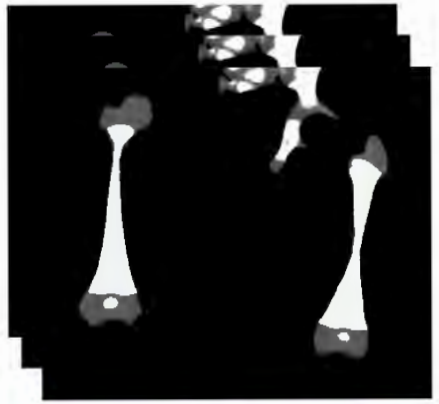
CT scans

- 4 specimens (8 femurs)

Dr. Ortolani (Mubarak, 2014)

Developing 3D surface models

Import CT scans



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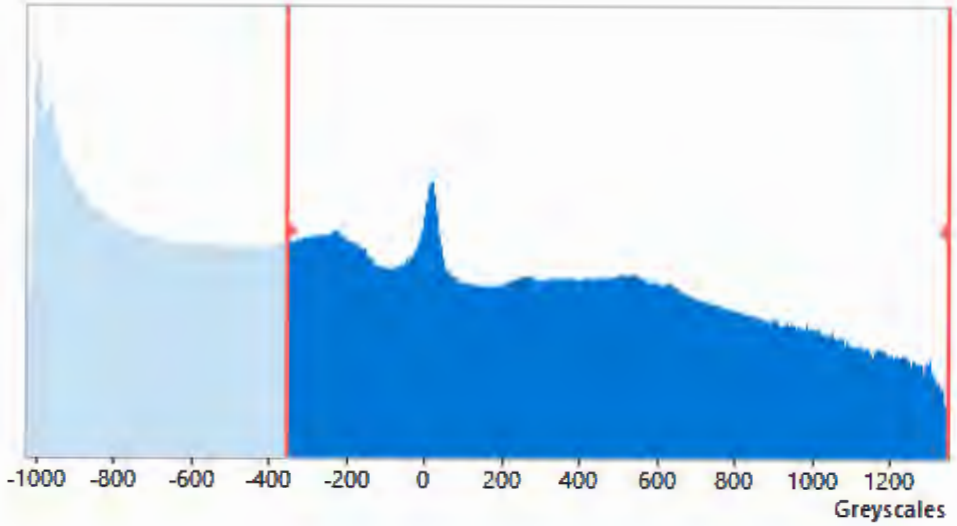
Segmentation

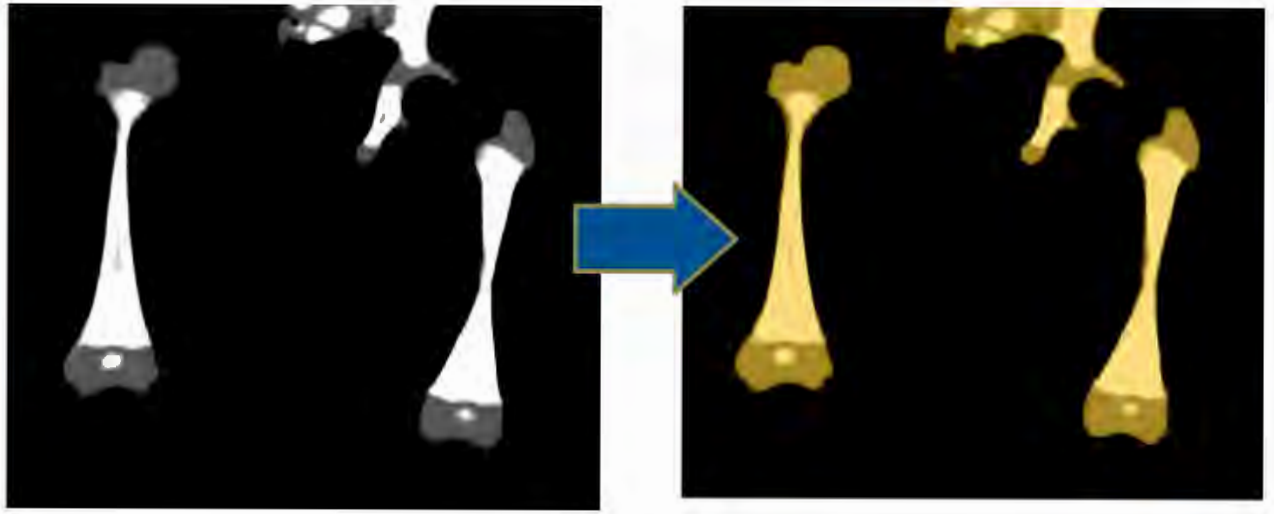
Create surface model

Export STL

Segmentation

Segment using threshold of -350

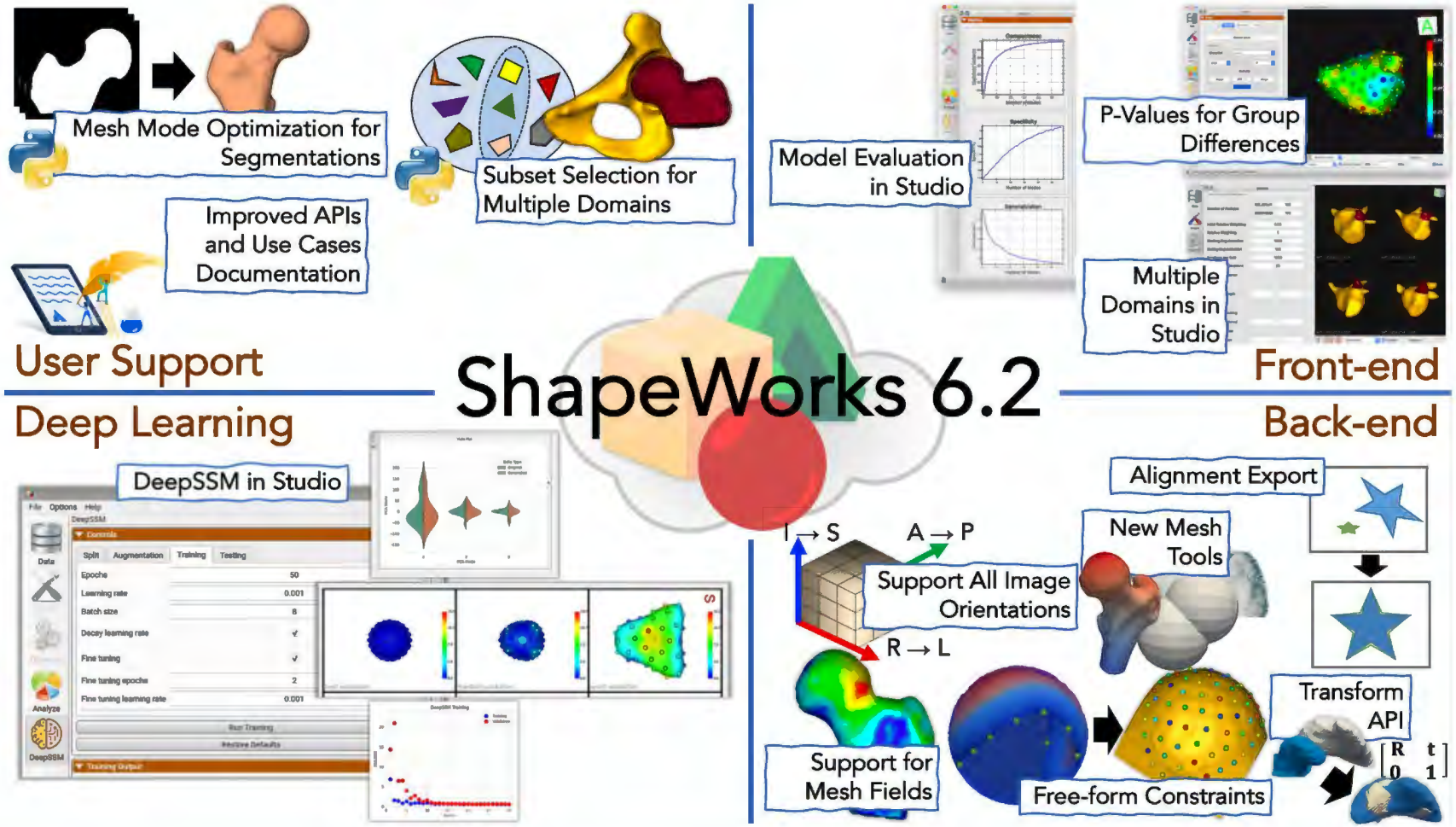




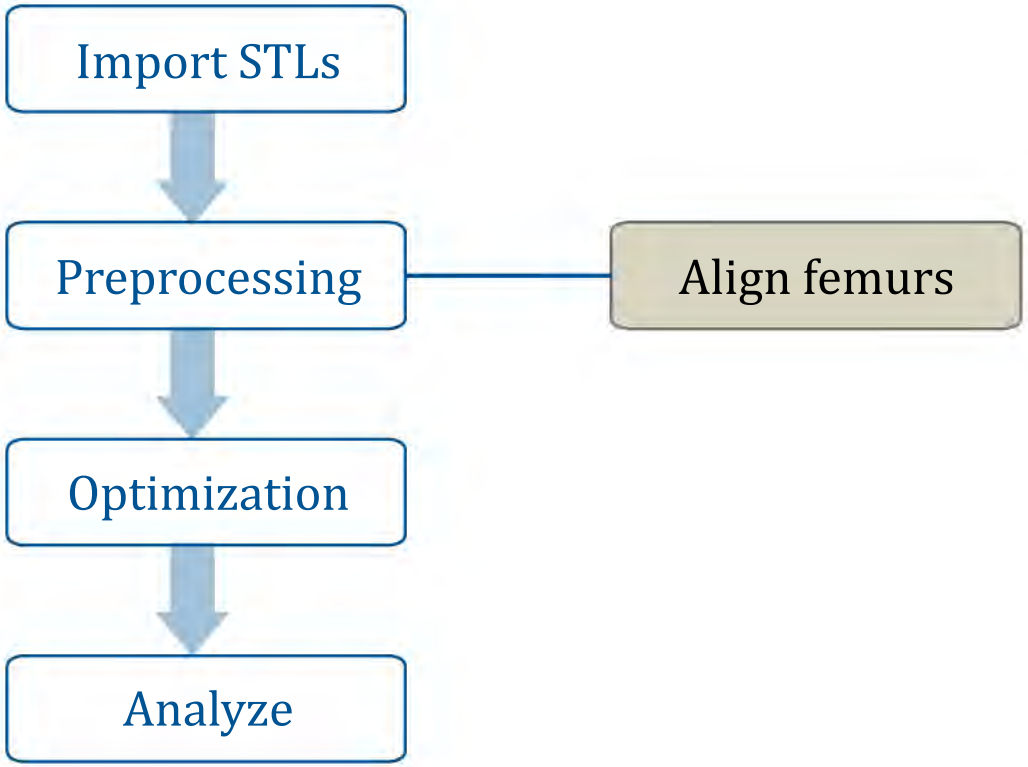
Segmented 3D surface models

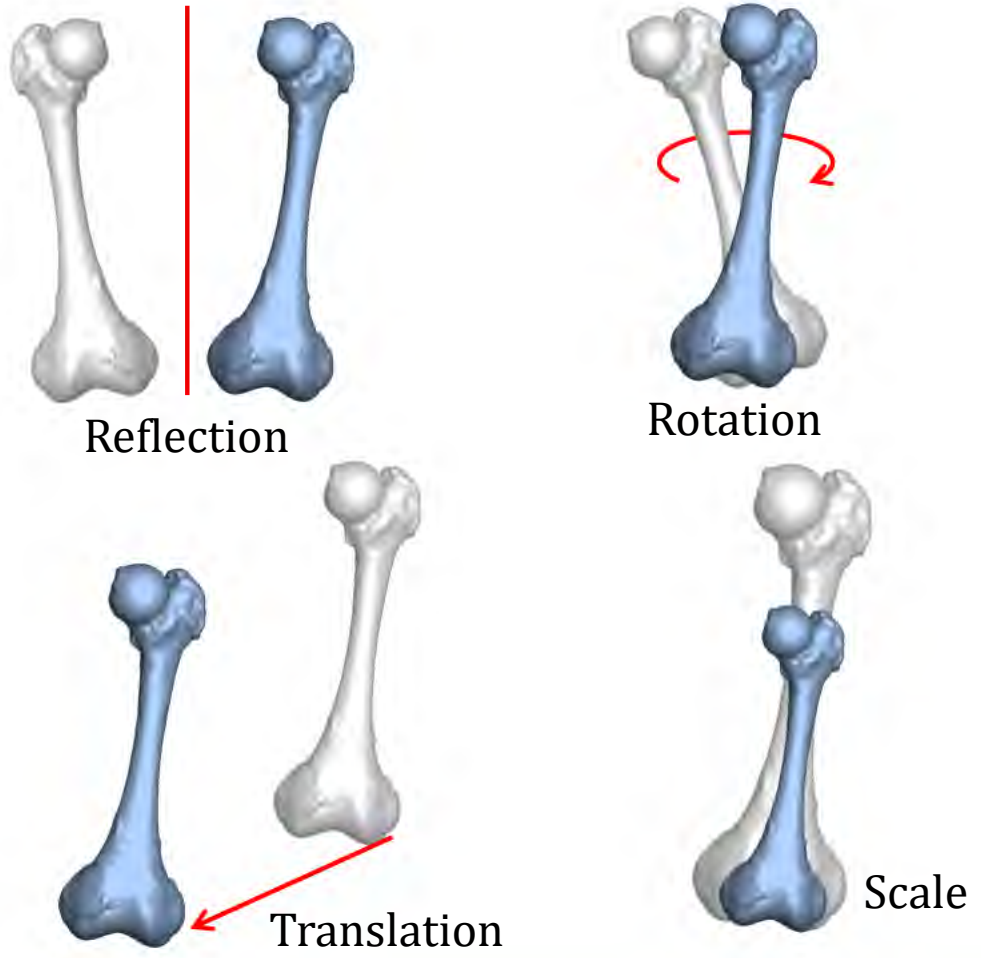
Specimen 387	Specimen 239	Specimen 398	Specimen 30
			

Particle-based SSM Process

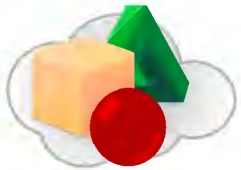


SSM - Preprocessing





SSM - Optimization



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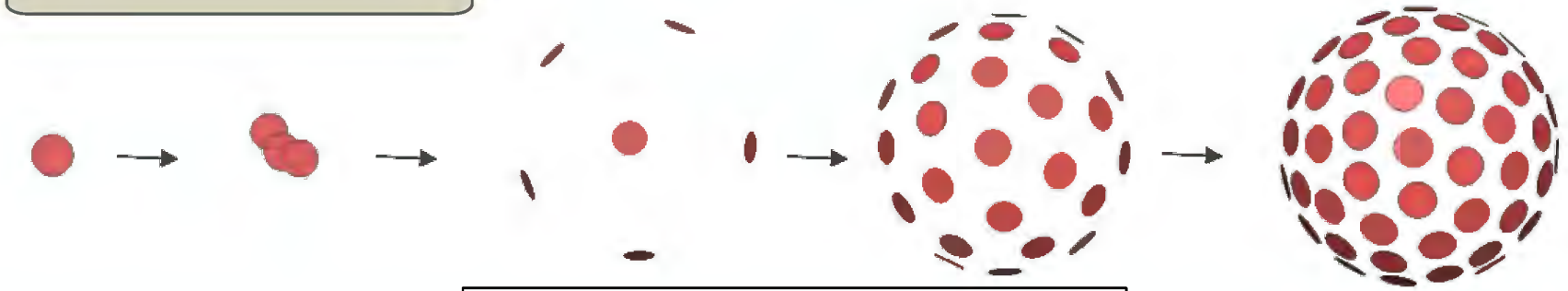
Import STLs

Preprocessing — Align femurs

Optimization — Correspondence

Analyze

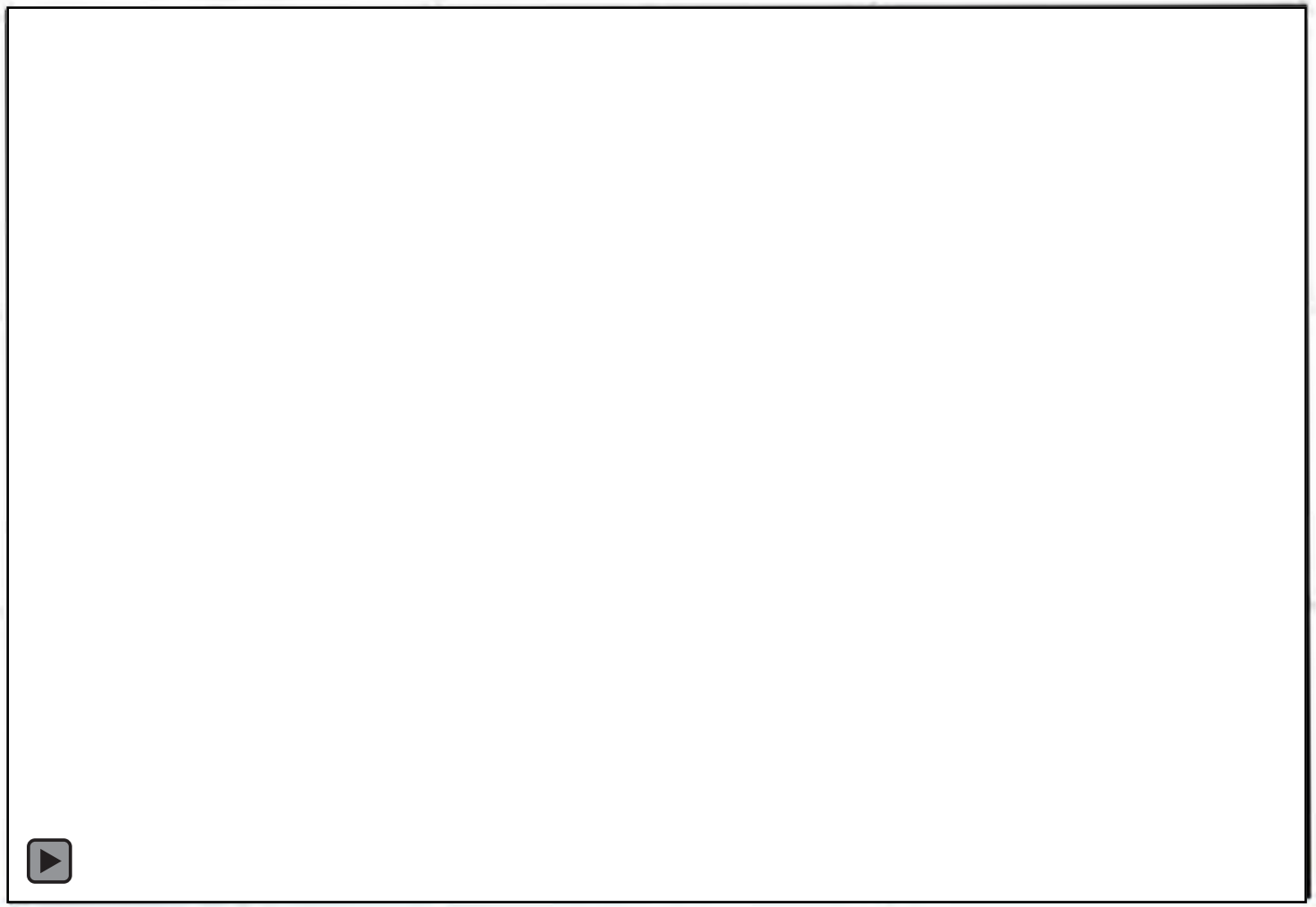


Multi-Scale Particle Optimization

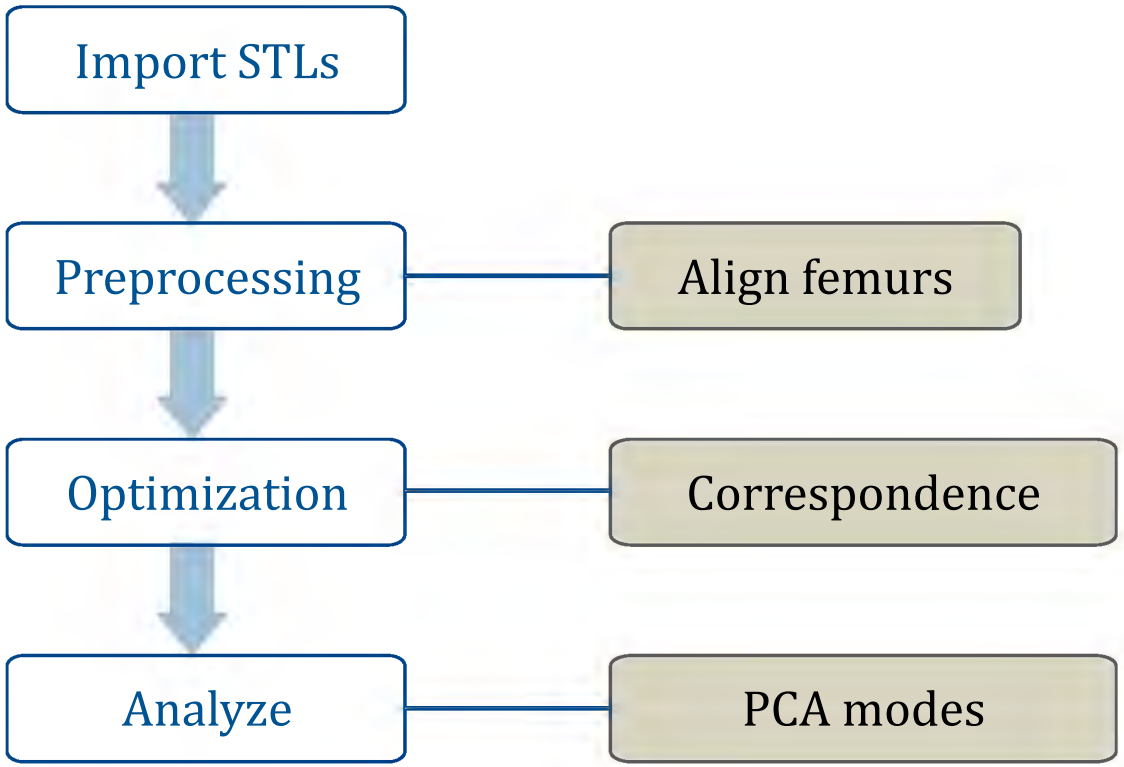
SSM - Optimization

512 particles

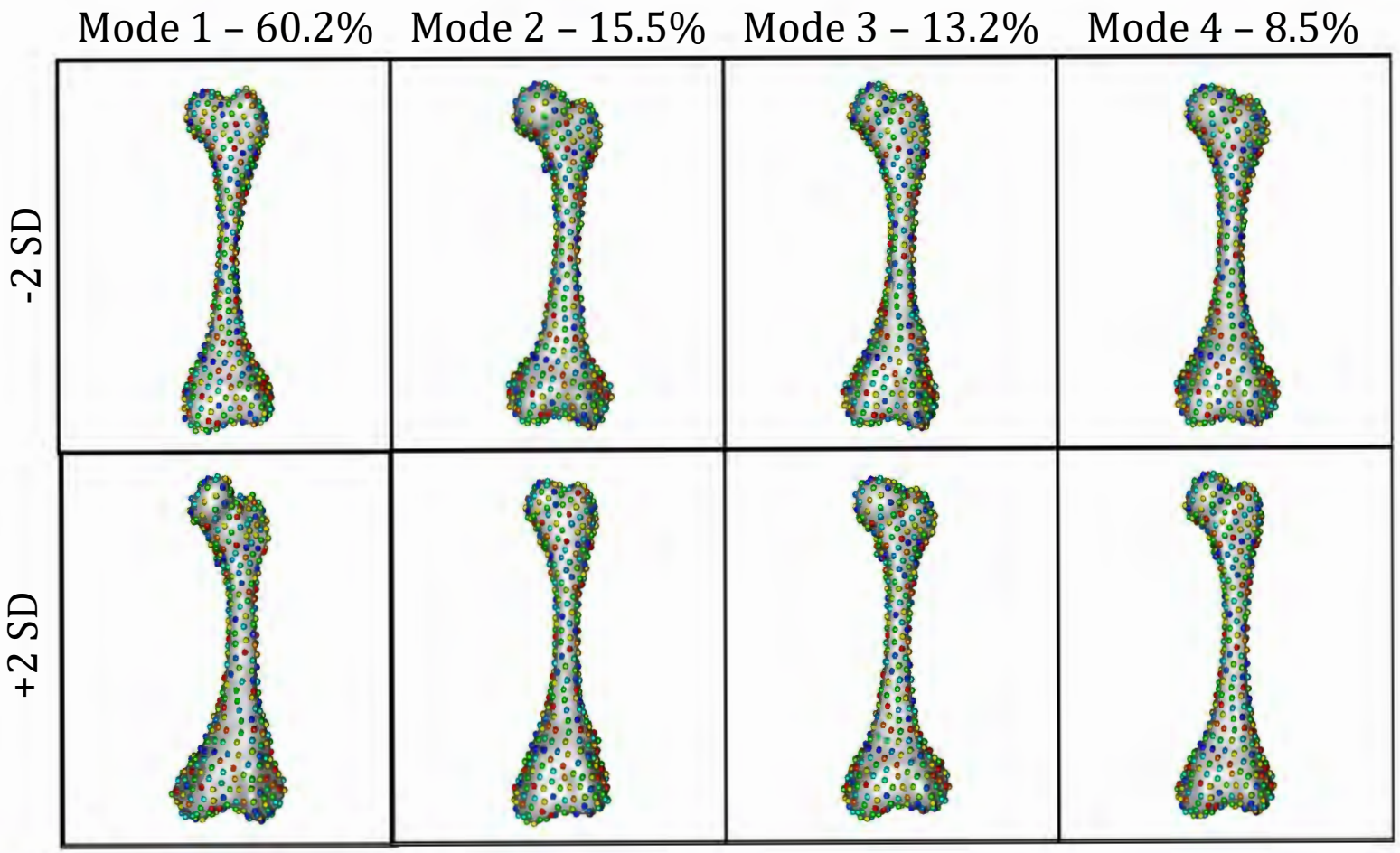
1000 iterations per split



SSM – PCA Modes

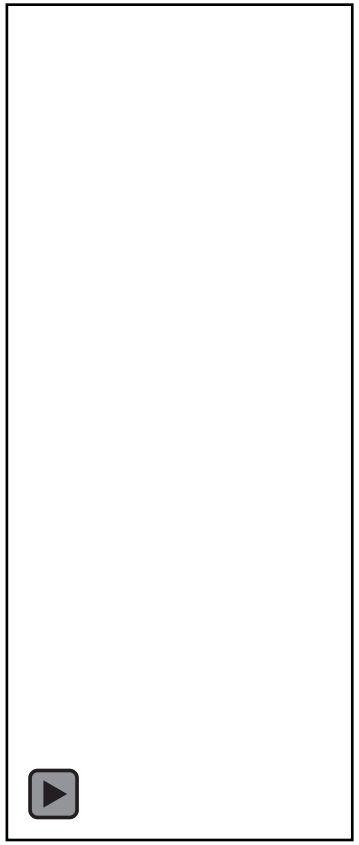


SSM – PCA Modes

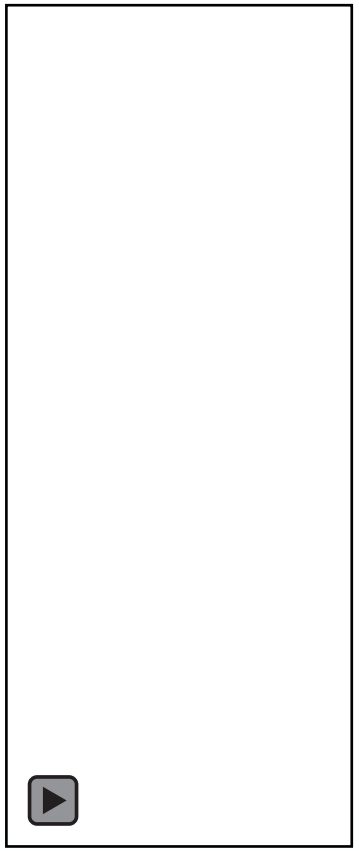


SSM – Preliminary Results – PCA

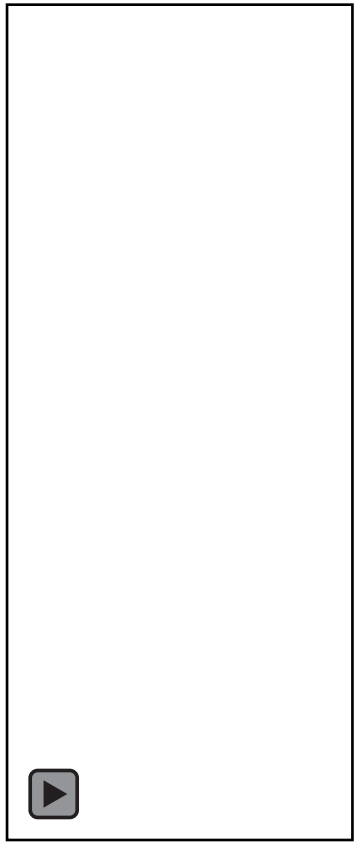
Mode 1 – 60.2%



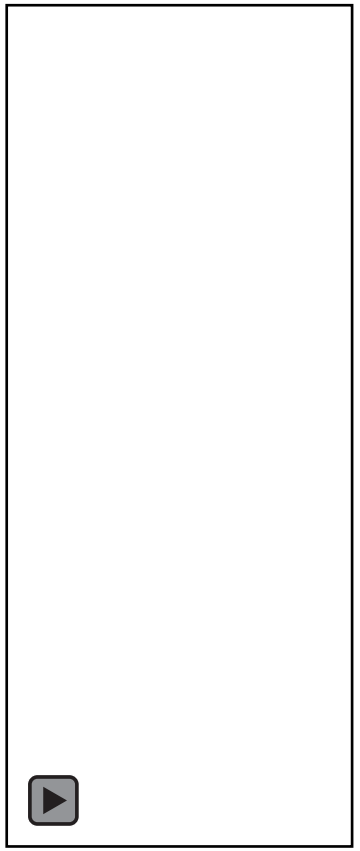
Mode 2 – 15.5%



Mode 3 – 13.2%



Mode 4 – 8.5%

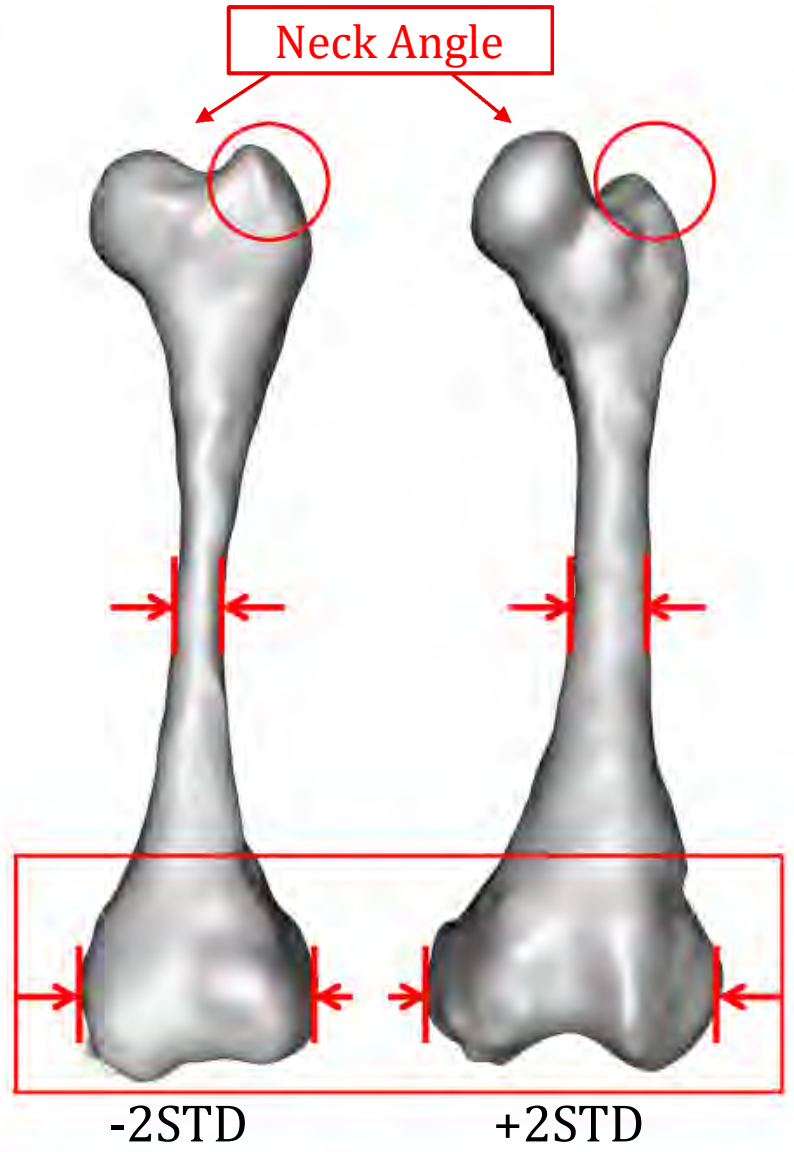


Range: -2STD to +2STD

SSM – Preliminary Results – PCA Mode 1

Mode 1: 60.2%

- Neck shaft angle
- Greater trochanter
- Shaft and distal width
- Prominence of condyles

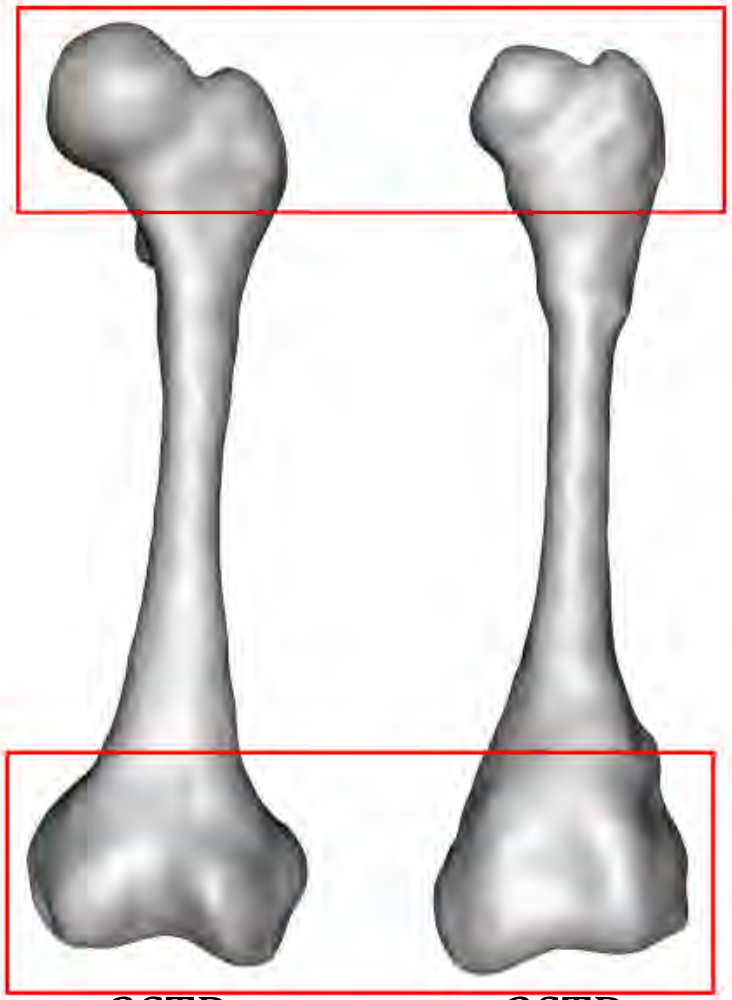


SSM – Preliminary Results – PCA Mode 2

Mode 2: 15.5 %

- Femoral head
- Medial-lateral angle of condyles

Cumulative variance: 75.8%

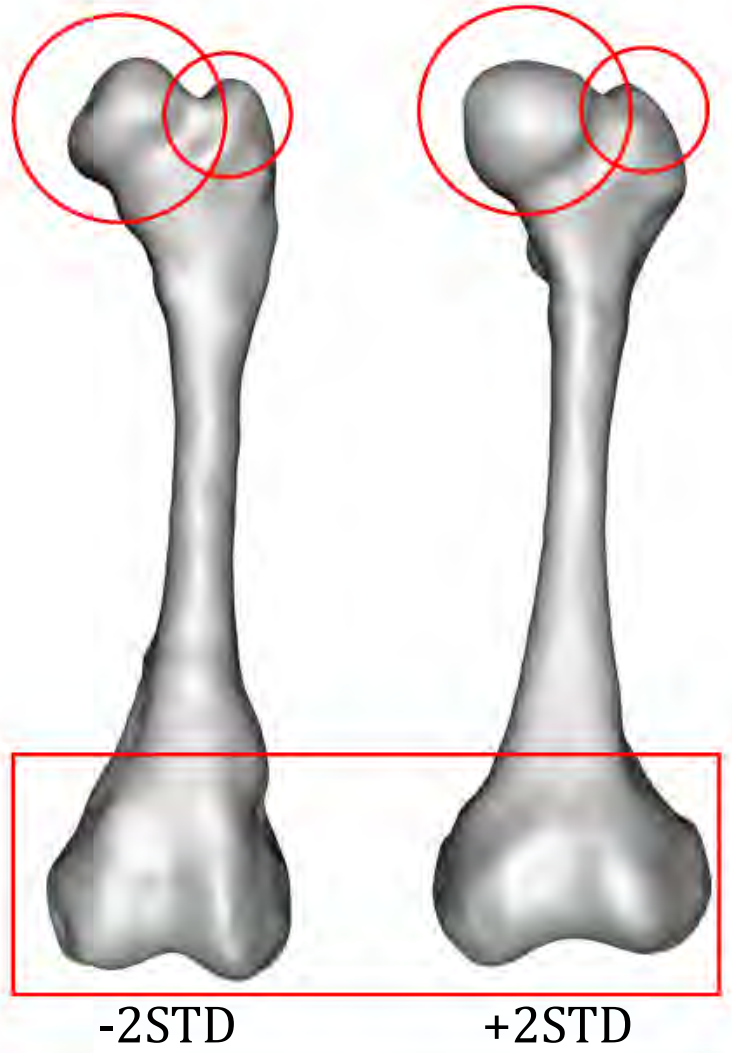


SSM – Preliminary Results – PCA Mode 3

Mode 3: 13.2%

- Sphericity of femoral head
- Trochanter prominence
- Condyles prominence

Cumulative variance: 89.0%

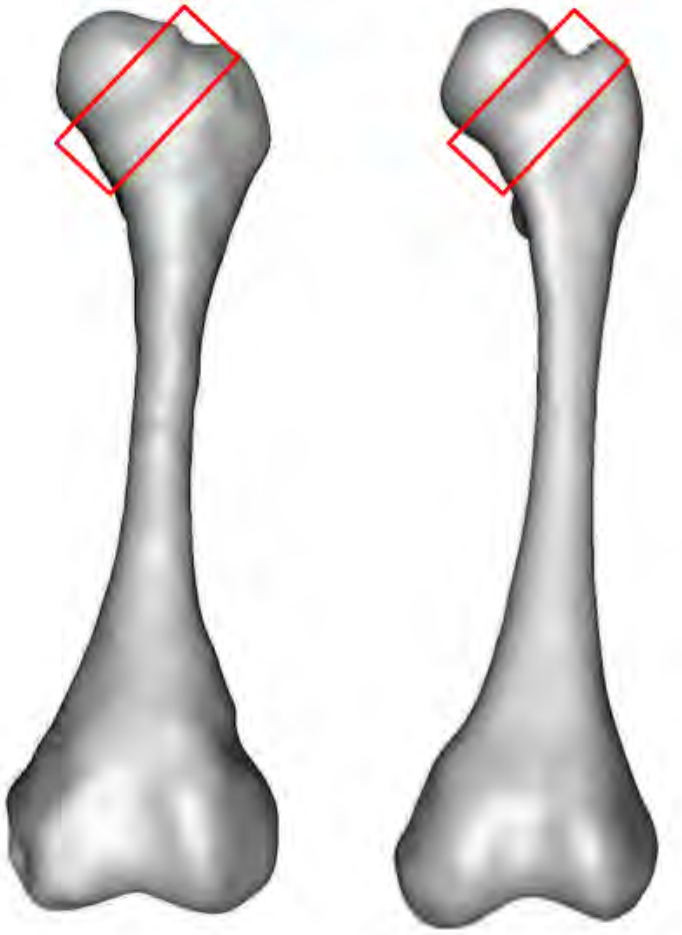


SSM – Preliminary Results – PCA Mode 4

Mode 4: 8.5%

- Femoral neck definition

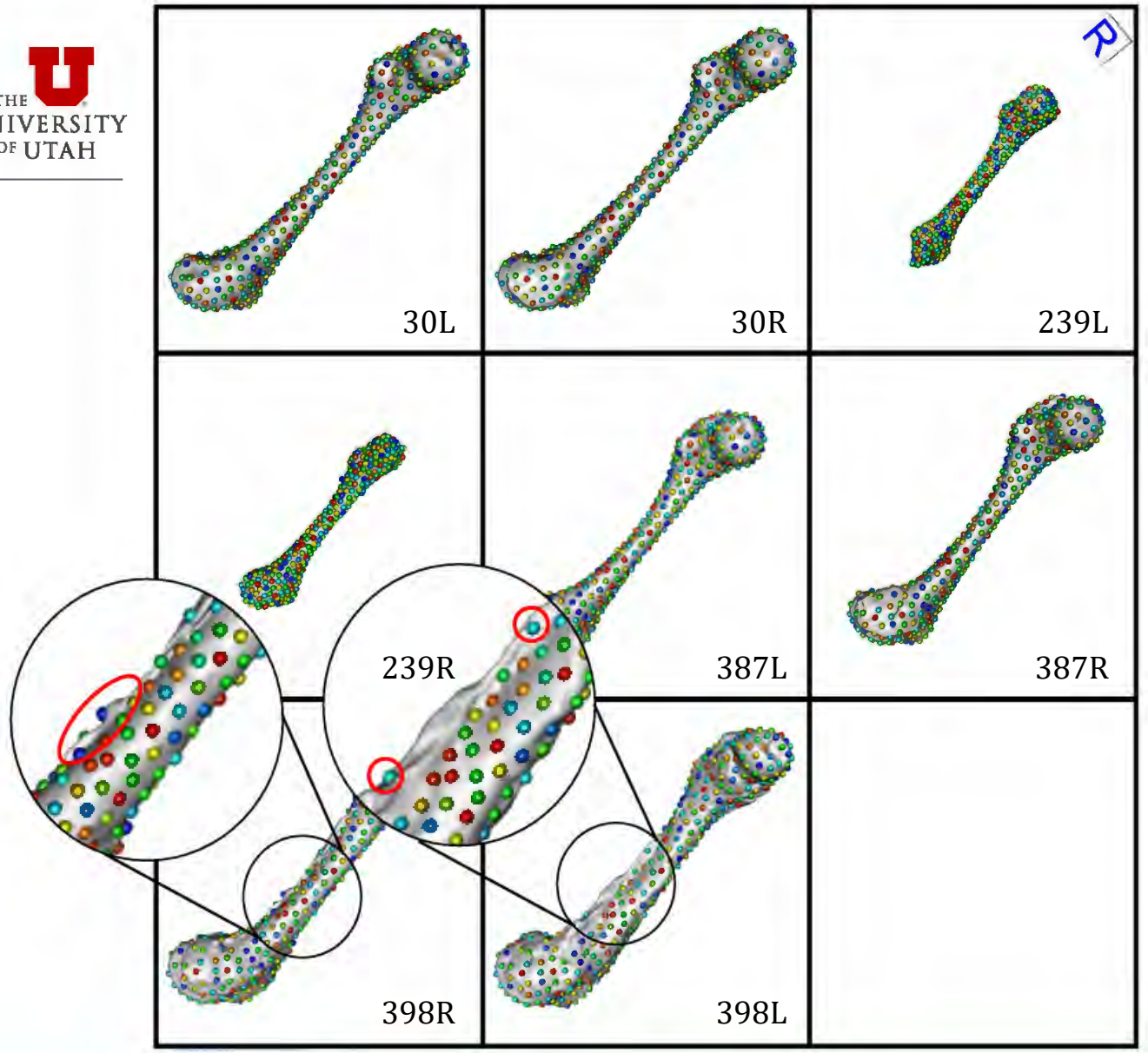
Cumulative variance: 97.5%



-2STD +2STD

SSM – Preliminary Results

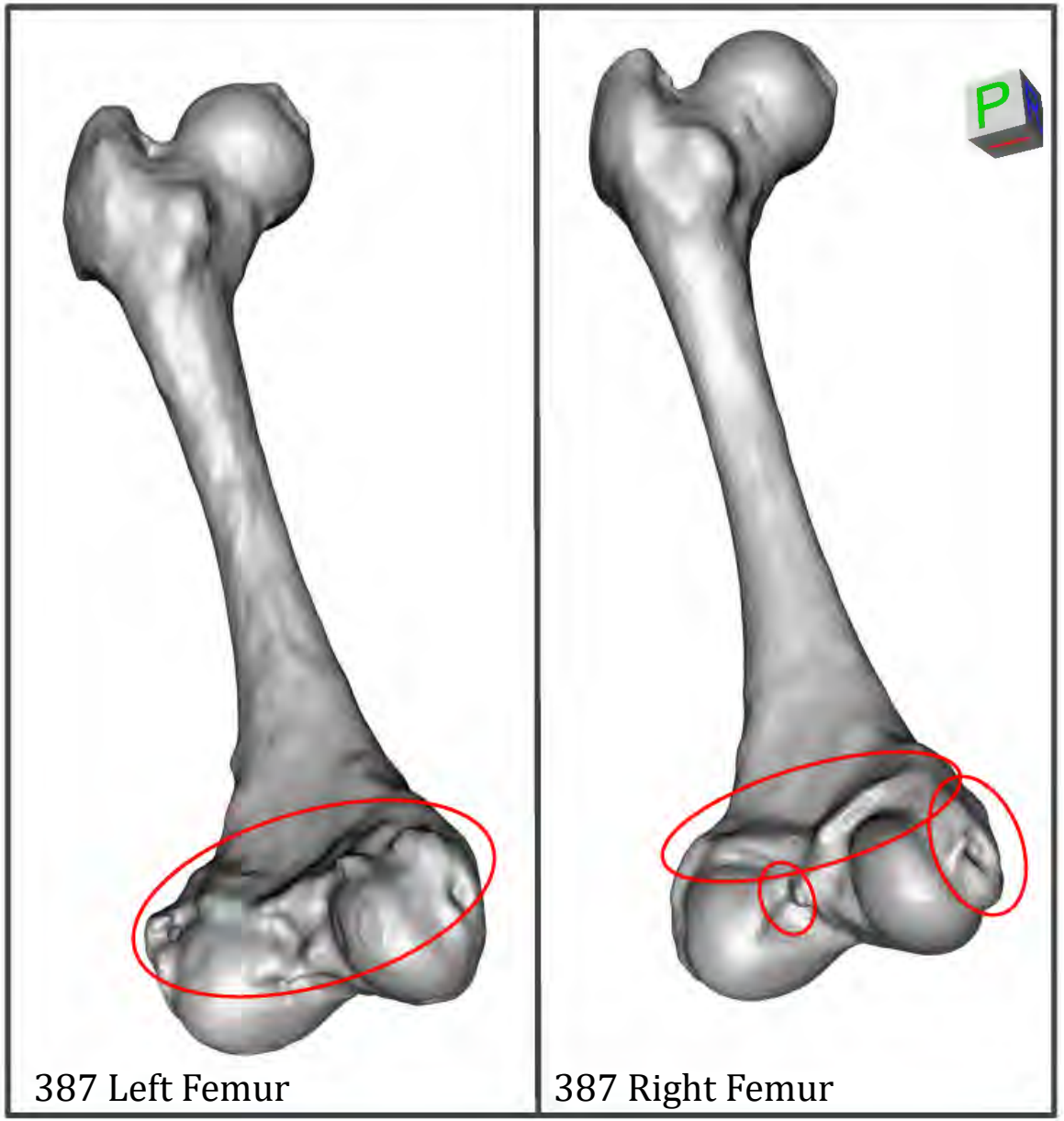
- Generally good correspondence
- Some challenges that require segmentation clean up



SSM – Preliminary Results

Some challenges that require segmentation clean up

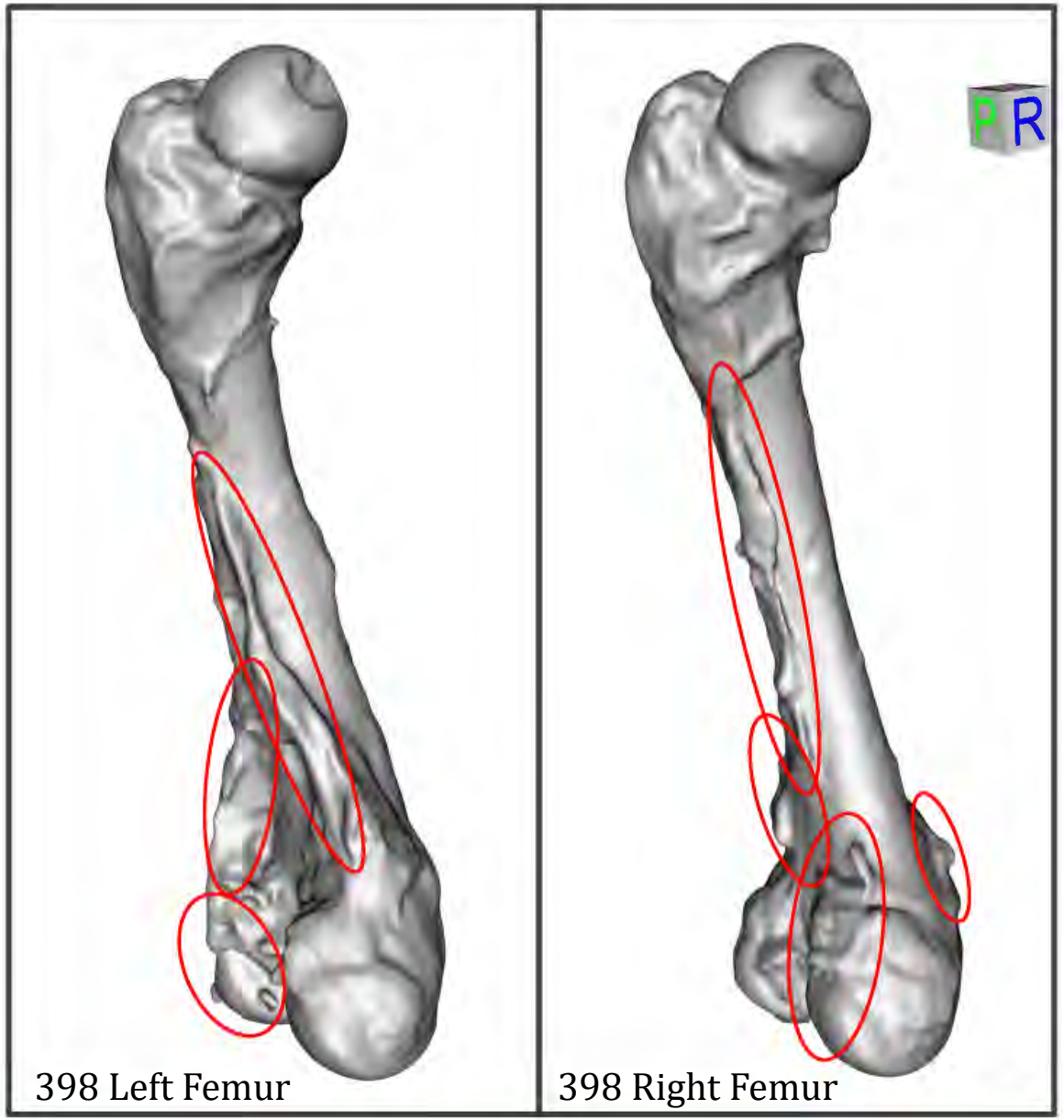
- Medial and lateral condyles
- Medial and lateral epicondyles



SSM – Preliminary Results

Some challenges that require segmentation clean up

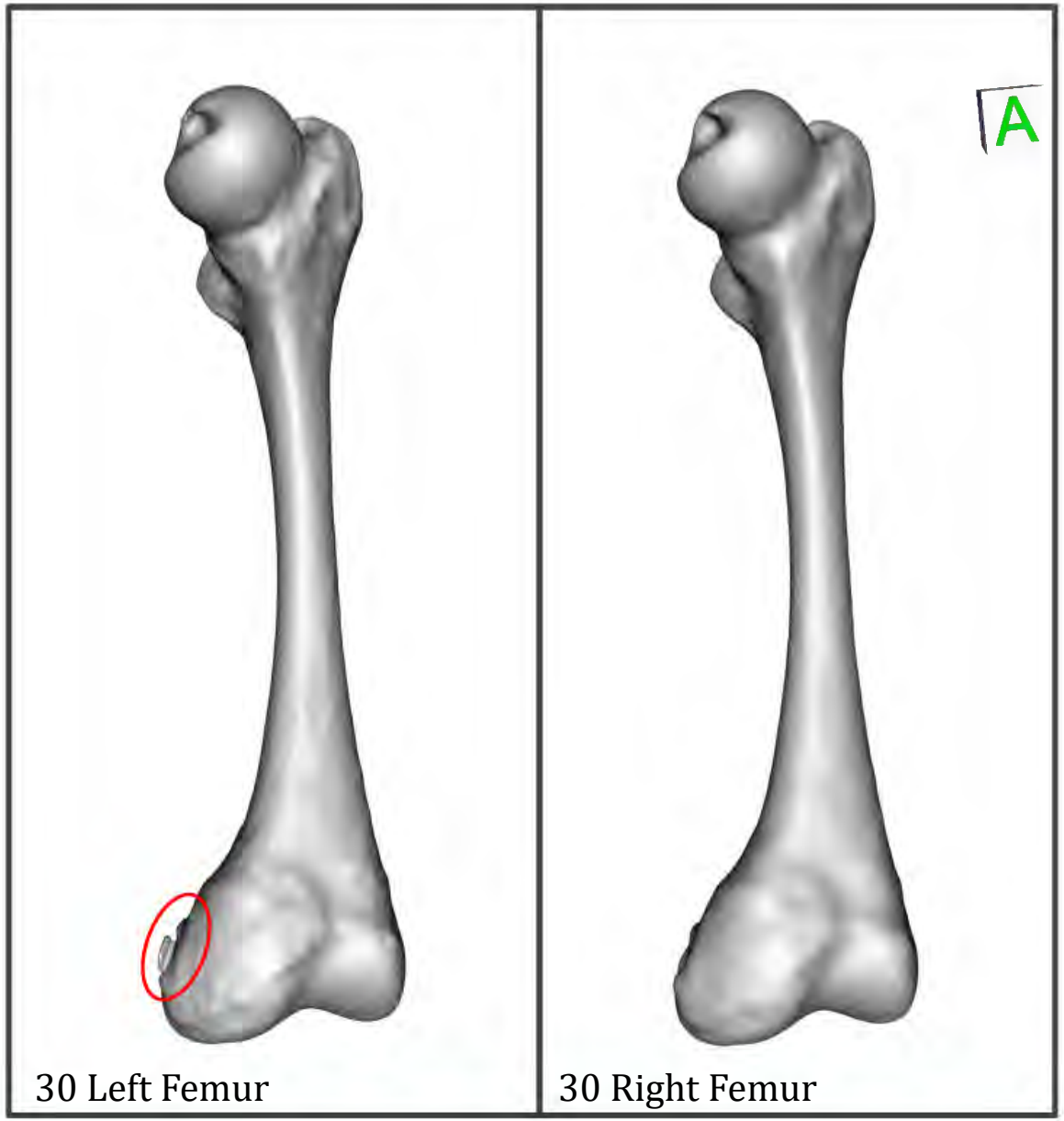
- Femoral shaft
- Medial and lateral condyles
- Femoral head



SSM – Preliminary Results

Some challenges that require segmentation clean up

- Medial condyle



SSM – Preliminary Results

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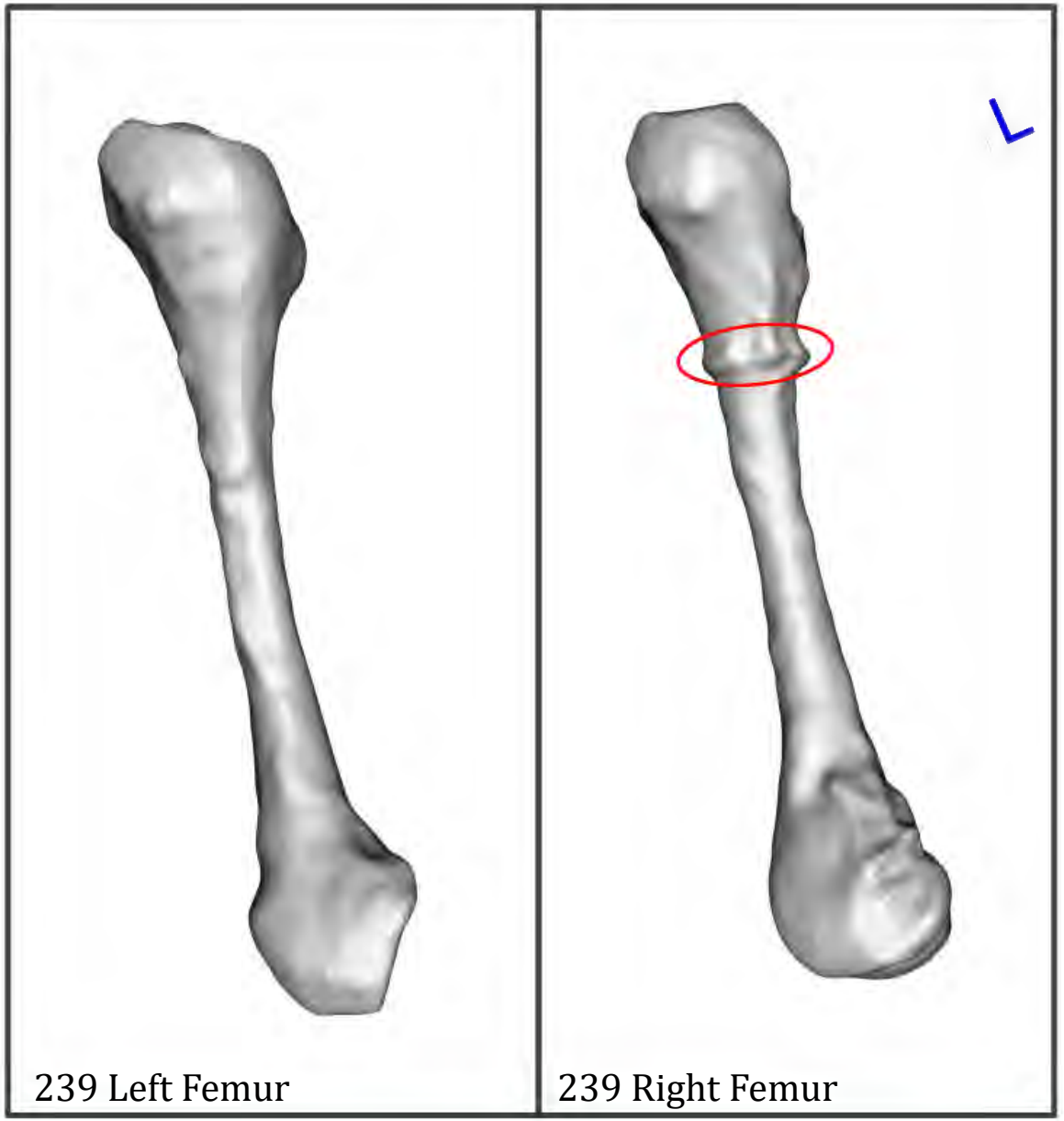
Some challenges that require segmentation clean up

- Femoral shaft



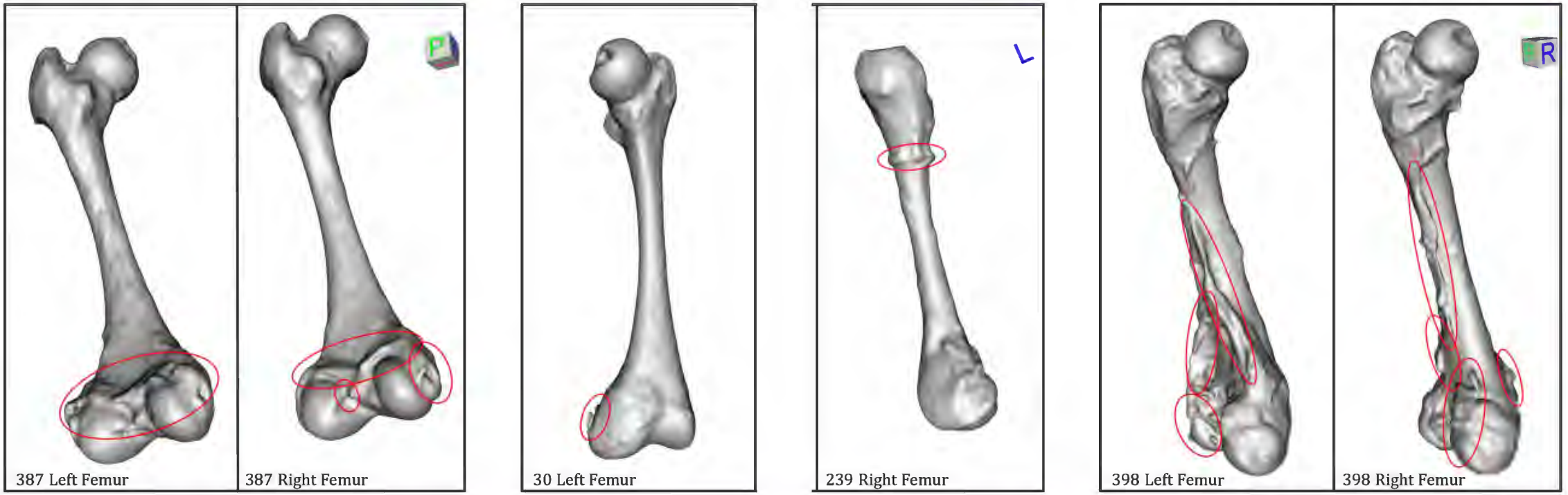
239 Left Femur

239 Right Femur

Future Work

Quantify the anatomy of the infant femur using shape models

- Manual segmentation
- Build statistical shape models of the cleaned femurs



Future Work

Quantify the anatomy of the infant femur using shape models

- Manual segmentation
- Build statistical shape models of the cleaned femurs

Assess the relationship between the variations in femur shape with the severity of hip dysplasia in the current models

- Request access to the entire Padua collection
  - With a larger collection, we can possibly make conclusions about the femur

Related Presentations & ShapeWorks Workshop

Related Presentations

- 11:35 pm – Combination of Statistical Shape Modeling and Statistical Parametric Mapping to Quantify Cartilage Contact Mechanics in Hip Dysplasia
- 1:55 pm – Application of Statistical Shape Modeling to Predict Clinical Metrics of Femoral Head Coverage in Patients with Developmental Dysplasia

ShapeWorks workshop tomorrow at 10:45 will include a live demo

Acknowledgement

Penny Atkins, PhD

Andrew Anderson, PhD

Victor Huayamave, PhD

Charles Price, MD

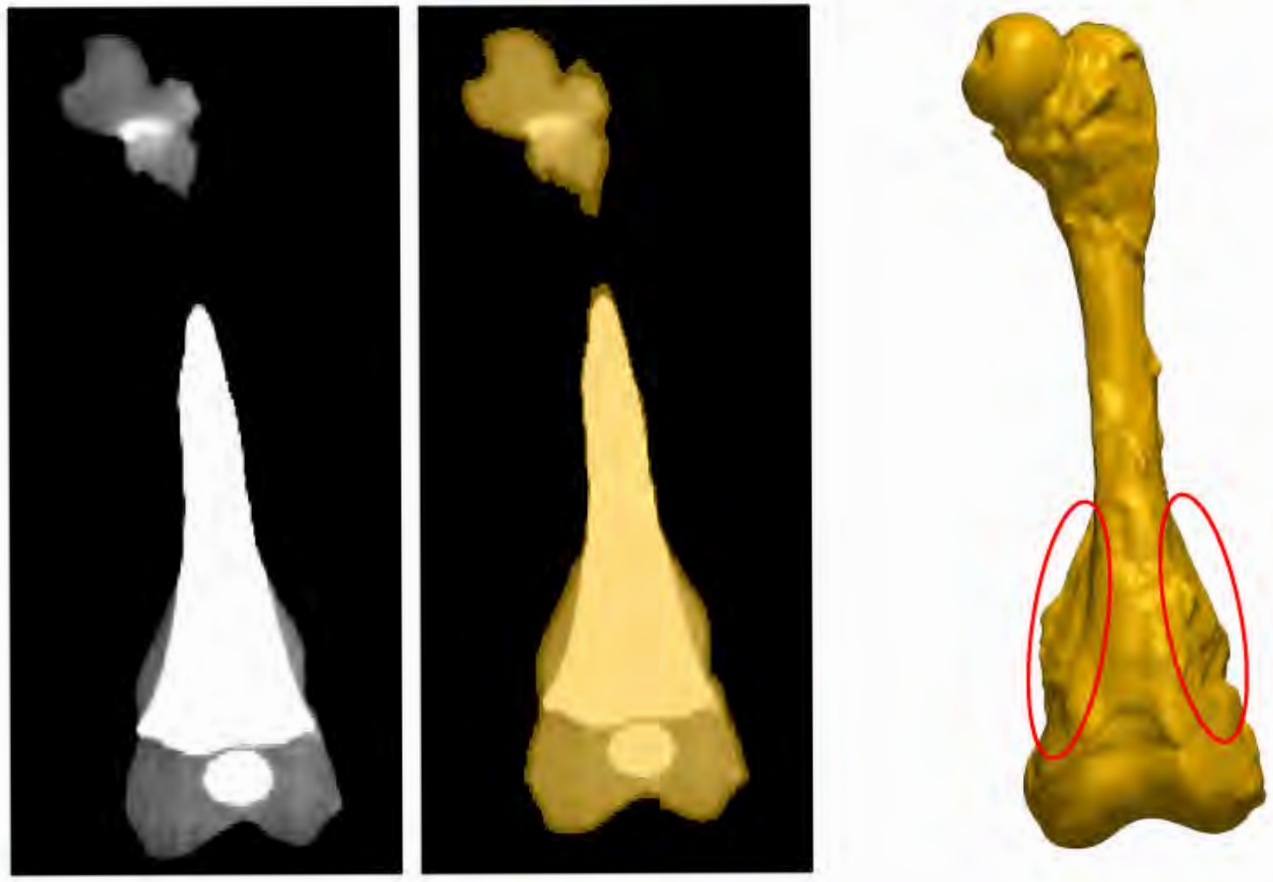
Questions

Appendix

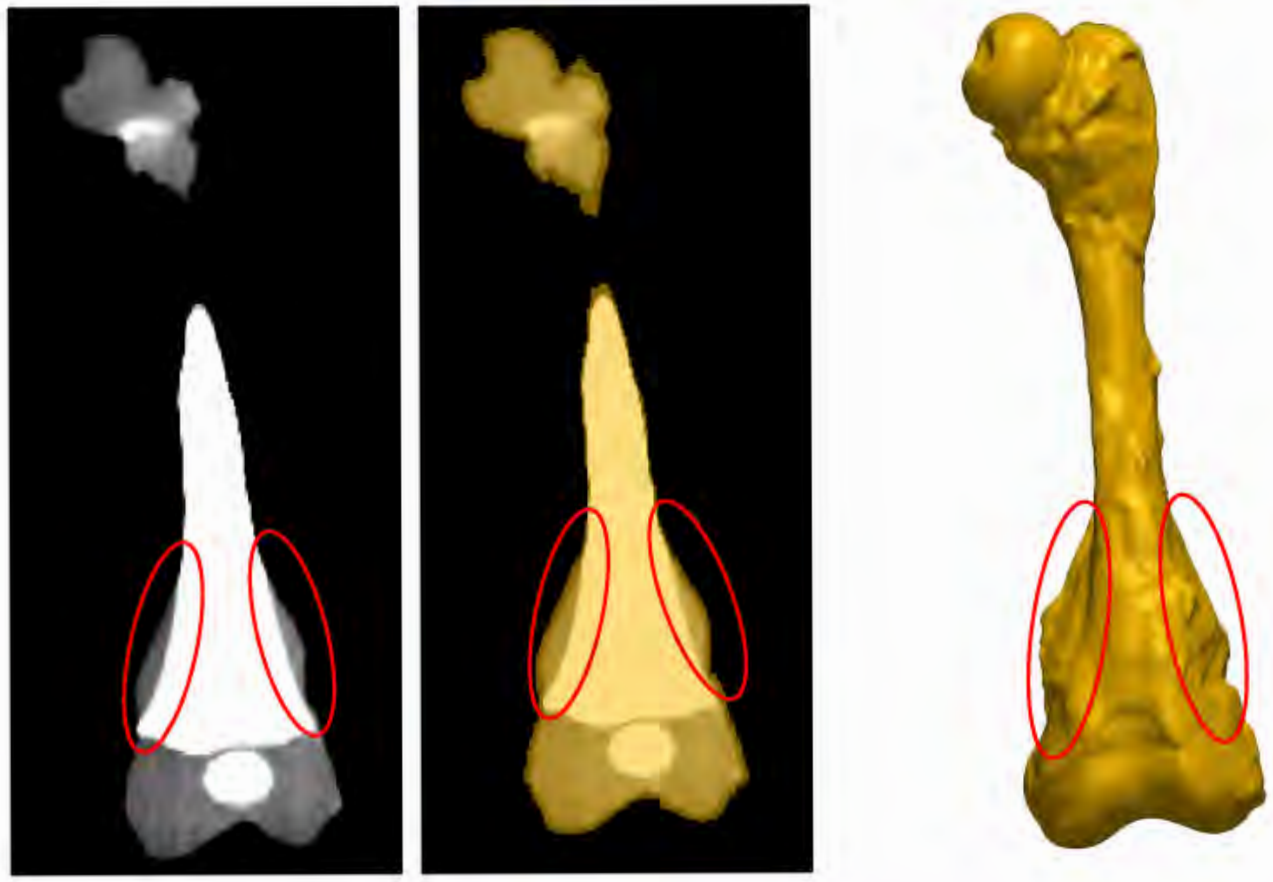
Segmentation – Refinement – 398L

Segmentation – Refinement – 398L

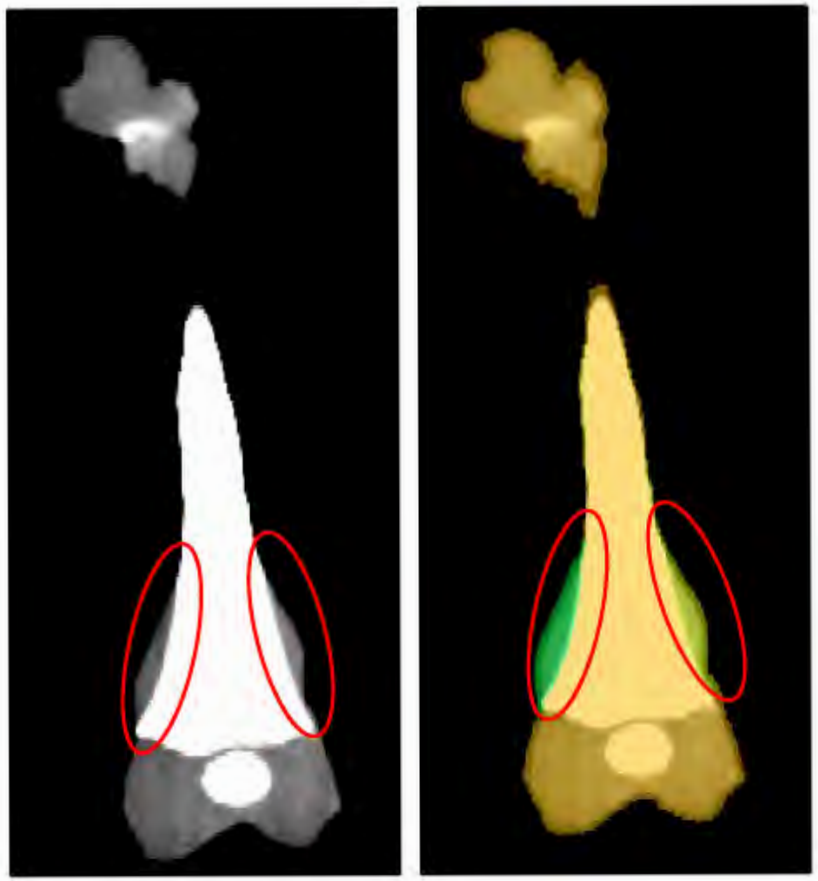
Segmentation – Refinement – 398L

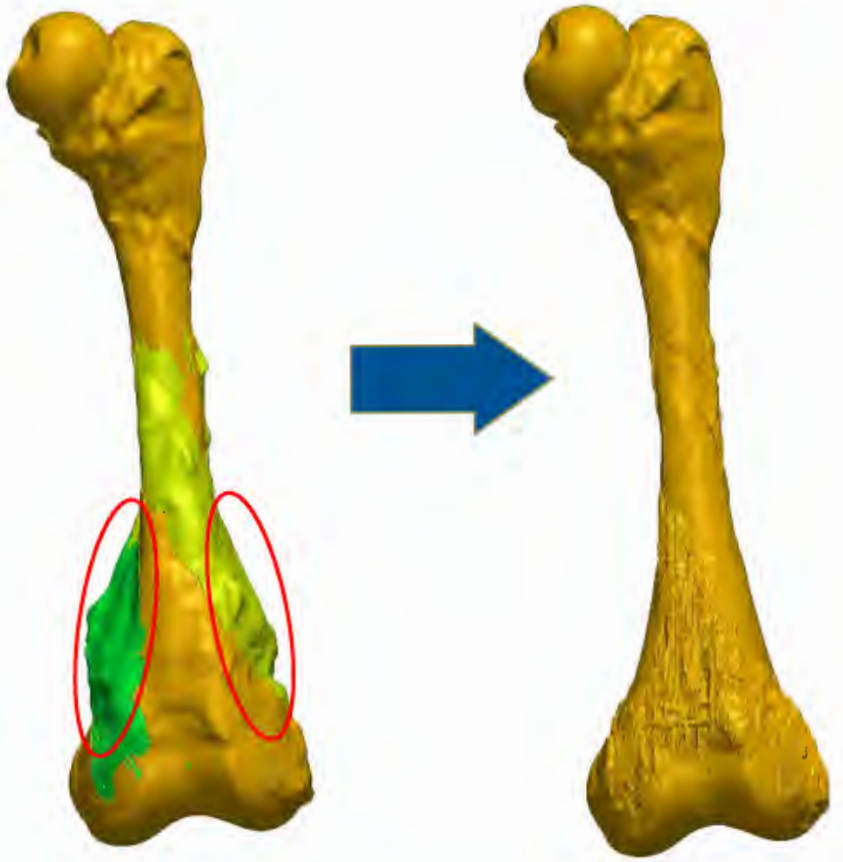


Segmentation – Refinement – 398L



Segmentation – Refinement – 398L





Segmentation – Refinement – Challenges

Distinguishing between soft tissue and cartilage

Split region tool does not work in this situation => Requires manual segmentation