



Development of Analysis Techniques for Dynamic Magnetic Resonance Imaging of the Knee

Application to Tibiofemoral Kinematics

- Knee osteoarthritis (OA) affects 10% men and 13% of women aged 60 and older (Zhang et al., 2010)
- Altered tibiofemoral kinematics in OA patients can potentially accelerate disease progression (Farrokhi et al., 2014)
- Even in ACL-deficient knees without instability symptoms, knee kinematics are altered (Yang et al., 2018)
- Understanding tibiofemoral kinematics is key to assessing knee joint function



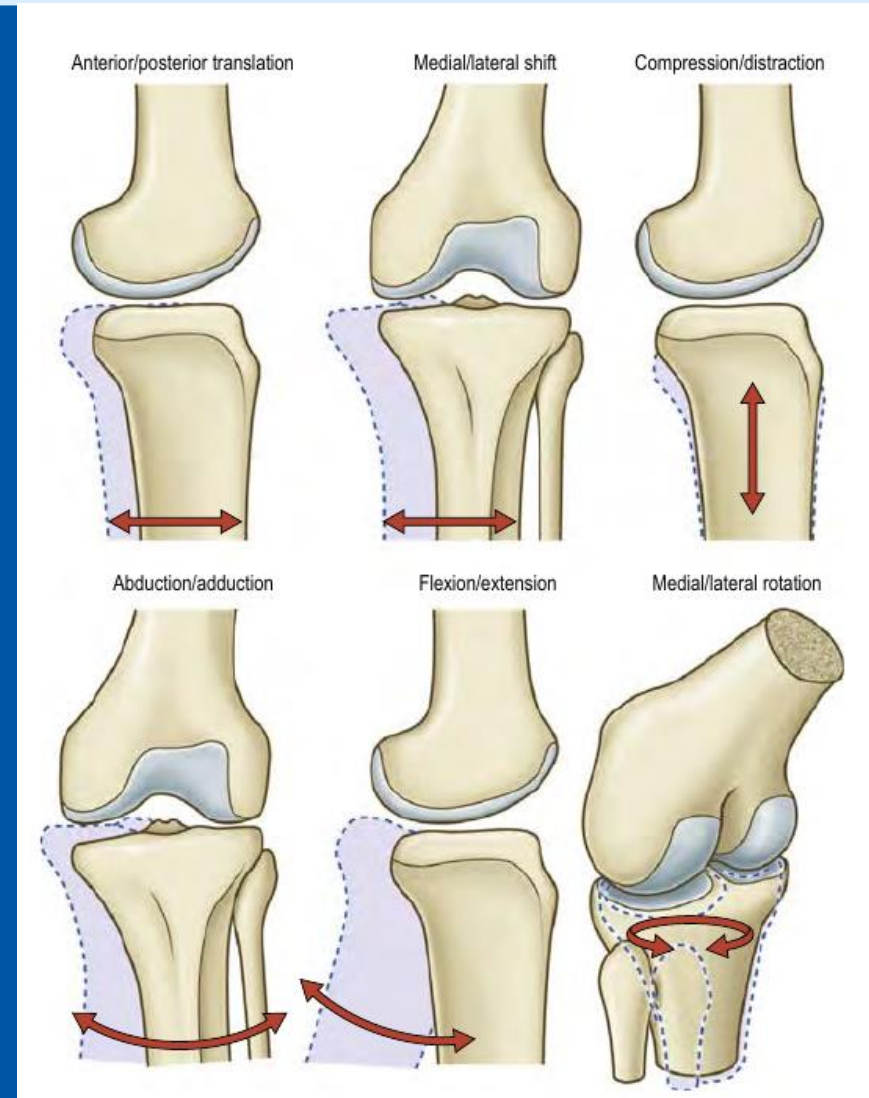
Six Degrees of freedom

3 Rotations

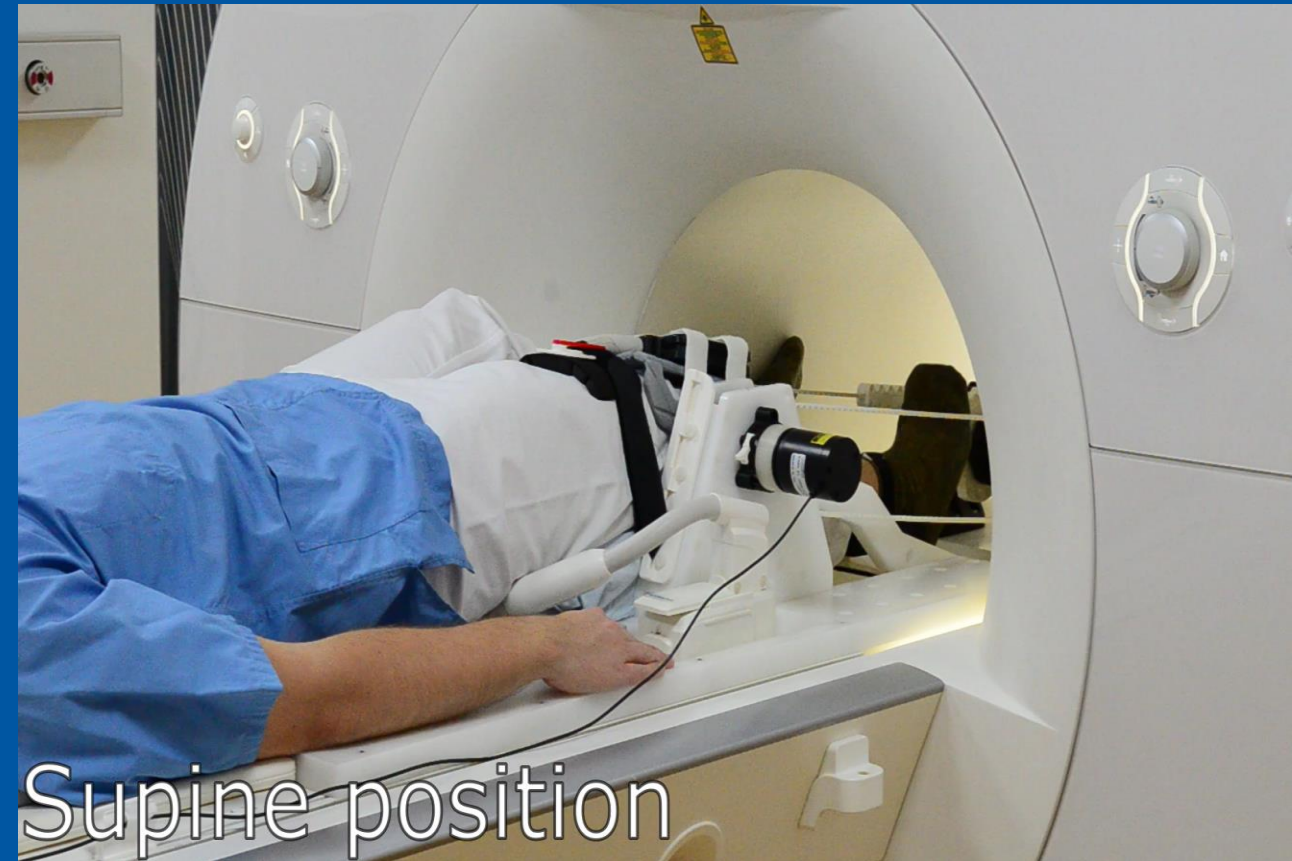
- Flexion-Extension
- Medial-Lateral
- Abduction-Adduction

3 Translations

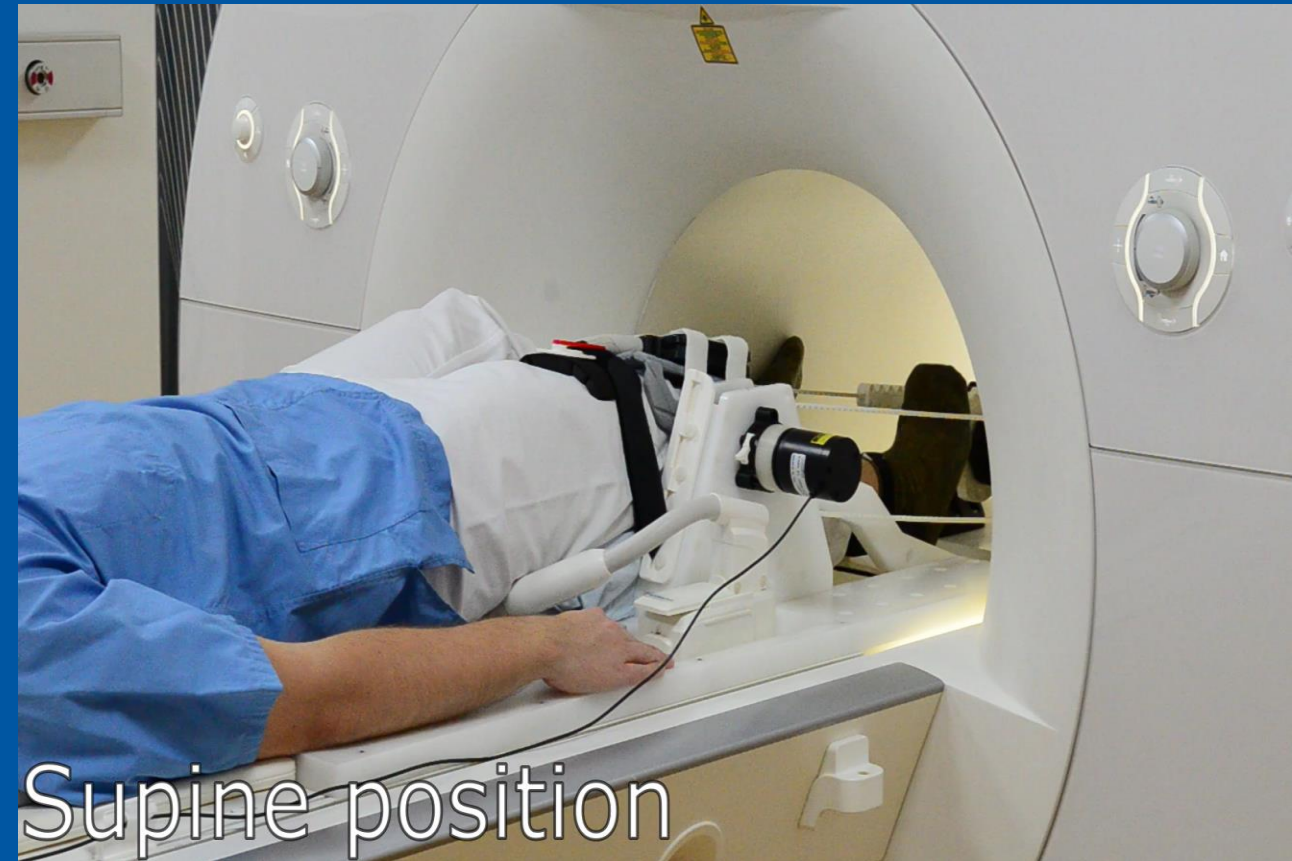
- Anterior-Posterior
- Medial-Lateral
- Compression-Distraction

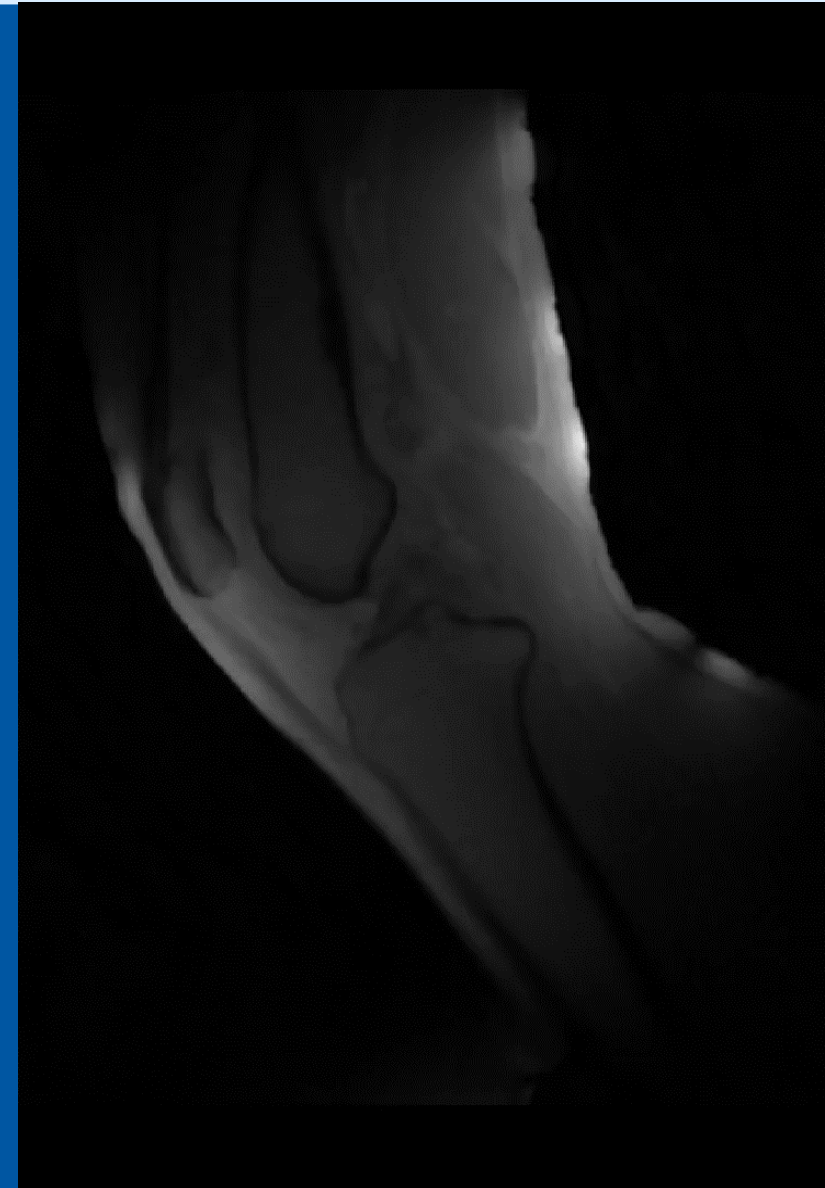
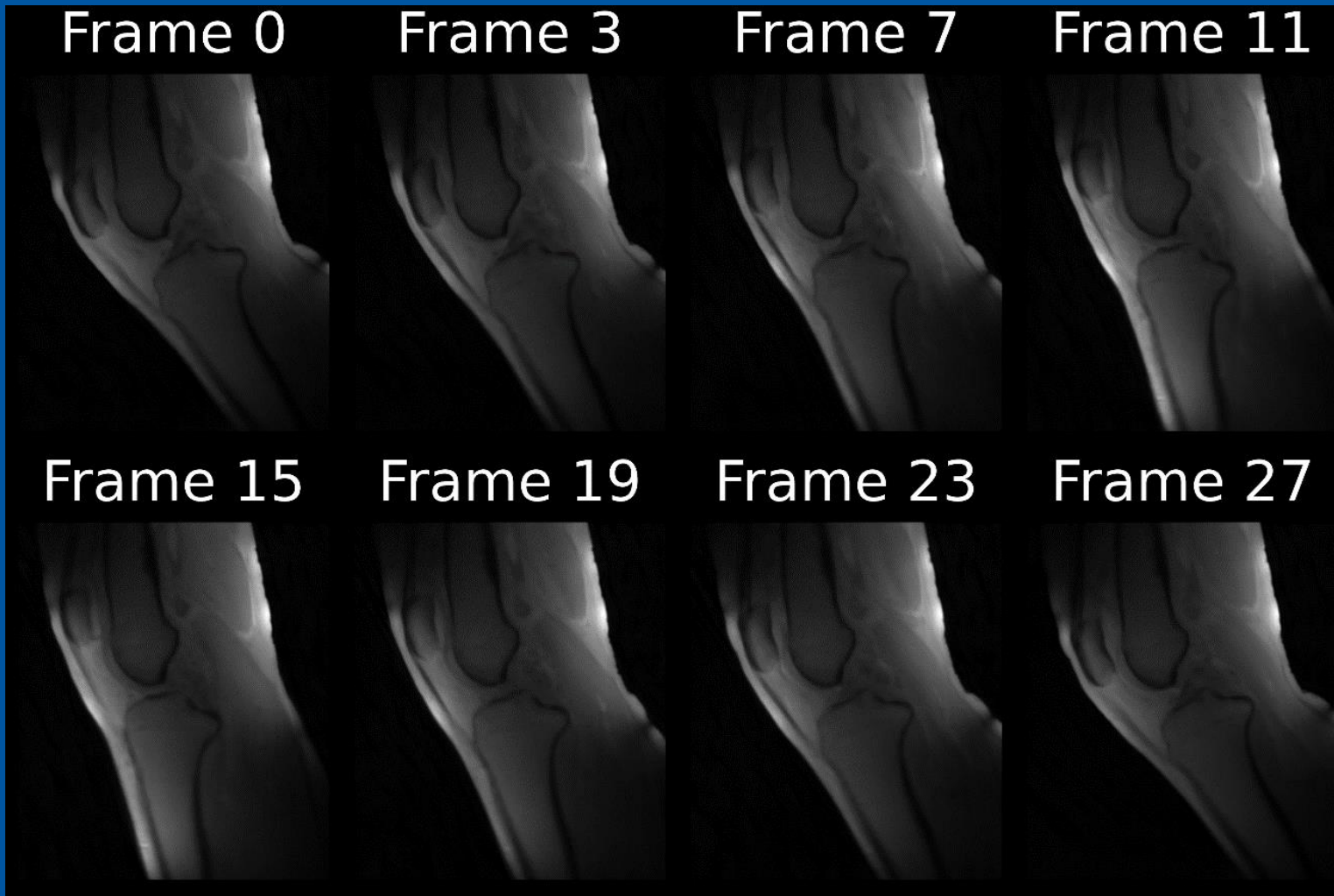


(Credit: Gray's Anatomy 42nd ed.)



- Repeated active open-chain knee flexion-extension exercise
- 5 volunteers
- Guided by the beat of a metronome at 60 bpm
- Once without additional weight and once with 12 kgs
- Each scan lasted a duration of 160 seconds
- Range of motion achieved within the scanner $\sim (30-46)^\circ$





Hystereses Thresholding (Pixels and their gradient magnitude)

Sigma: 0.50, Low: 0.00, High: 5.00



Strength of gaussian blur

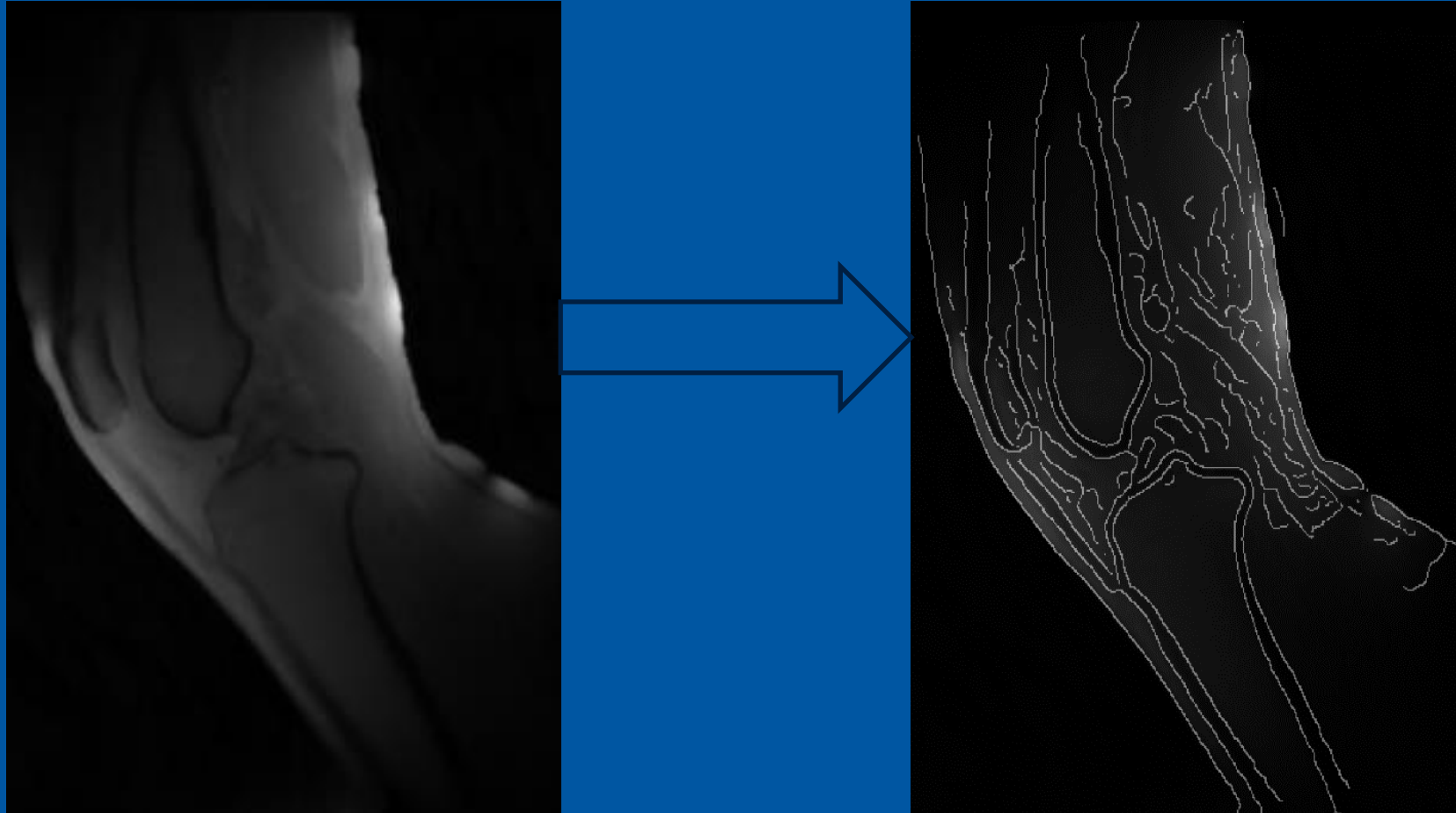
Sigma: 0.50, Low: 0.00, High: 5.00



Low Threshold: lower values are discarded (not an edge)

High Threshold: values higher are 'Strong Edges'

In Between: 'Weak Edges' Only kept if connected to a strong edge

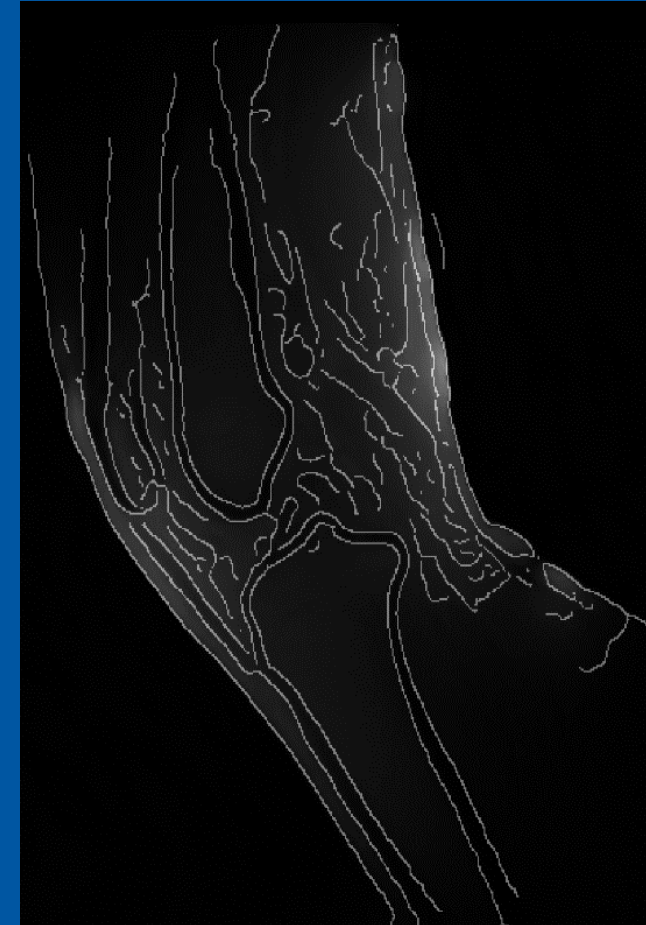




- Treated the series of 2d arrays as a 3d volume.



- $3 \times 3 \times 3$ structuring element
- 26-way connectivity



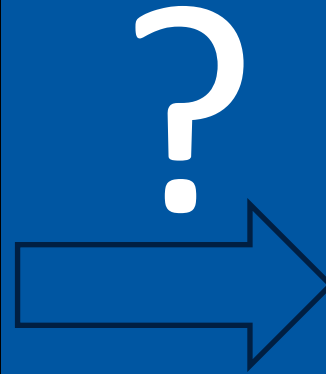
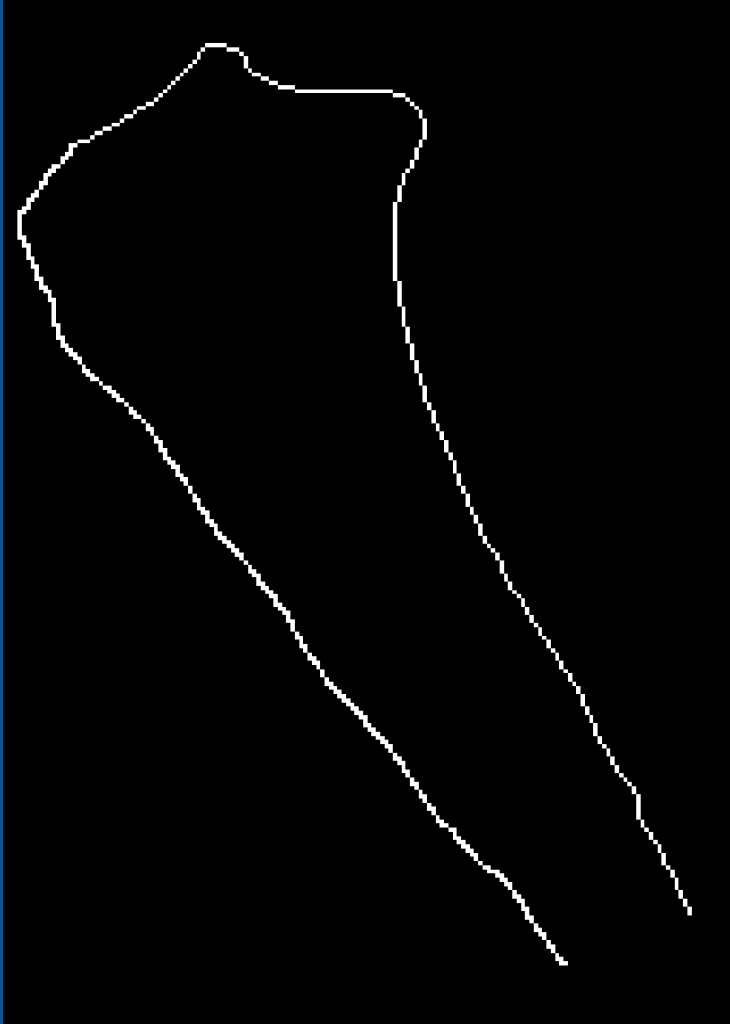
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Skeletonization

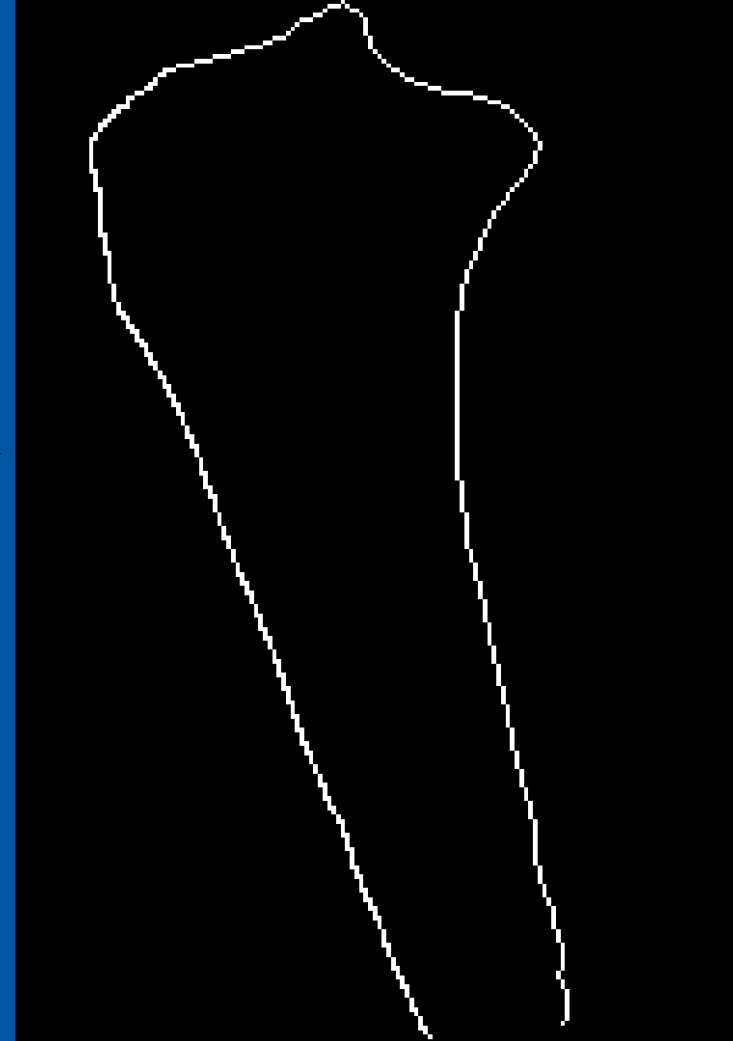
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Remove small objects

SET R



SET Q



SET R



Inefficient
computation



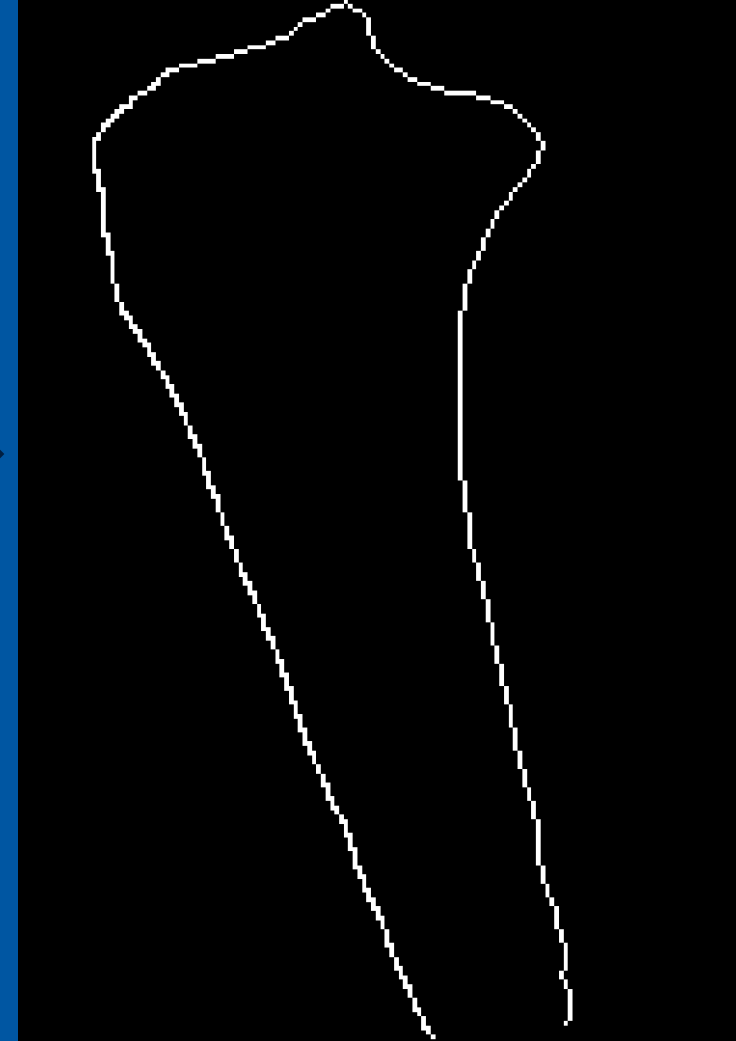
Lack of
correspondance

Order matters

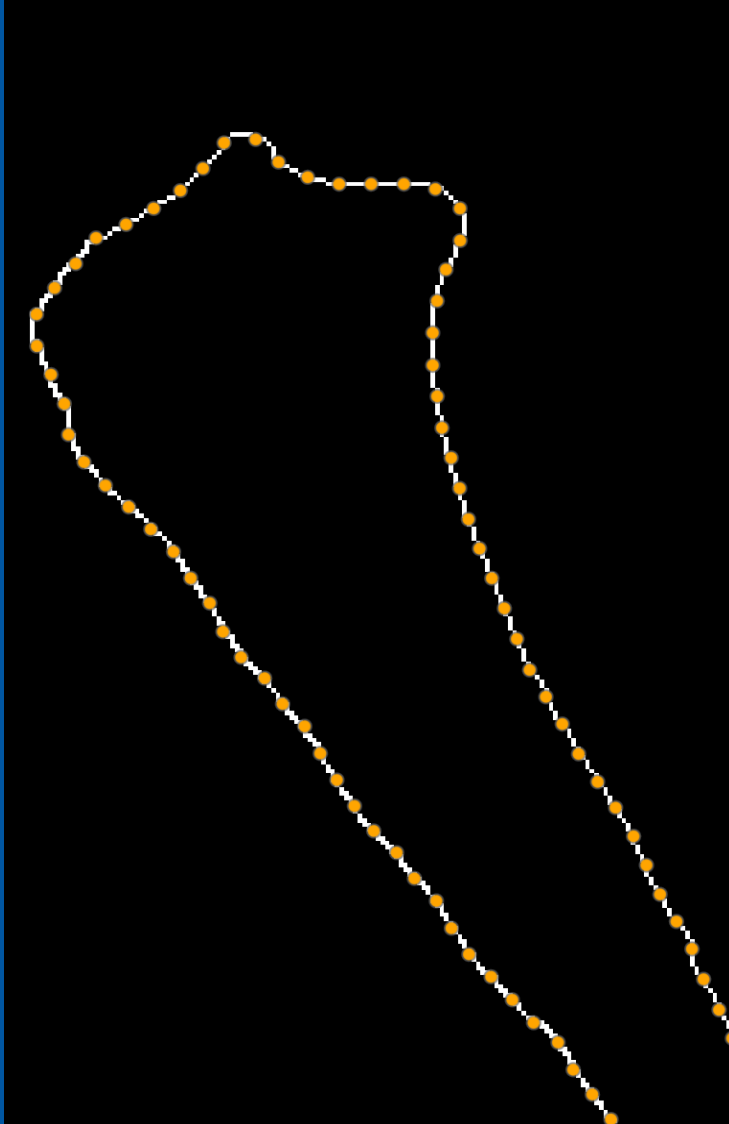
Inconsistent
sampling

Uneven number
of points

SET Q



SET R \Rightarrow SET P



1. Sorting:

- most distal and posterior point for the tibia, most proximal for the femur
- nearest neighbor approach to create an ordered path

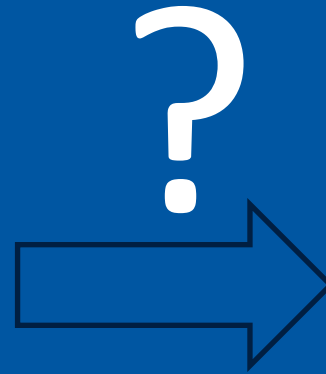
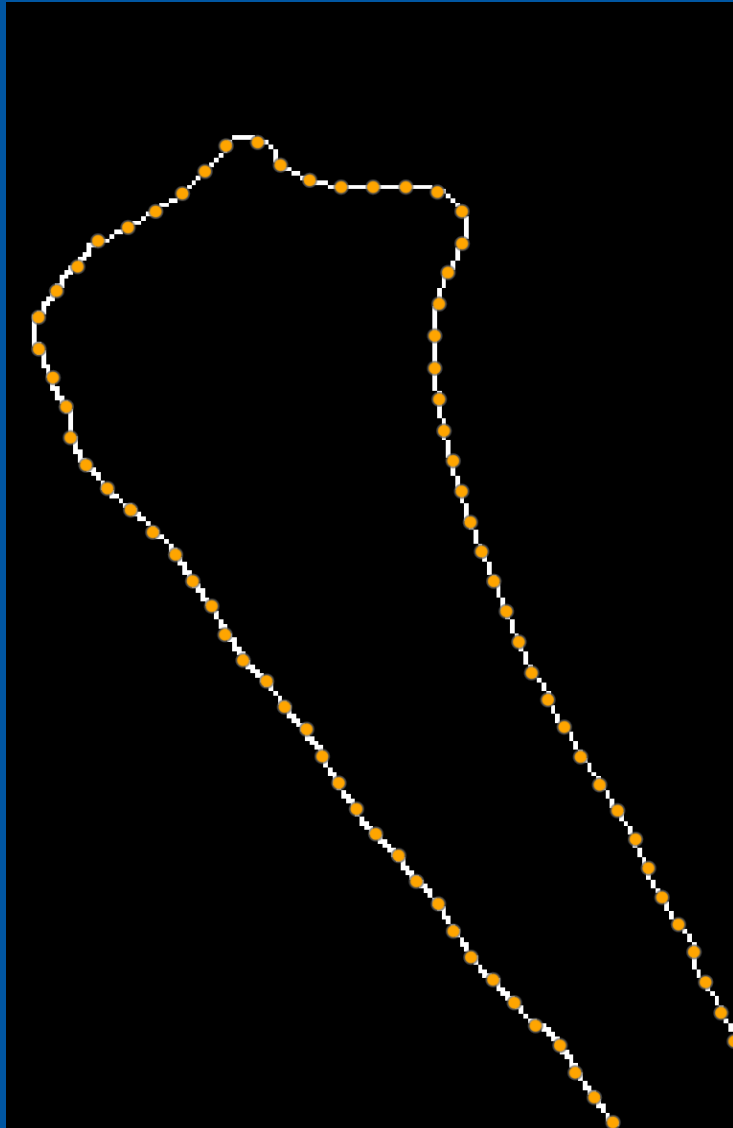
2. Cubic Spline Interpolation:

- create a smooth, continuous curve that passes through all points in ordered set R
- parameterize the curve using arc length

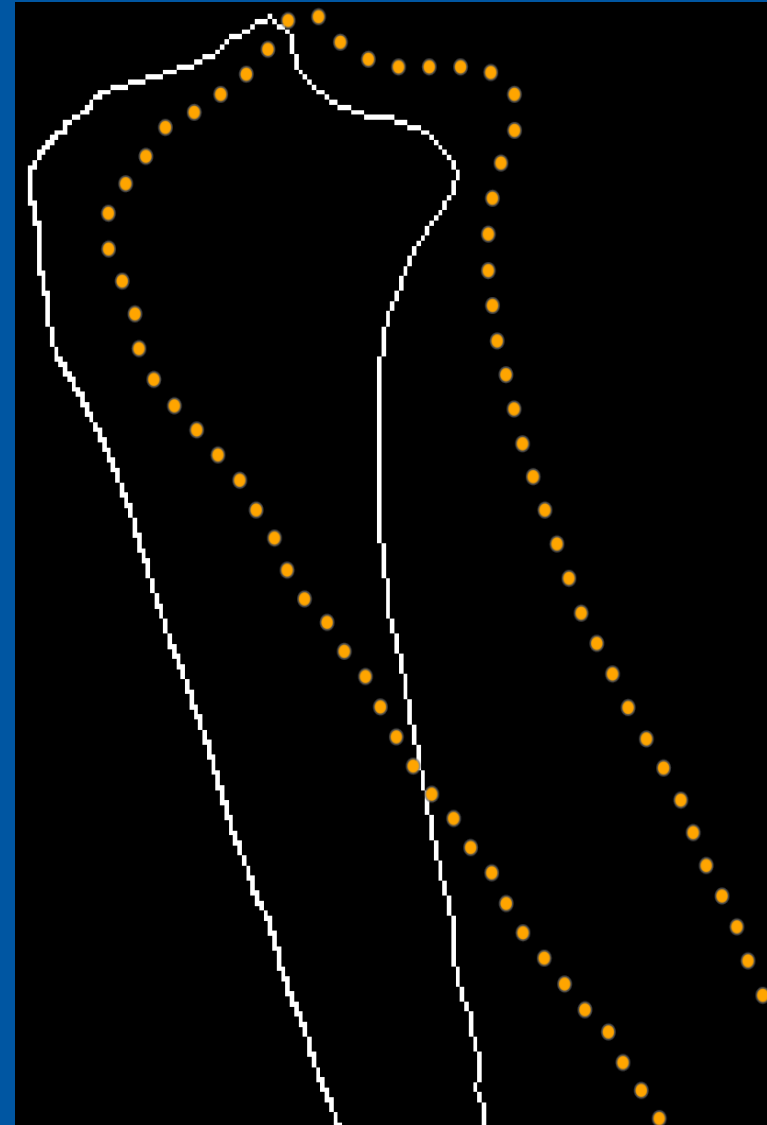
3. Downsampling and point placement

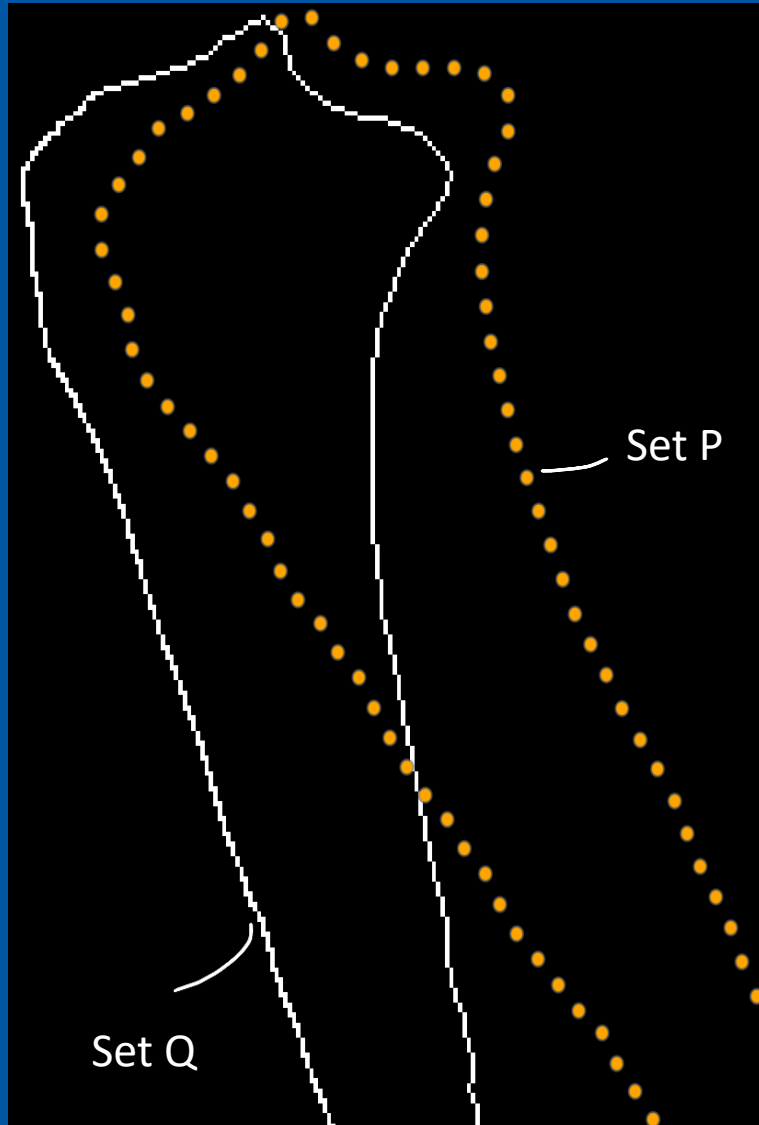
- Equal interval = total arc length of spline / desired number of points
- place points along the spline at these equal arc length intervals

SET P



SET Q





1. A point in set P (x,y) undergoes the following transformation:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \mathbf{R}(\phi) \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

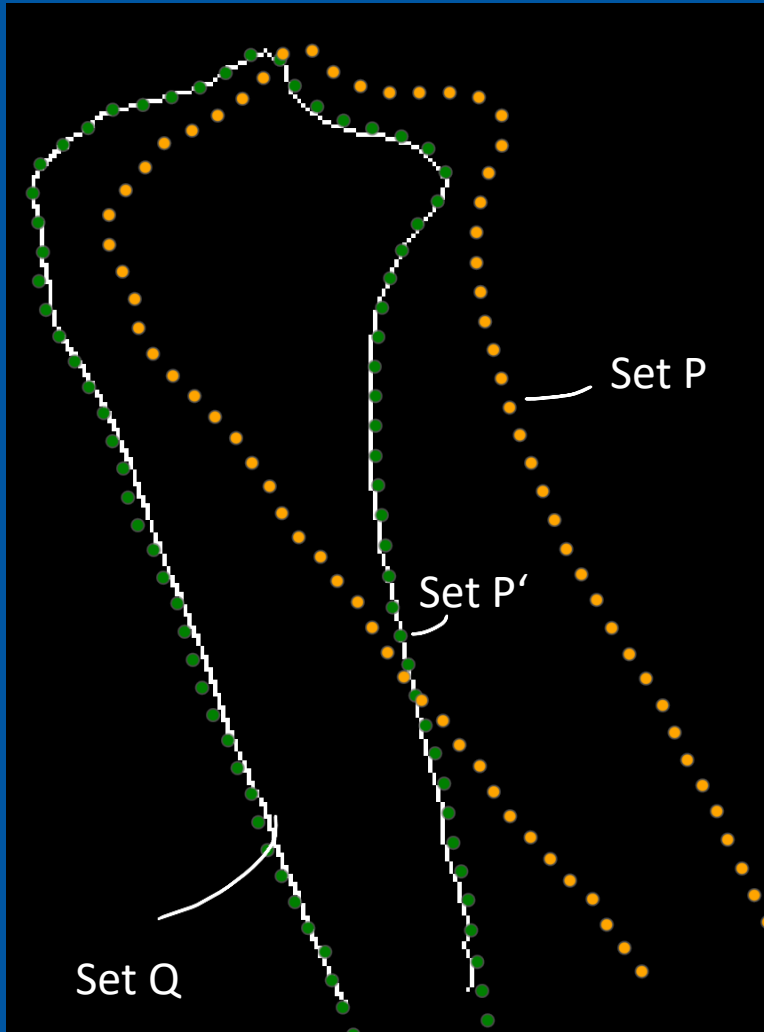
where, $\mathbf{R}(\phi)$ is the 2D rotation matrix: $\begin{bmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{bmatrix}$

And $(\Delta x, \Delta y)$ are the translations in the sagittal plane.

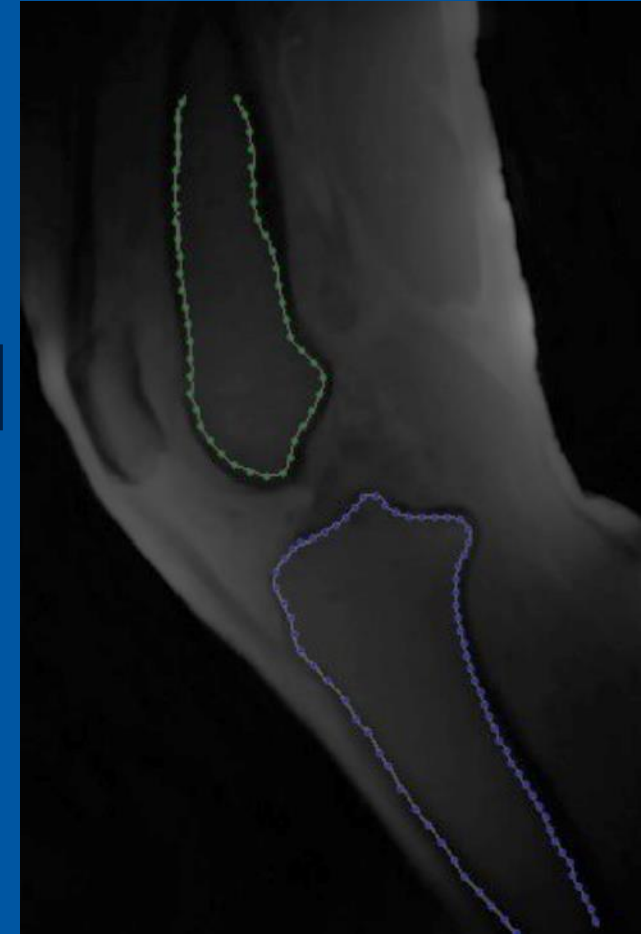
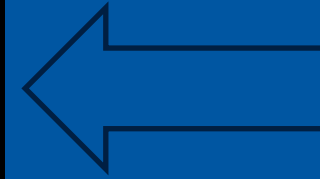
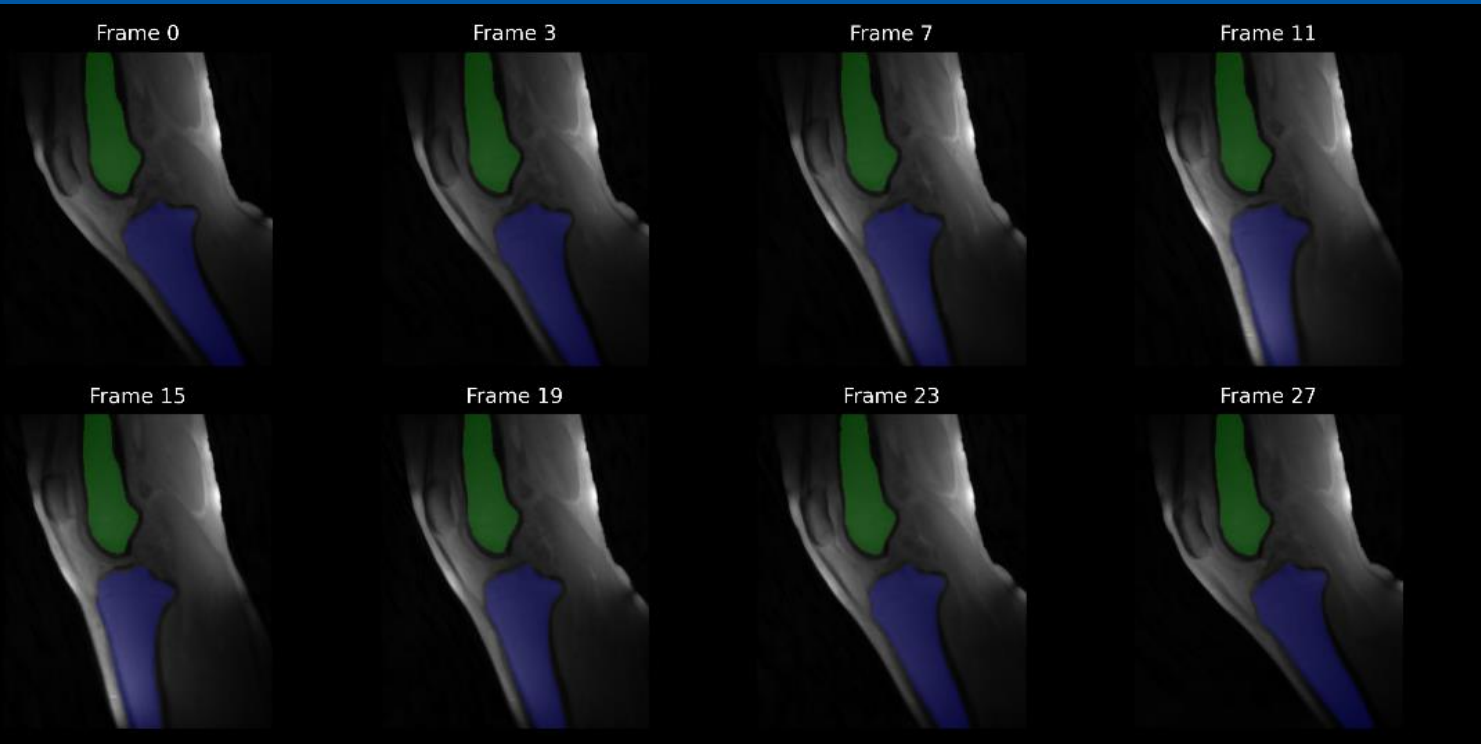
- Optimize for: $(\Delta x, \Delta y, \phi)$

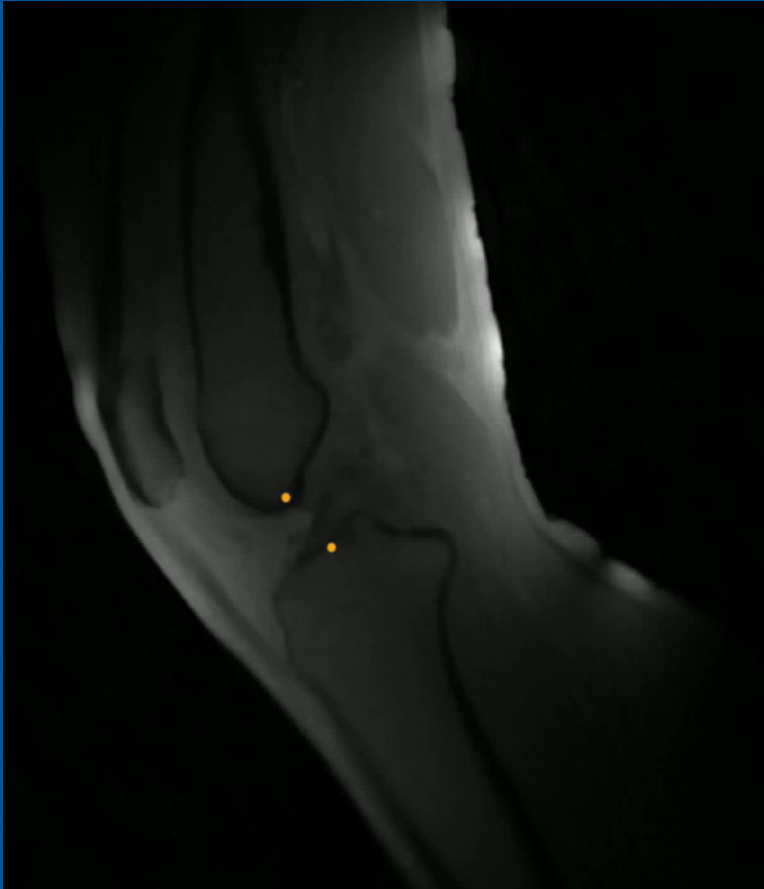
2. A cost function that quantifies the misalignment between each (x', y') and its nearest neighbour in set Q.

$$C(\Delta x, \Delta y, \phi) = \sum_{p=1}^N \min_{q \in Q} \left(\sqrt{(x_q - x'_p)^2 + (y_q - y'_p)^2} \right)$$



- Frame-by-frame transformation. Each transformed frame is used as reference for the next.
- Nelder-Mead simplex algorithm („fmin search“)
- Parameters:
 - Initial guess: $[0,0,0]$
 - Maximum iterations: 1000
 - Function tolerance and parameter tolerance: $1e-8$
- Once the set of parameters are obtained, any shape drawn on one frame on the bone will automatically be transformed to the rest of the frames

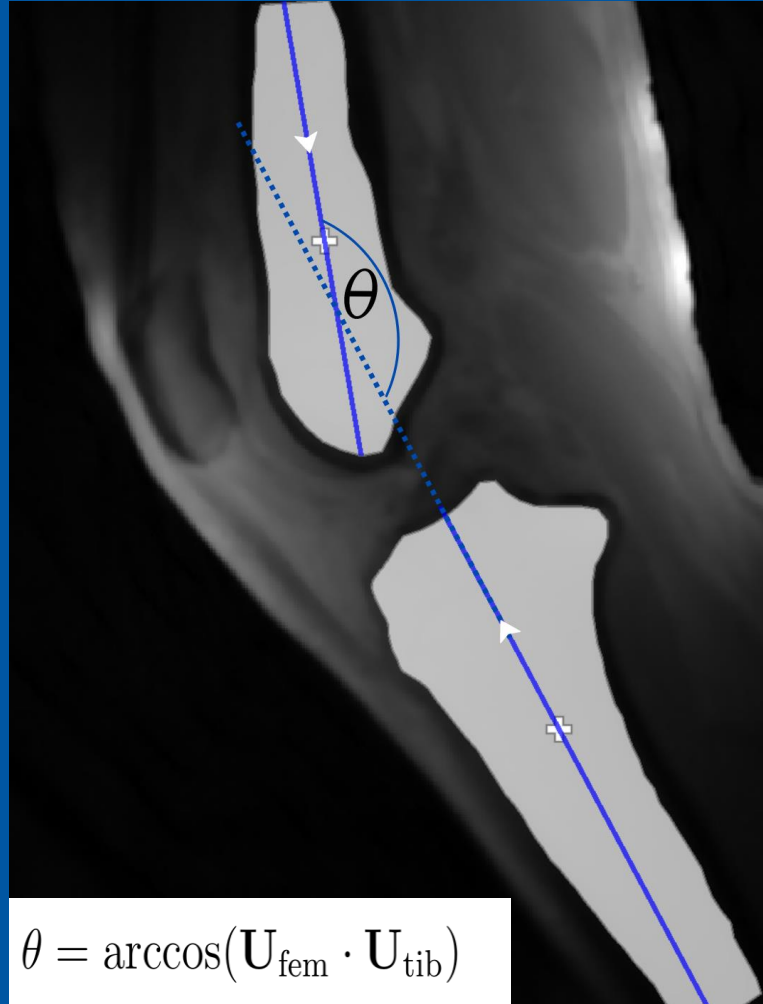


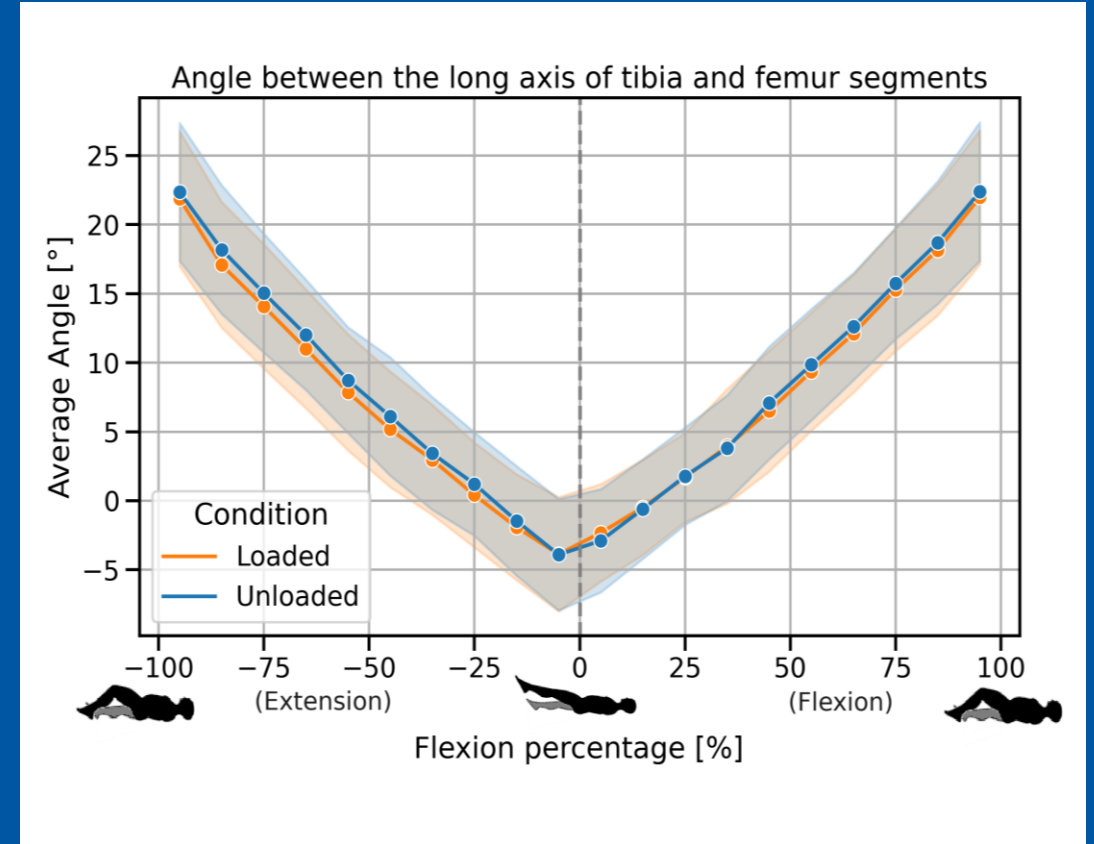
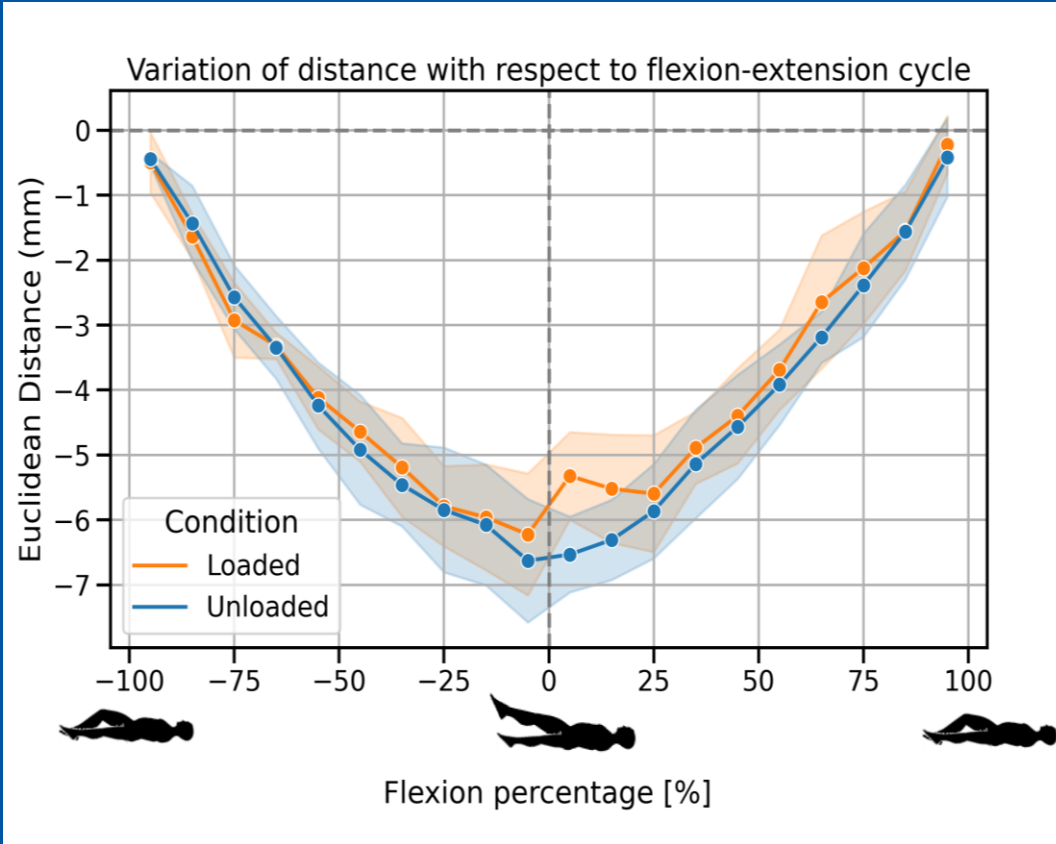


Distance measurement



Angle measurement







Thank you for your attention!

