

Image Guidance for Robot-Assisted Ankle Fracture Repair: Seminar Presentation

By: Anthony Wu

Mentors: Dr. Jeffrey H. Siewerdsen and Dr. Wojtek Zbijewski

Background: Ankle Fracture and Syndesmosis

- Fibula fractures cause disruption in the ankle joint
- During surgery, doctors must estimate where to shift the fibula
- If the doctors are inaccurate by a few millimeters, patients can suffer from osteoarthritis



Source of Graphic: Mercy Medical Center

Project Summary

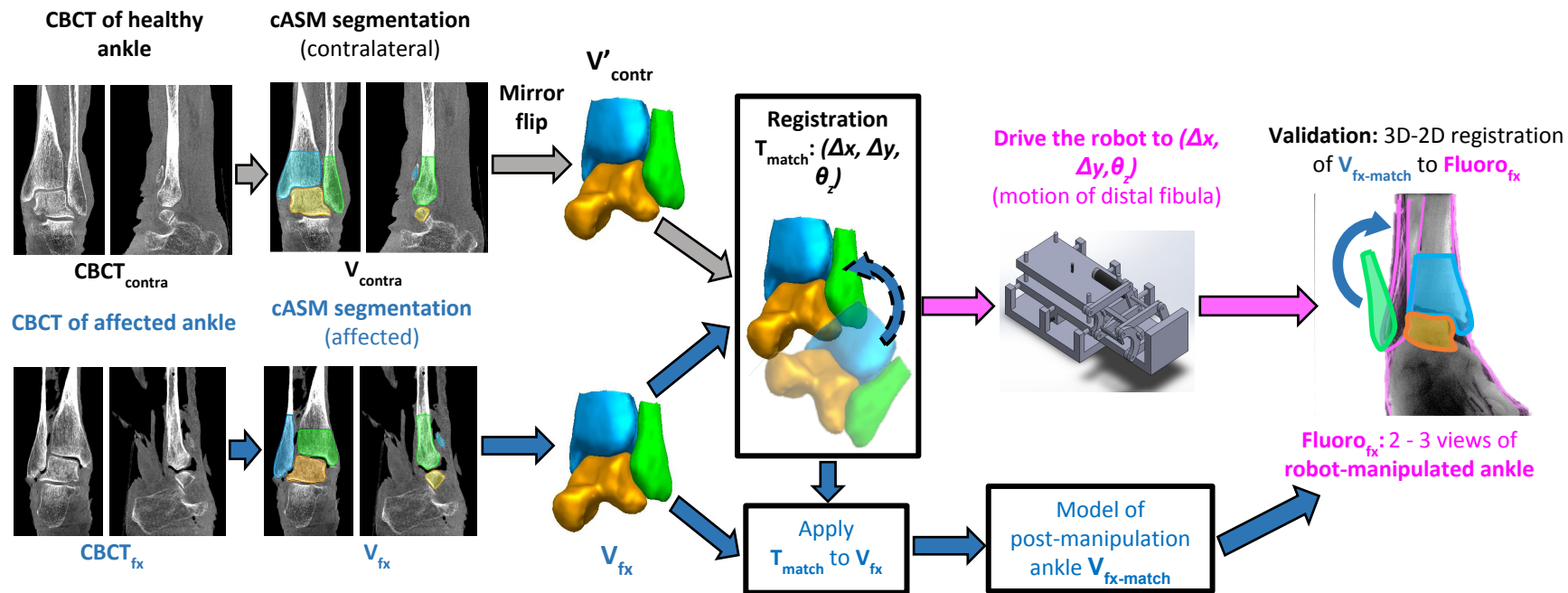


Figure by Wojtek Zbijewski

Deliverables

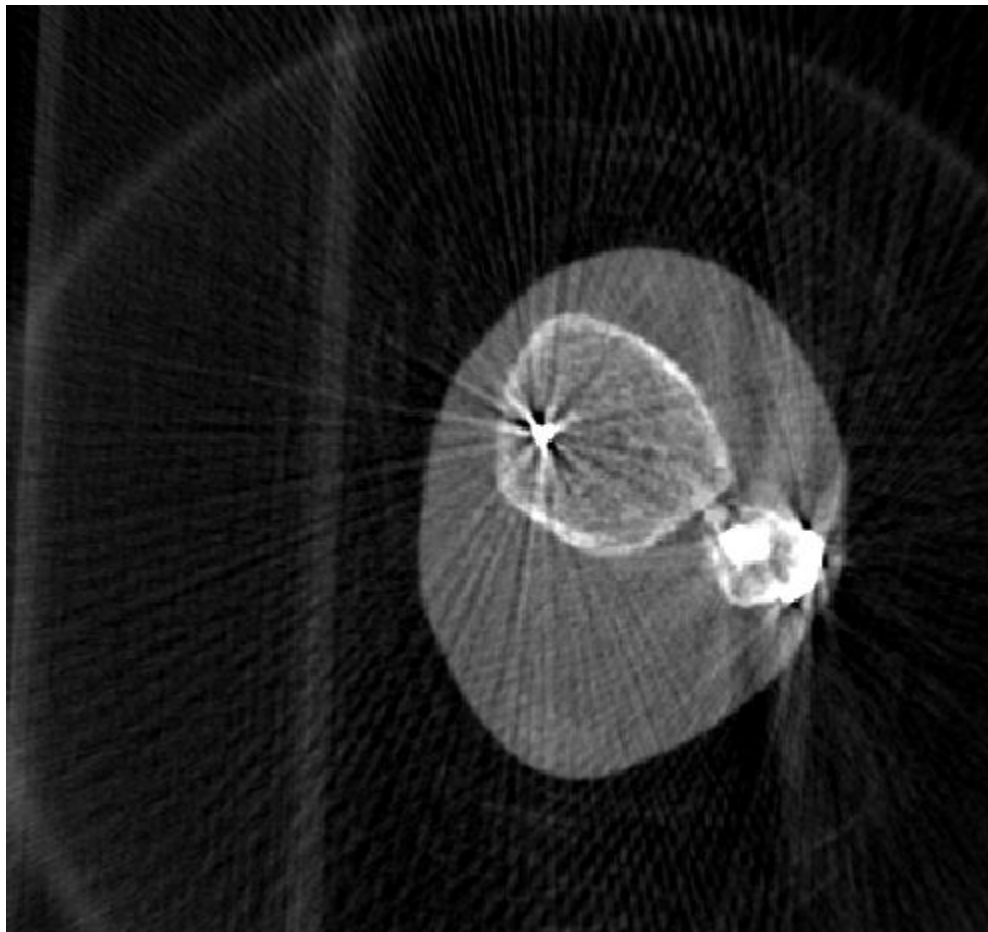
Minimum	Expected	Maximum
<ul style="list-style-type: none">○ Validate accuracy of Coupled Active Shape Model with average segmentation error of 5 mm for high quality cone beam images○ Perform error analysis on failure modes on low quality CT images	<ul style="list-style-type: none">○ Validate accuracy of joint deep learning - cASM model with mean segmentation error of 2mm for low quality CT images of healthy ankles without metal artifacts	<ul style="list-style-type: none">○ Publish paper○ Incorporate metal artifacts and unhealthy ankle data into deep learning - cASM model with mean segmentation error of 2mm

Paper Selected

[1] Xu, S., Uneri, A., Jay Khanna, A., *et al.* Polyenergetic known-component CT reconstruction with unknown material compositions and unknown x-ray spectra. *Physics in Medicine & Biology* 62 (8), 3352–3374 (2017).

Background

- Two types of metal reduction approaches
 - Correction Methods: Replace metal data with non-metal data, typically through interpolation
 - Model-based Methods: Incorporate specific key metal components into reconstructing CT image
- The proposed polyenergetic KCR model is considered to be a model-based approach



iStar Lab: Cadaver Sample

Problems

- Current methods lack information near metal
 - In image to the right, there are still black streaks underneath metal



iStar Lab: Cadaver Sample

Purpose and Significance

- Improve upon the Polyenergetic Known Component Registration technique for metal reduction in CT images
- Demonstrate that the only knowledge needed to reconstruct high quality CT images was a metal component's shape
- Illustrate that specific knowledge of X-ray beam spectrum and material composition of metal components was not needed

Polyenergetic KCR Model

- Advantages
 - Allows for very accurate reconstruction of CT image
 - Can reconstruct CT images with multiple metal components
- Disadvantages
 - Polyenergetic KCR methods require much computational burden
 - A lot of information is required of these models

Key Terms & Equations

- k - spectral coefficients
 - Relates to survival probability of X-ray photons passing through material
- Λ - shape registration coefficients
- $p\{n\}$ - path length of component
- $\mu^*(\Lambda)$ - unknown background anatomy that depends on Λ

$$\bar{y} = \mathbf{D}\{g\} \exp(-\mathbf{A}\mu_*(\Lambda)) \prod_{n=1}^N f^{(n)}(\mathbf{A}T(\lambda^{(n)}) b_i^{(n)}),$$

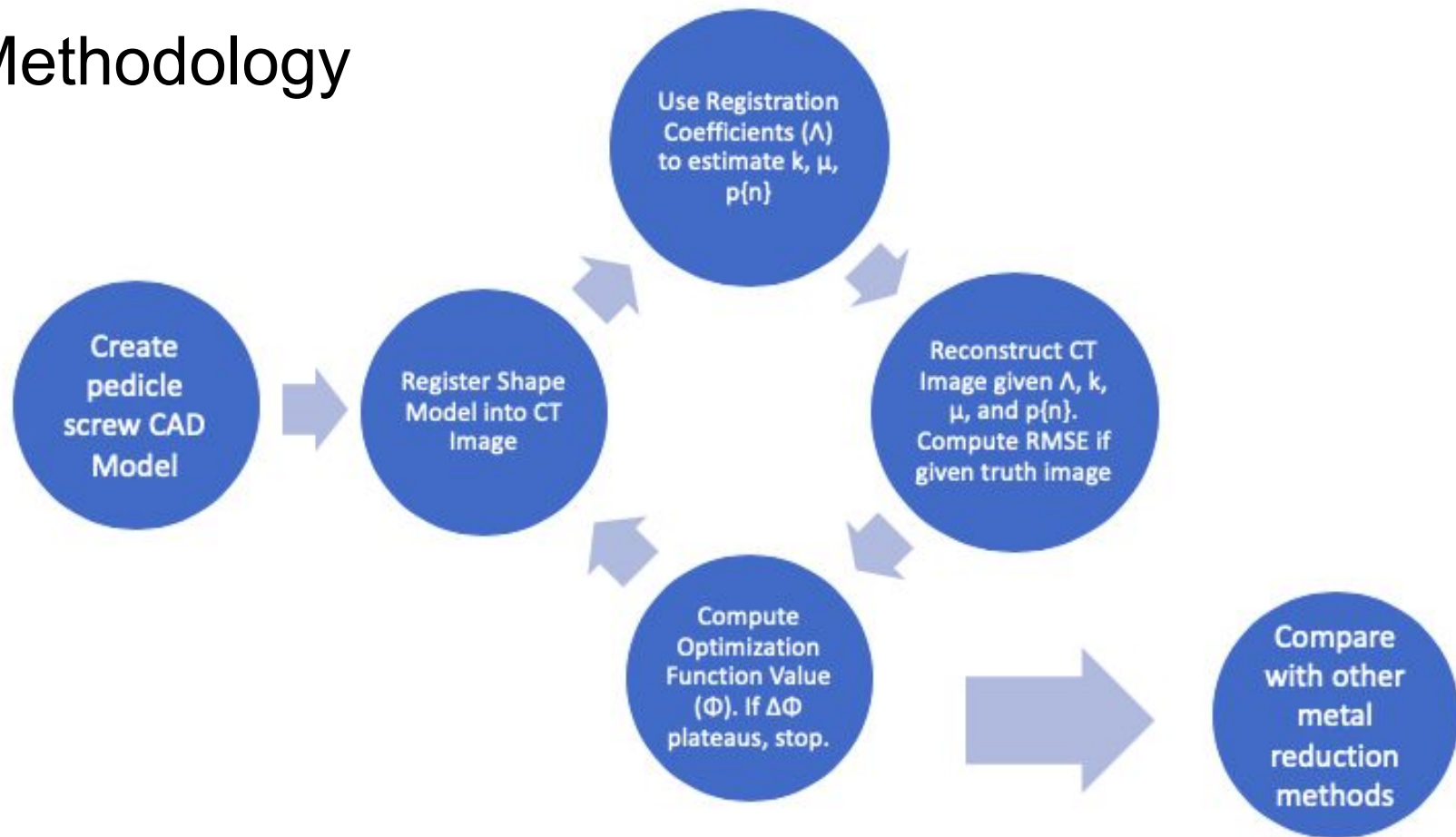
$$f^{(n)}(p^{(n)}; \kappa^{(n)}) = \exp\left(\sum_{k=1}^K \kappa_k^{(n)} (p^{(n)}(\lambda^{(n)}))^k\right),$$

$$\{\hat{\mu}_*, \hat{\kappa}, \hat{\Lambda}\} = \operatorname{argmin} \Phi(\mu_*, \kappa, \Lambda; y) = \operatorname{argmin} L(\mu_*, \kappa, \Lambda; y) - \beta R(\mu_*)$$

$$L(\mu_*, \kappa, \Lambda; y) = \|\mathbf{A}\mu_*(\Lambda) - \sum_{n=1}^N \sum_{k=1}^K \kappa_k^{(n)} (p^{(n)}(\lambda^{(n)}))^k - \log(\mathbf{D}\{g\} * \bar{y}^{-1})\|_w^2$$

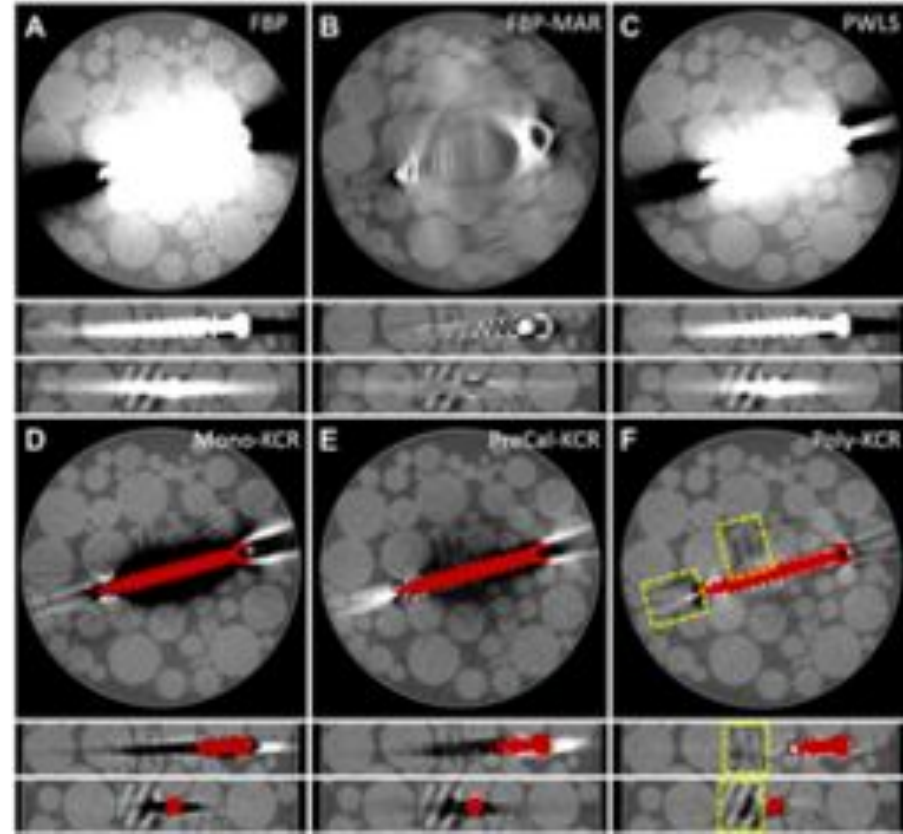
$$R(\mu_*) = \sum_j \sigma_j^2 \sum_{\{k \in \mathcal{N}_j\}} \psi(\mu_{*j}(\Lambda) - \mu_{*k}(\Lambda)),$$

Methodology



Results - Phantom Experiment

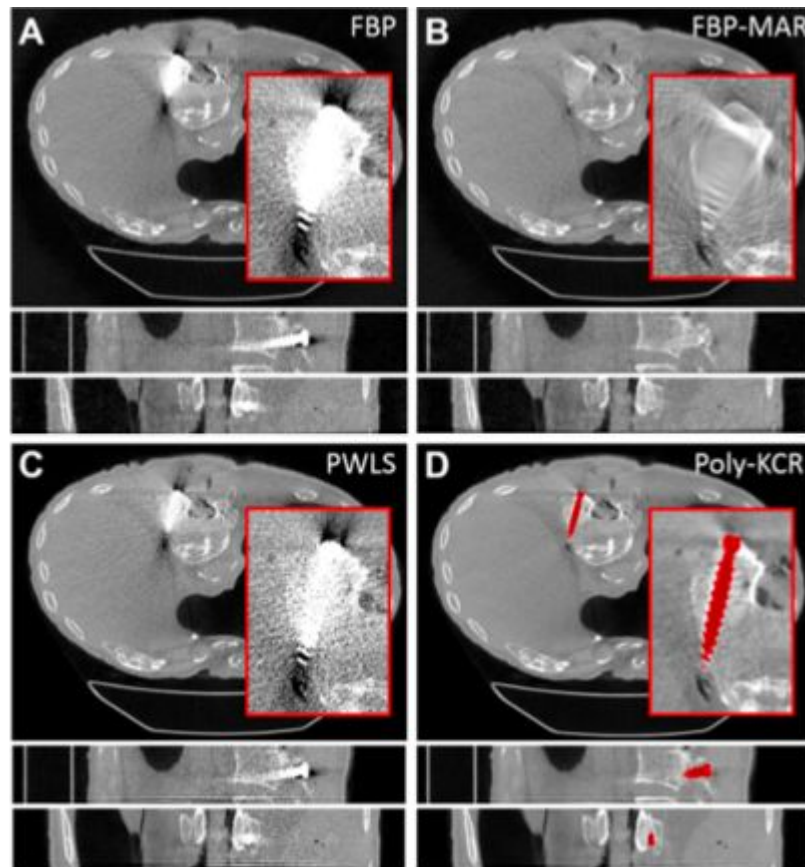
- Still some dark streaks at tip and on side of the screw, but better performance compared to other methods



Phantom Experiment - FBP (A) vs FBP-MAR (B) vs PWLS (C) vs Mono-KCR (D) vs PreCal-KCR (E) vs Poly-KCR (F) (Xu et al. 28)

Results

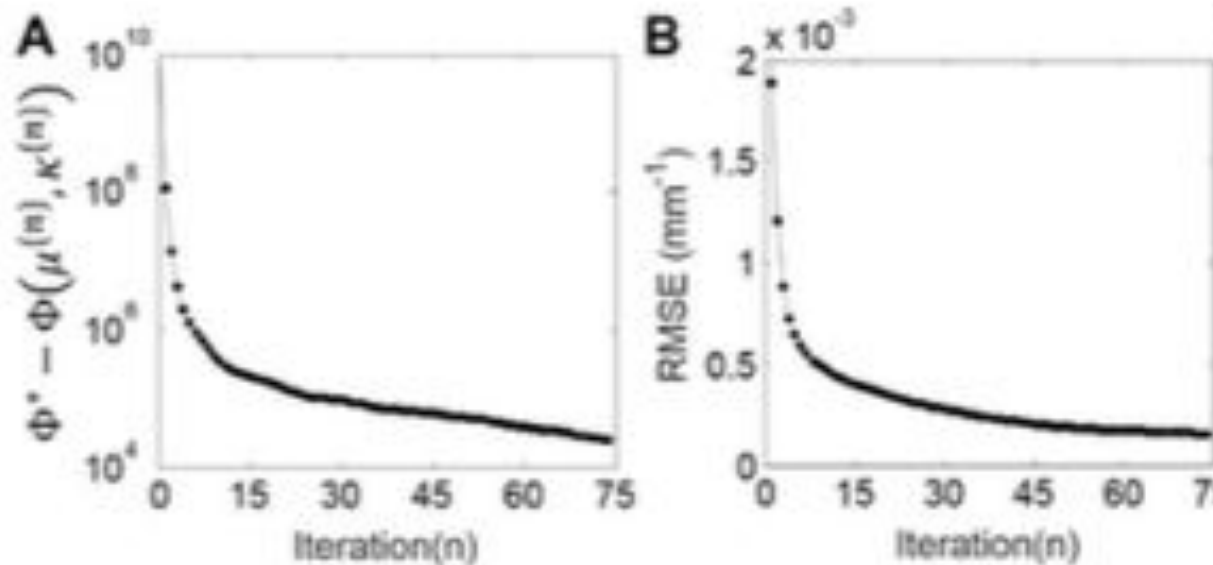
- Cadaver Experiment
 - Similar results as the phantom experiment



Cadaveric Torso Experiment - FBP (A) vs FBP-MAR (B) vs PWLS (C) vs Poly-KCR (F) (Xu et al. 29)

Results

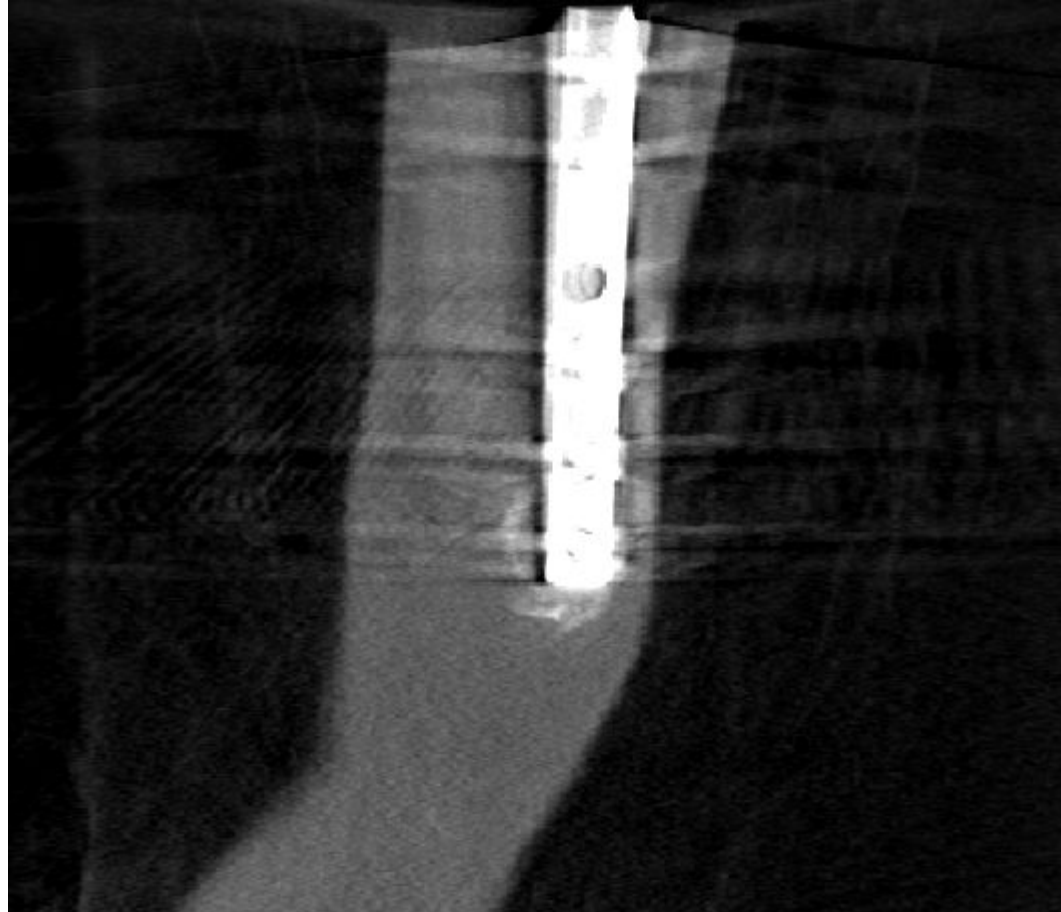
- Plateau of RMSE and $\Delta\Phi$ within 75 iterations
- Suggests fast convergence of model
- Given grayscale of 0.018mm to 0.028 mm per slice



Root Mean Squared Error between truth image and reconstructed image
(Xu et al. 25)

Assessment

- Advantages
 - Shows the utility of a Polyenergetic KCR model with only knowledge of a shape model of a metal component
 - Provided pseudocode to replicate study
- Limitations
 - Only tested on pedicle screws
 - Did not perform experiment with multiple metal components in the cadaver/phantom
 - Did not compare to other polyenergetic KCR models



iStar Lab: Cadaver Sample