Known-Component Registration

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Group 1: High-Precision Drill Guide Placement with the UR5

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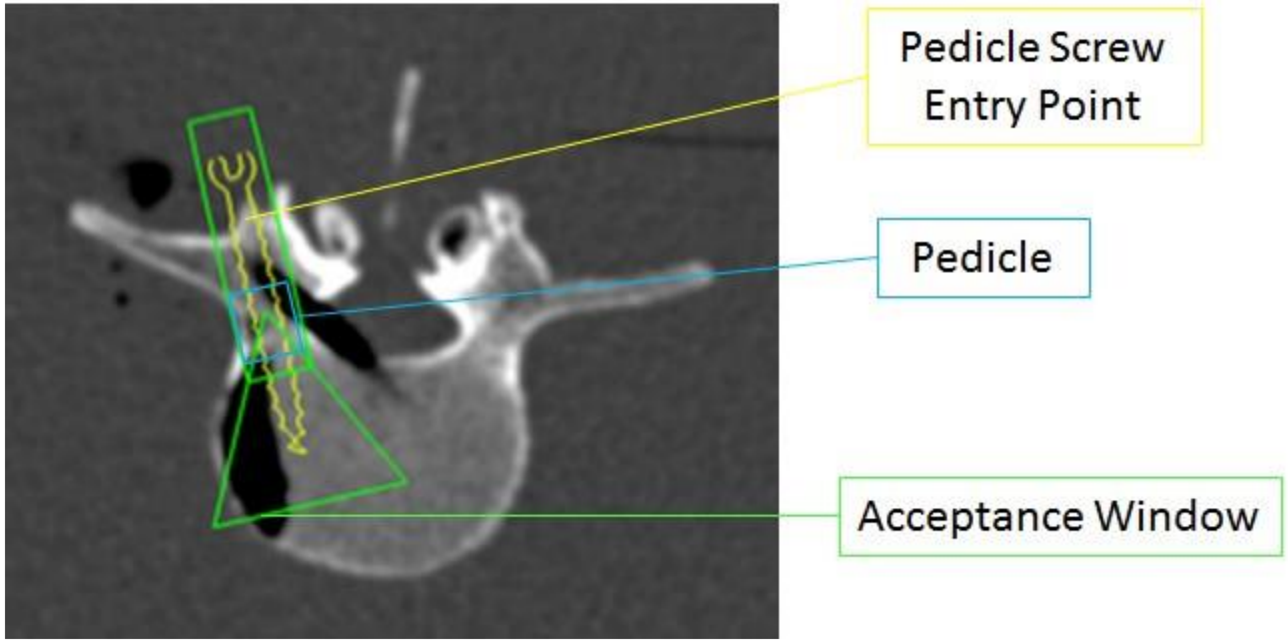
Project Overview

- Goal: to improve pedicle screw placement procedures
- Current standard of care involves “free-hand” placement of screw
- Optical Tracker Solution vs. 3D-2D Registration Solution



Paper Selection

"Known-component 3D-2D registration for quality assurance of spine surgery pedicle screw placement"

- Describes namesake technique: known-component registration (KC-Reg)
- Allows for localization of a "known component" in some 3D space (ie. preoperative CT)

Background

- Known Component
  - Surgical tools (fixation hardware, guide wires, needles, screws) that are structurally known beforehand
  - Varying degrees of structural knowledge

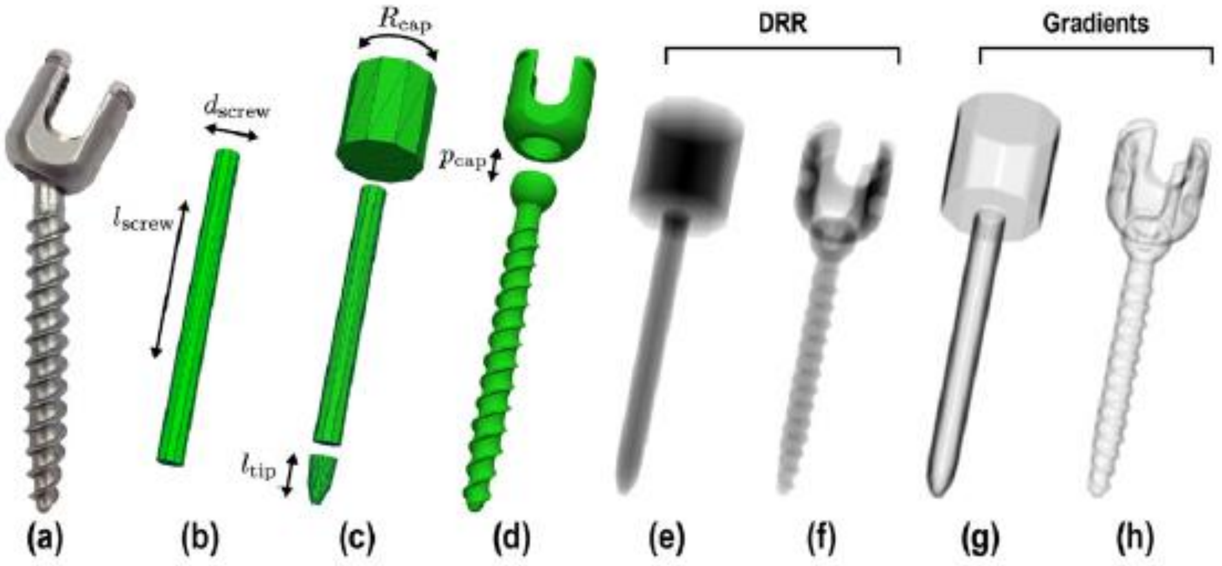
- 3D-2D Registration
  - Iteratively match intraoperative 2D radiographs to digitally reconstructed radiographs (DRRS) from a preoperative 3D CT volume.
  - Maximize image similarity

Significance

- Could remove the necessity for an optical tracking in our current system
- Removes physical clutter from operating space
- Eliminates problems associated with tracking reliability
- Tool simplification

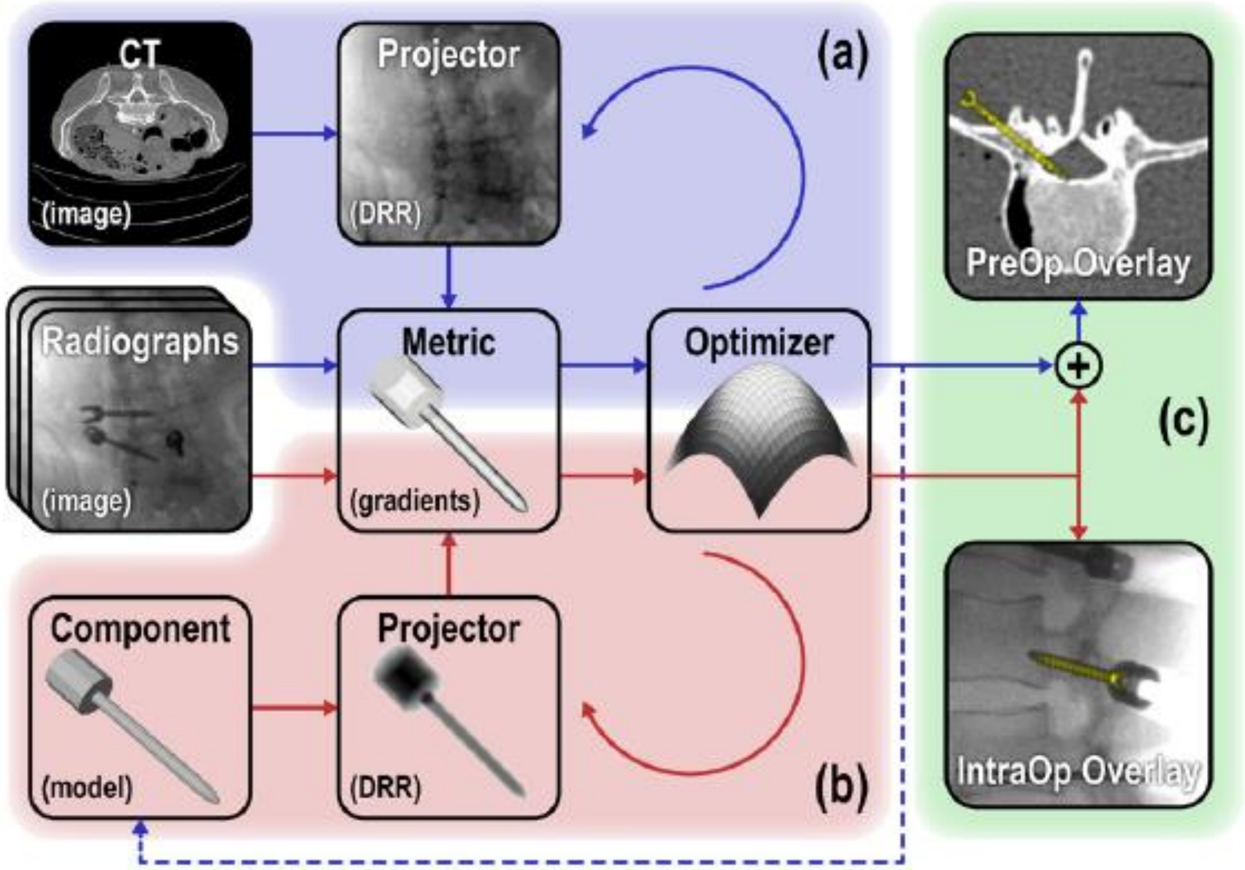
Background: Known Components

- Parametrically Known Component (pKC)
    - pKC1 – most simple parametrization
    - pKC2 – more complex, multi-component parametrization
- Exactly Known Component (eKC)
    - CAD model



Flow of Technique

- KC-Reg goes along with standard 3D-2D registration



Mathematical Methods

- Maximizing the similarity metric

Gradient Correlation (Penney 1998)

Directional Gradients of Fixed Radiograph (f) and Moving DRR (m)

$$\mathrm{GC}(f,m) = \frac{1}{2}(\mathrm{CC}(\nabla_x f, \nabla_x m) + \mathrm{CC}(\nabla_y f, \nabla_y m))$$

Average Normalized Cross Correlation

(i, j) 2D Image Pixel Coordinates

$$\mathrm{CC}(f,m) = \frac{\sum_{i,j}(f_{i,j} - \overline{f})(m_{i,j} - \overline{m})}{\sqrt{\sum_{i,j}(f_{i,j} - \overline{f})^2}\sqrt{\sum_{i,j}(m_{i,j} - \overline{m})^2}}$$

Maximize Total GC Across All Projection Views

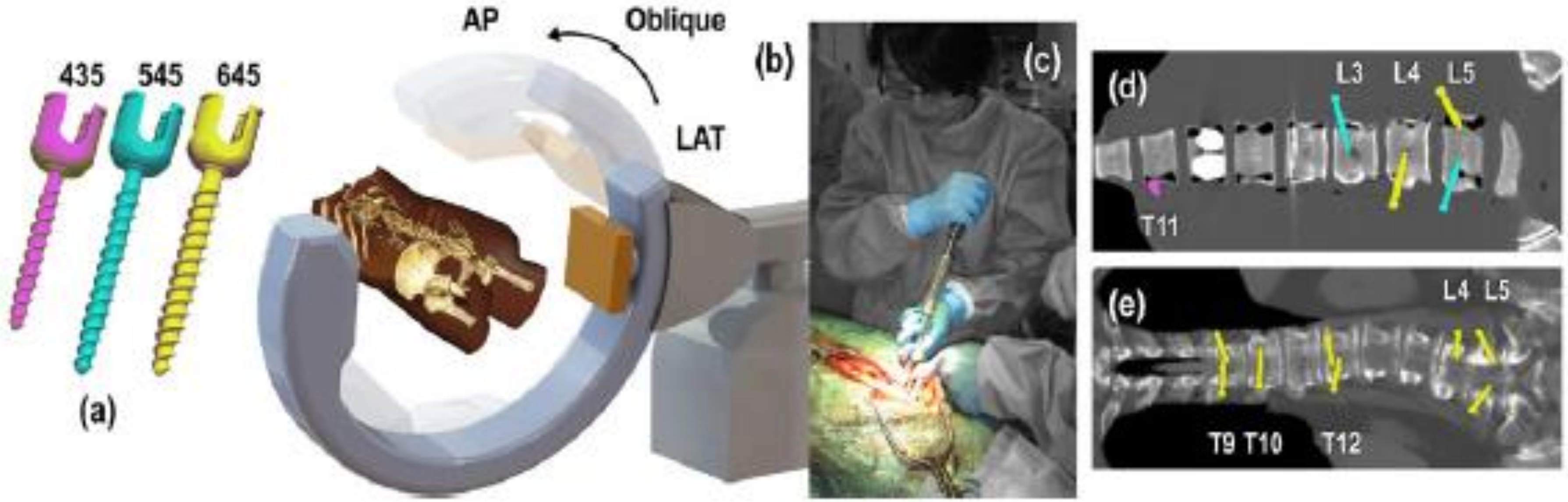
$$\hat{\Phi} = \arg\max_{\Phi} \sum_{\theta} \mathrm{GC}(f_\theta, m_\theta(\Phi))$$

Moving DRR Computation

$$m_\theta(\Phi) = \mathcal{P}_\theta \mathcal{T}(\Phi) \circ M$$

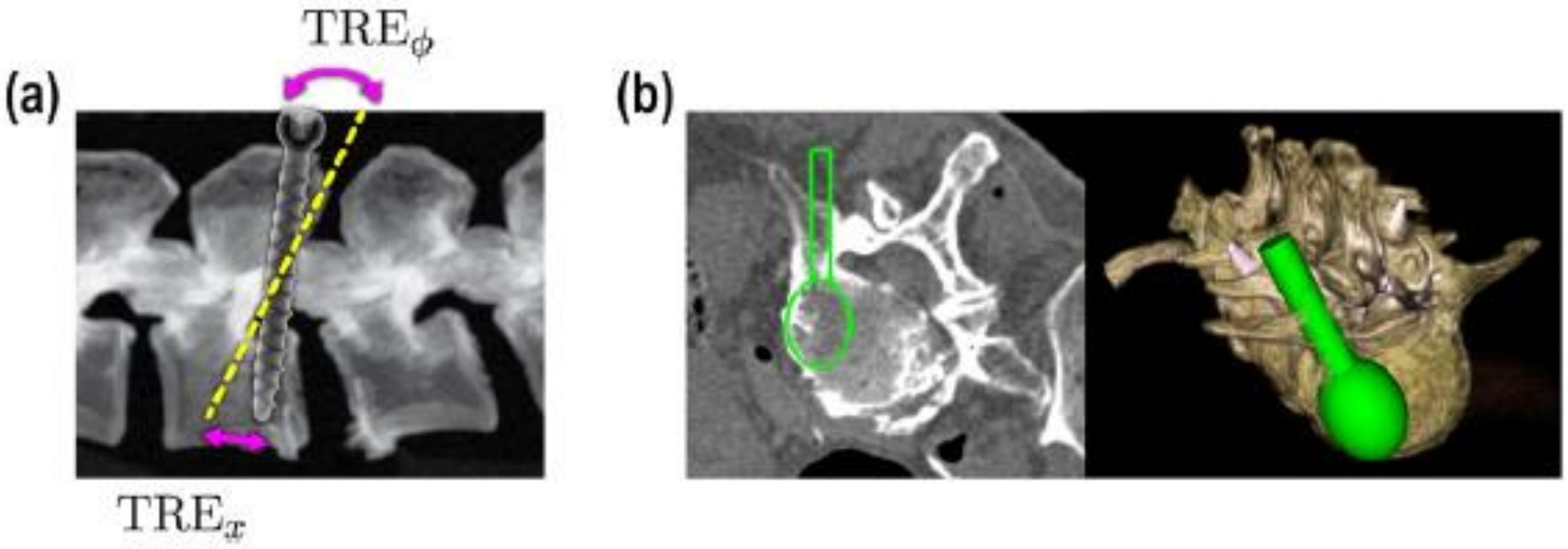
Experimental Setups

- Anthropomorphic torso phantom with 5 pedicle screws
- Human torso cadaver with 8 pedicle screws
- Intraoperative radiographs obtained with mobile C-arm as shown
- QA analysis: geometric accuracy, device verification, visualization relative to acceptance window



Geometric Accuracy of Registration

- TRE computed in terms of translational and rotational components
  - Ground truth determined from 3D-2D registrations using all available views (200 projections acquired over a semicircular arc using mobile C-arm)



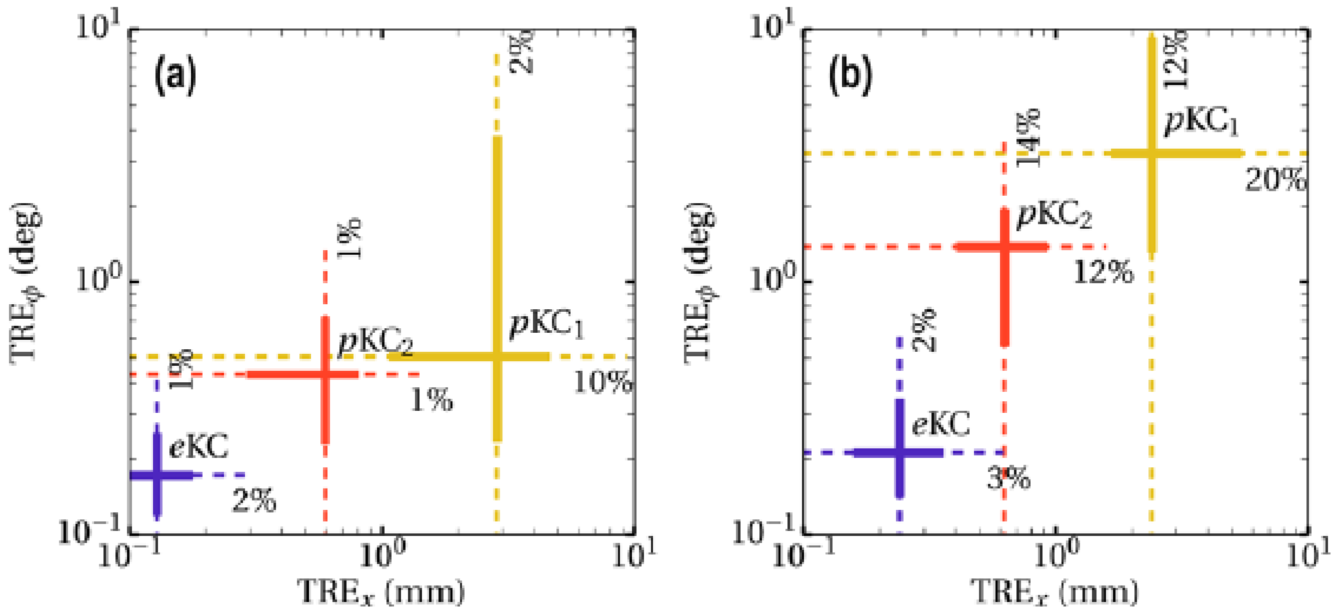
$(\hat{R}, \hat{t})$ registration estimate

$$\mathrm{TRE}_x = \hat{t} - t_2$$

$$\mathrm{TRE}_\phi = \cos^{-1} \frac{\hat{R}_z \cdot R_z}{\hat{R}_z \cdot R_z}$$

Geometric Accuracy Results

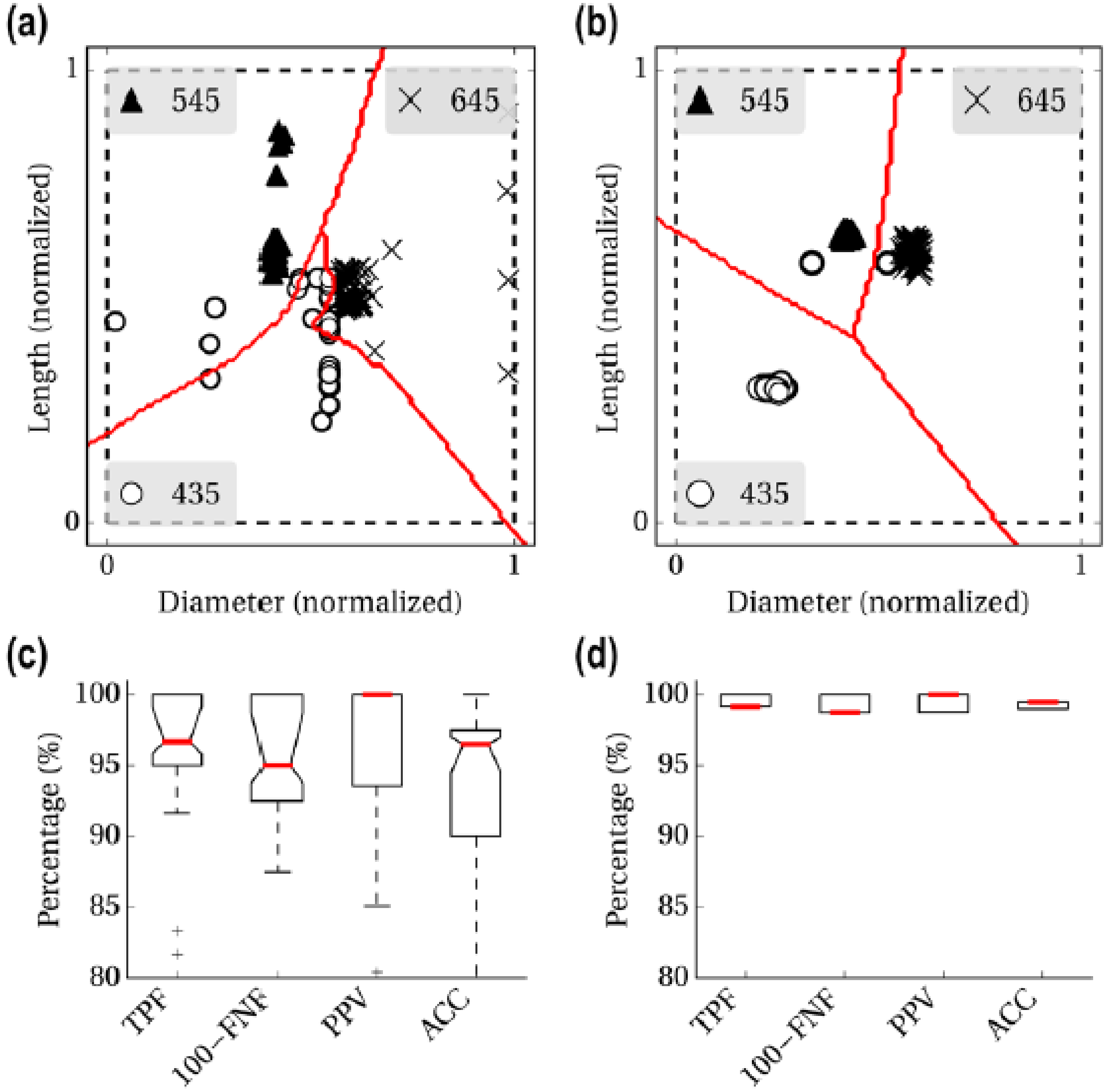
- Higher-order known components offer lower TRE
  - 92% of 40 repeat registrations per target screw within gold standard TRE accuracy levels of <1 mm in translation and <5 degrees in rotation for eKC
  - Median translational and rotational errors for eKC were 0.2 mm and 0.2 degrees
- Cadaver presents higher TRE likely due to deforming soft tissue and more complex gradients in real anatomy



Device Verification & Results

- Extension of KC-Reg methodology to detect instances in which device in 2D intraoperative image differs from that specified in planning
- 200 data samples of registration solution output parameters (length, diameter) used to train multi-class learning-based classifier
- Decision boundaries for classification reasonable in both cases
- Higher-order pKC2 had better classification results (99.3% vs pKC1 92.9%)

$$
\begin{aligned}
TPF &= TP / P \\
FNF &= FN / P \\
PPV &= TP / (TP + FP) \\
ACC &= (TP + TN) / (P+N)
\end{aligned}
$$



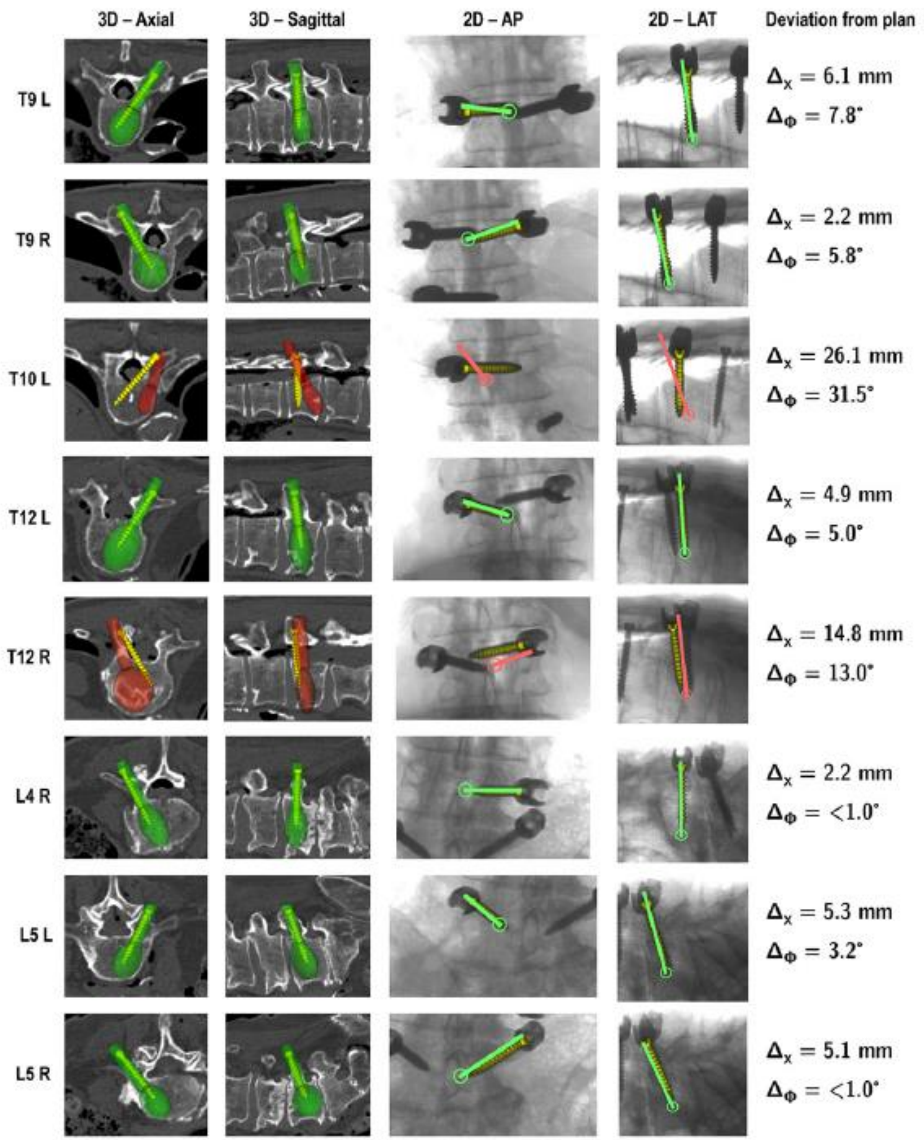
Visualization Within Acceptance Window

- Screws purposely misplaced

- Assessment if screws were within acceptance window

- Acceptance window defined around planned trajectory

- KC-Reg result was able To correctly identify whether or not screws were properly placed



Assessment

Pros

- Overall well-described methodology surrounding the experiments
- Detailed in outlining how models were parametrized
- Powerful potential in substituting out optical tracking for described techniques
- Results very cleanly and intuitively discussed

Cons

- Organization slightly misleading
  - Could have been improved with more initial description on known-components
- Perhaps could have presented some additional base information surrounding the classification methods

Questions?