Semi-automatic Segmentation of Vertebral Bodies in Volumetric MR Images Using a Statistical Shape+Pose Model

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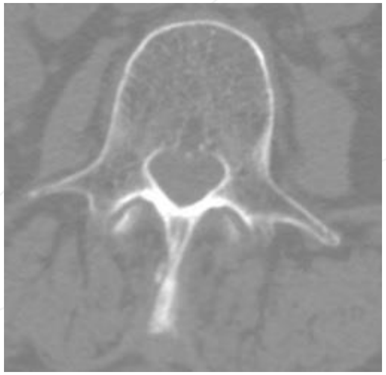
Purpose

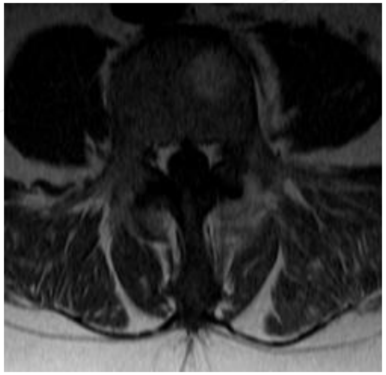
- Segmentation of vertebral structures enables quantitative analysis of spine pathologies.
  - deformations caused by different pathologies
  - slipped vertebra, herniate disk, disk/vertebra degeneration
- Also has applications in image-guided interventions.

Challenges of MR Segmentation

- Poor contrast of bone structures.
- Variation in surrounding soft tissue contrast.
- Magnetic field inhomogeneity.
- Large inter-slice gap (around 4 mm) in typical clinical MR images compared to CT.



CT



MR

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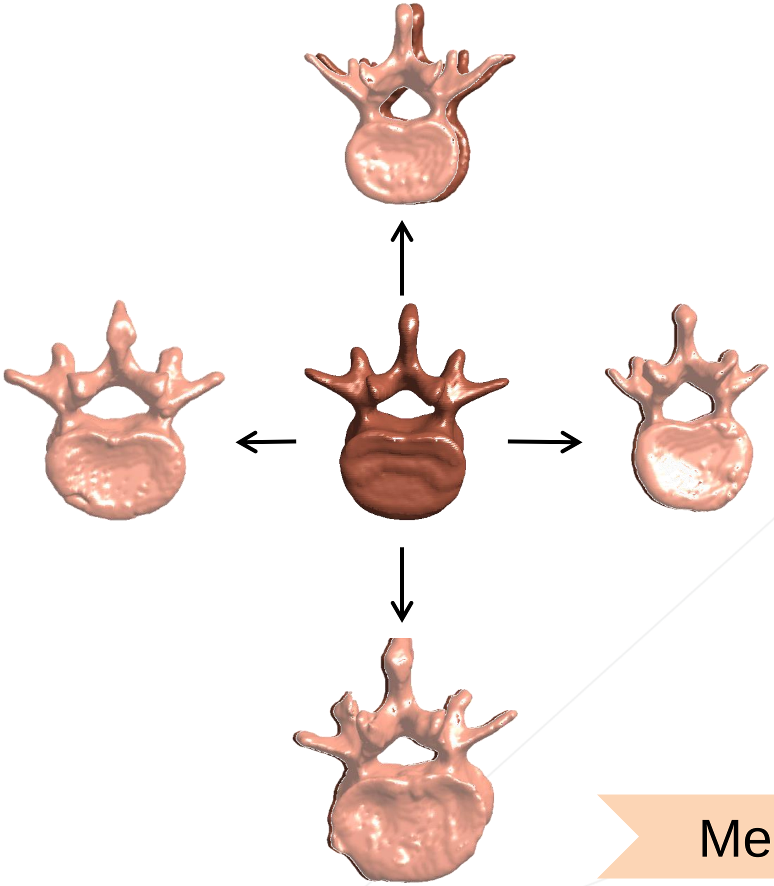
Related Work

- Most approaches are in 2D
  - [Egger’12], [Carballido-Gamio’04], [Shi’07], [Huang’09].
- 3D Methods are mostly evaluated on MR images with inter-slice gap of 1.2 mm or less.
  - [Kadoury‘13], [Stern’11], [Neubert’12].
- Each vertebra is mostly segmented independently.
  - [Hoad’02], [Stern’11], [Neubert’12].

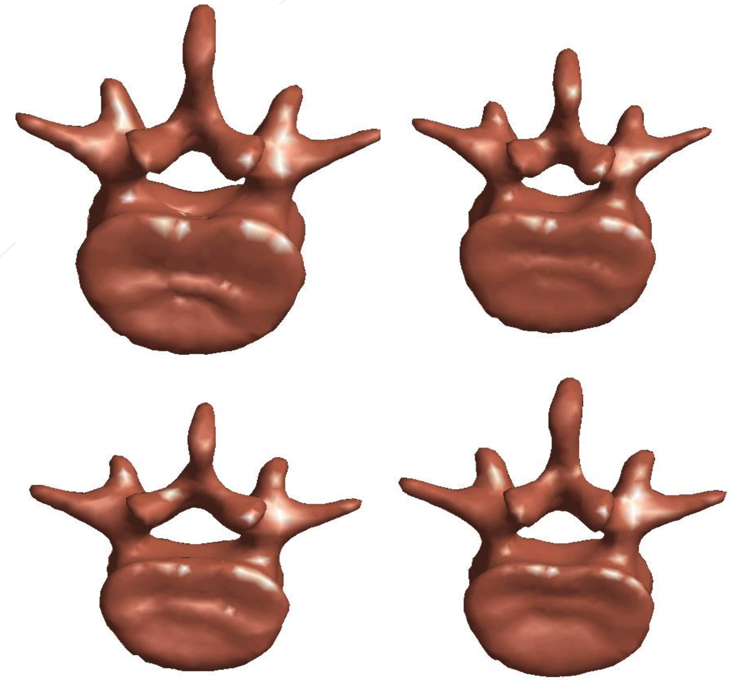
This Work

- We propose a method for simultaneous segmentation of multiple vertebrae.
- Registration-based segmentation technique.
- Alignment of a statistical multi-vertebrae model to MR images.

Statistical Shape Models



First four modes of shape variation



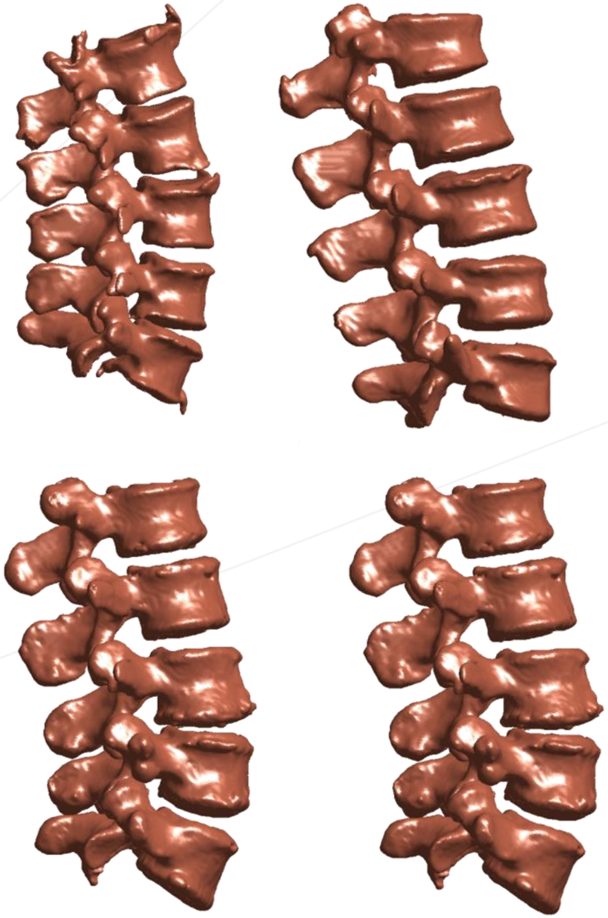
Mean shape → Transformation → PCA

Rasoulian *et al.,* Group-wise registration of point sets for statistical shape models, TMI, 2012

Cootes *et al*., Active shape models-their training and application. Computer Vision and Image Understanding, 1995.

Multi-object models?

- Traditional approach is not working
  - Shape and pose are not correlated
  - Shape and pose do not belong to the same space



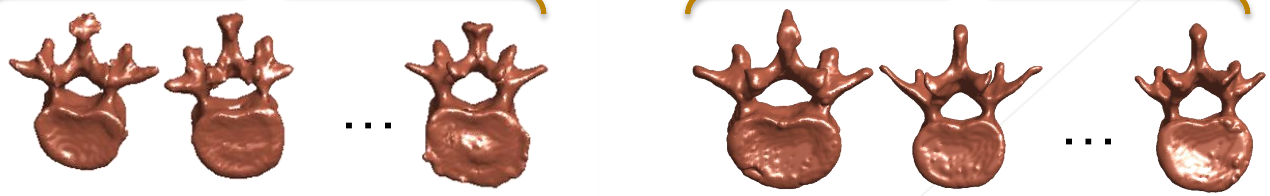
Training set

Lu *et al.*, Statistical multi-object shape models, International Journal of Computer Vision, 2007.
Bossa and Olmos, Multi-object Statistical Pose+Shape Models, ISBI, 2007.
Duta and Sonka, Segmentation and interpretation of MR brain images. an improved active shape model, TMI, 1998.

Shape statistics

L1 Training set

L2 Training set



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Mean Shape and Variations

Mean Shape and Variations

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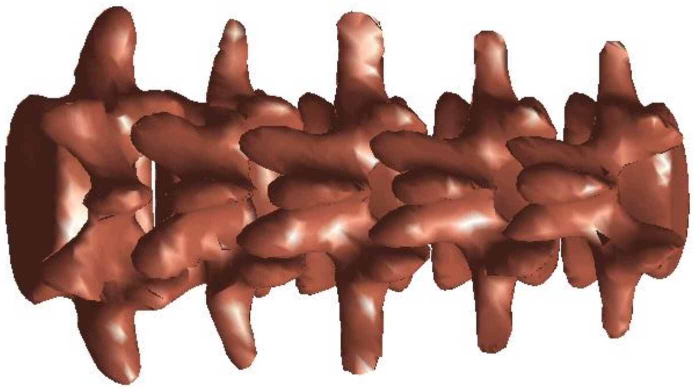
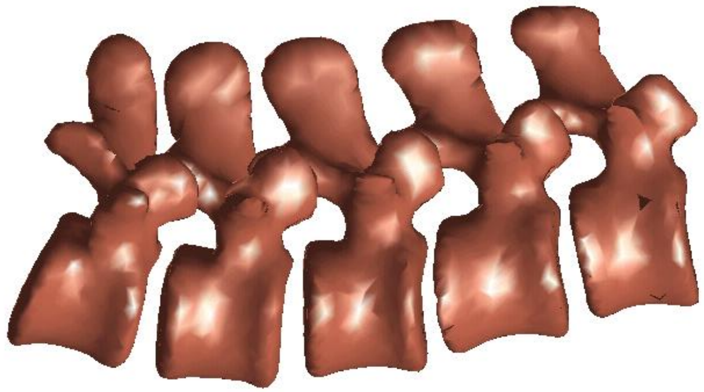
Concatenate the variations and perform the PCA

Shape variations

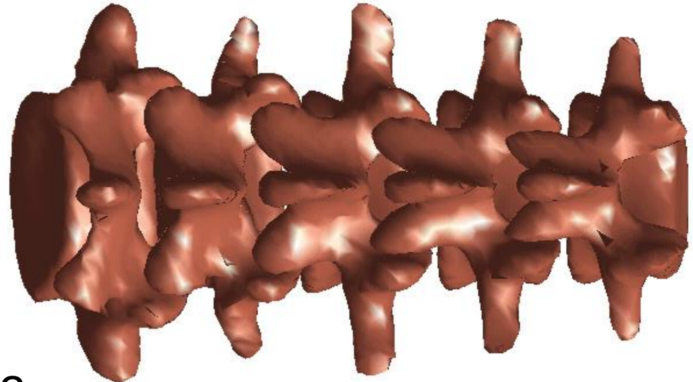
First Mode



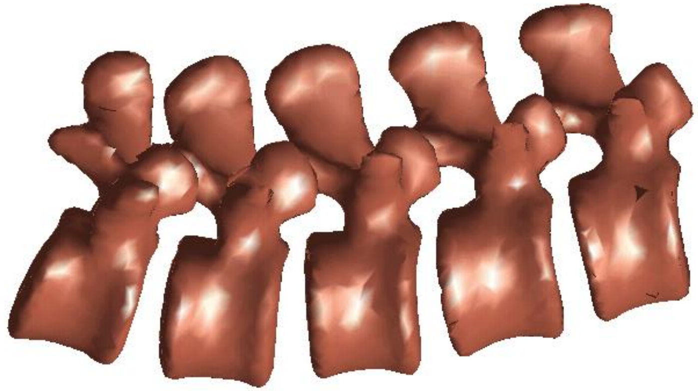
Second Mode



Third Mode



Fourth Mode



N=32

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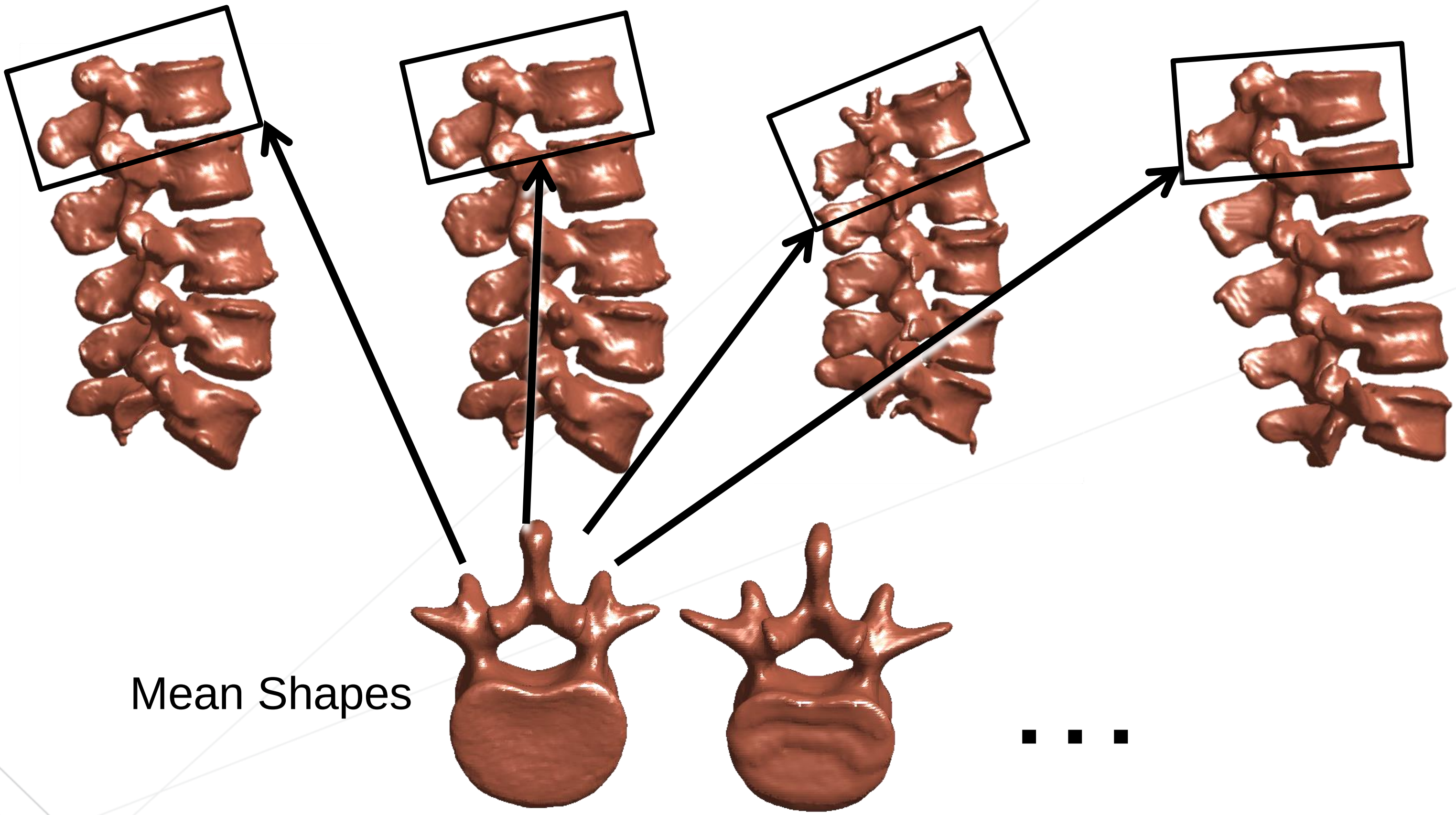
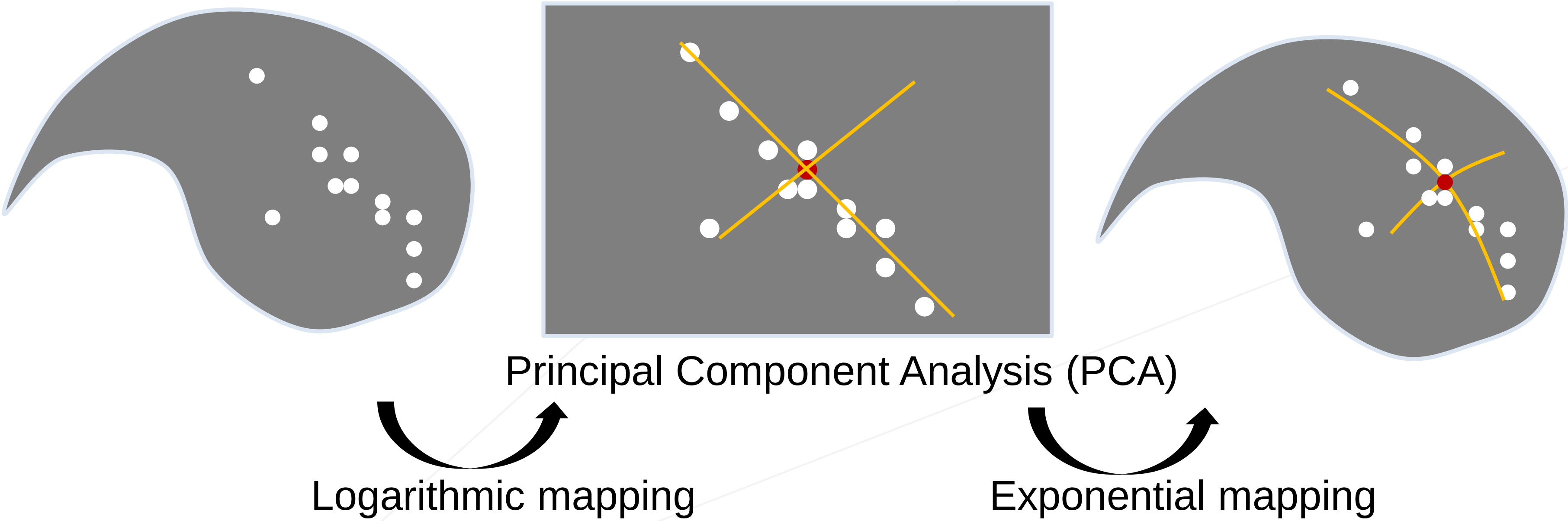
Pose variations

- Pose are represented by similarity (rigid+scale) transformations



Principal Geodesic Analysis (PGA)

- Similarity transformations form a Lie group

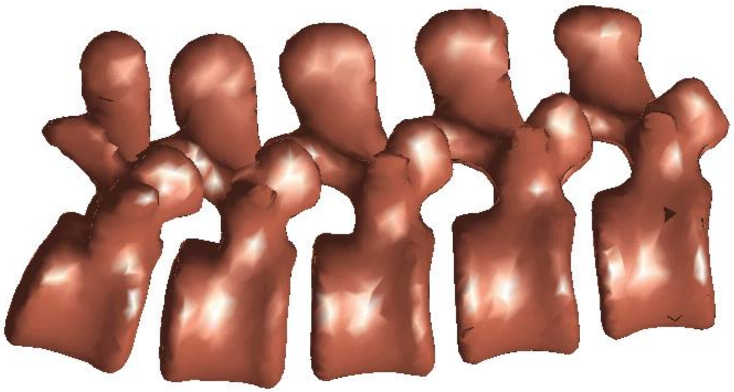


Pennec, Intrinsic statistics on Riemannian manifolds: Basic tools for geometric measurements. Journal of Mathematical Imaging and Vision, 2006.

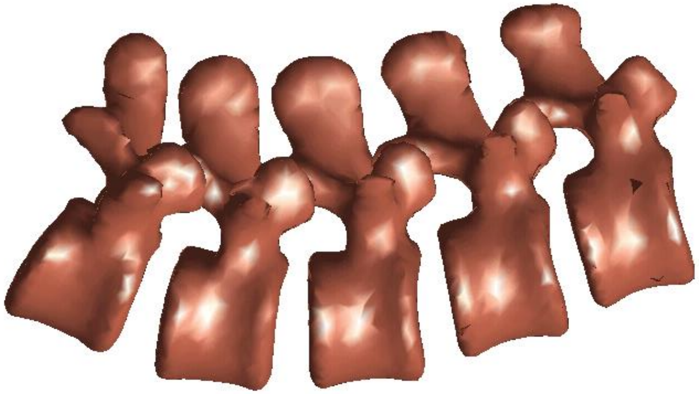
Fletcher *et al.*, Statistics of shape via principal geodesic analysis on lie groups. CVPR, 2003.

Pose variations

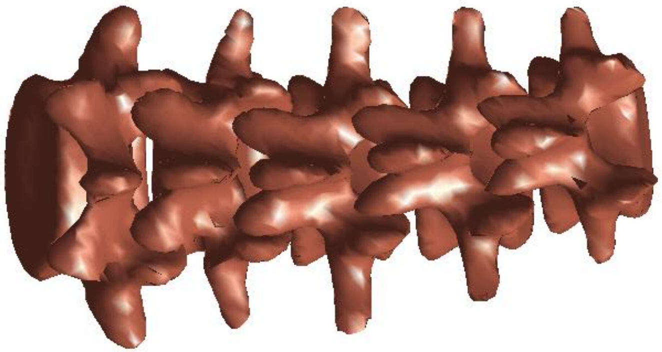
First Mode



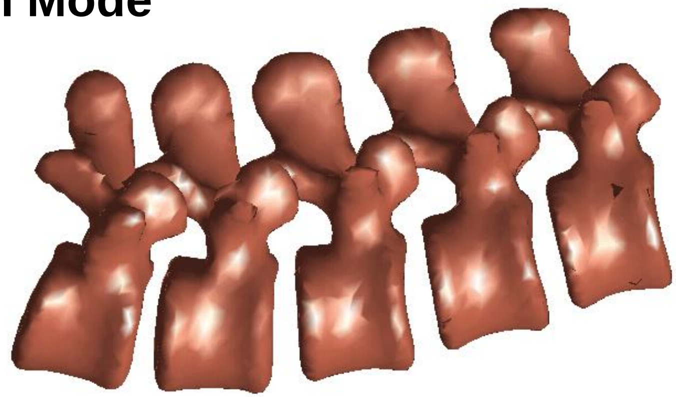
Second Mode



Third Mode



Fourth Mode



N=32

Transformation of the model

- Transform the model by assigning weights to shape and pose modes of variations and a rigid transformation:

$$s = \Phi(w_s, w_p, T)$$

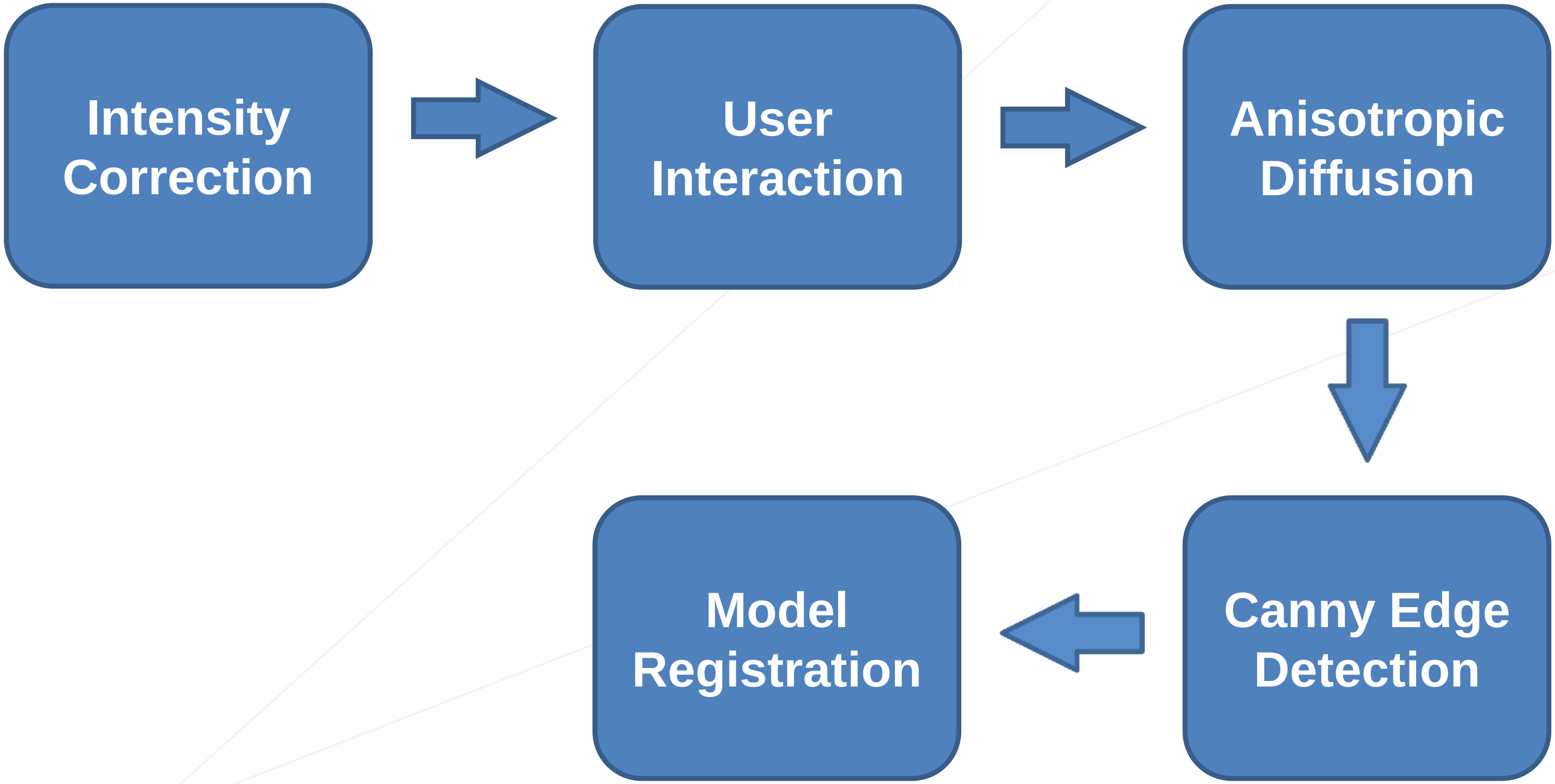
- w_s :weights for the shape variations
- w_p :weights for the pose variations
- T :rigid transformation

Statistical Shape+Pose Model

- Takes advantage of the correlation between shape and pose of different vertebrae in the same patient.
- Previously used for vertebra segmentation in CT[1].
- We aim to find simple and fast pre-processing steps to adapt it to MR segmentation.

[1] Rasoulian *et al.*, TMI, 2013

Method


Intensity Correction
User Interaction
Anisotropic Diffusion
Canny Edge Detection
Model Registration

Pre-processing

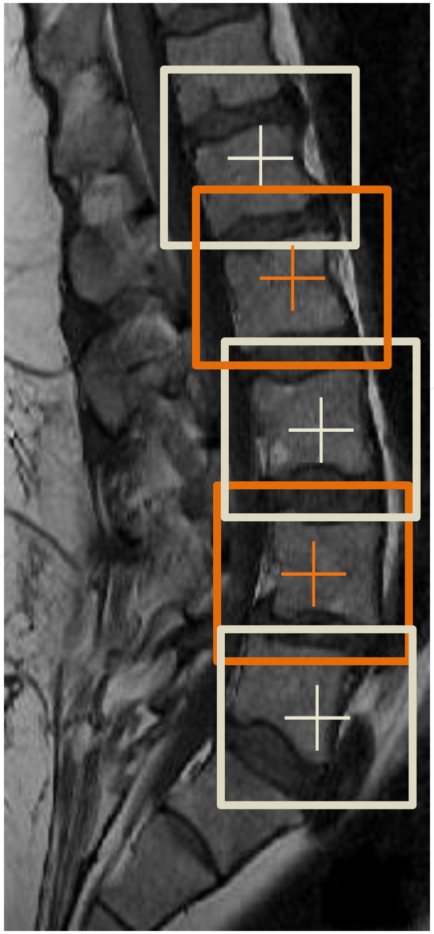
- Intensity correction

Original image

Intensity-corrected image

User Interaction

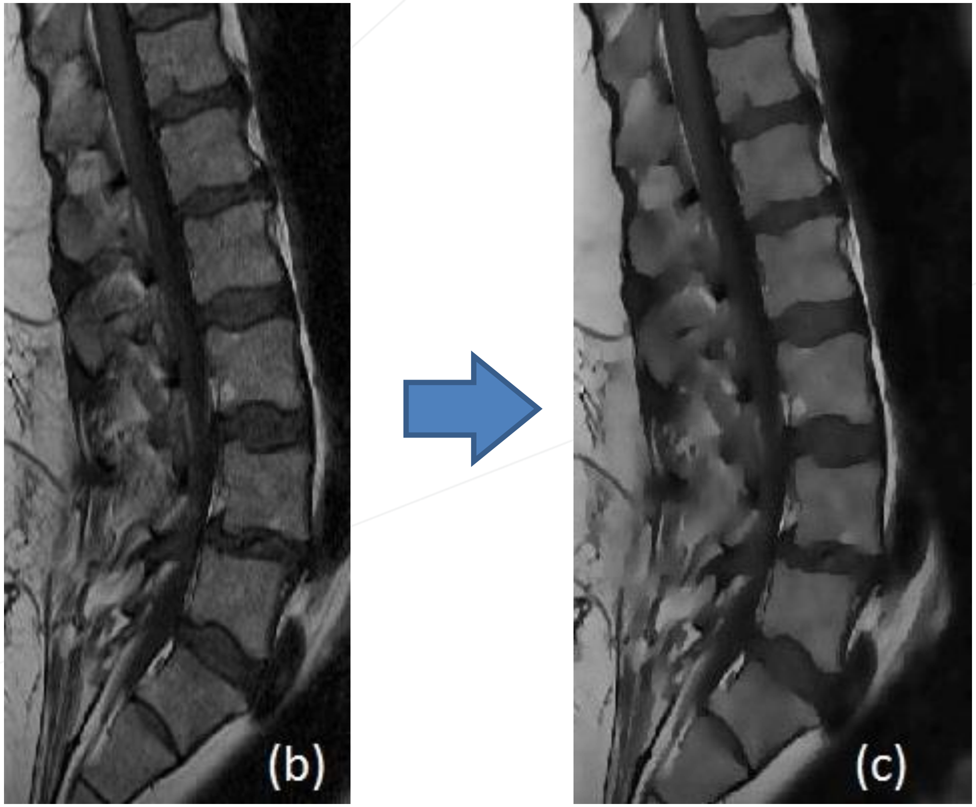
- Mid-sagittal slice of intensity-corrected image is shown to the user.
- User clicks on each vertebra to start the segmentation process.
- Anisotropic diffusion and Canny edge detection is only applied on boxes centered to the clicked points.



Clicked points and boxes

Pre-processing

- Anisotropic diffusion

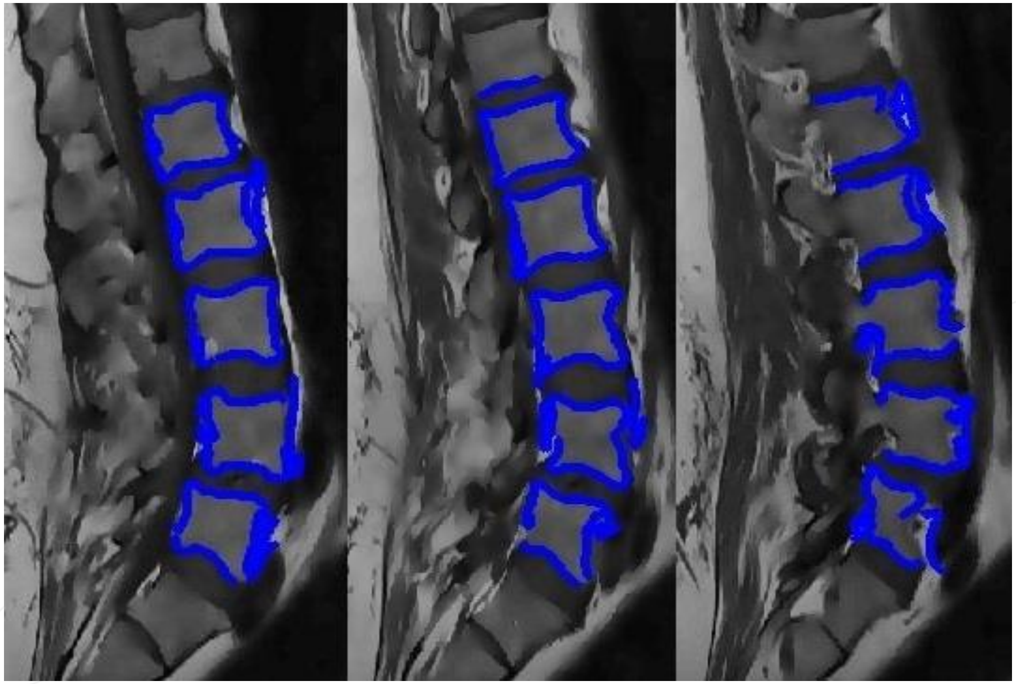


Intensity-corrected image

After anisotropic diffusion

Canny Edge Detection

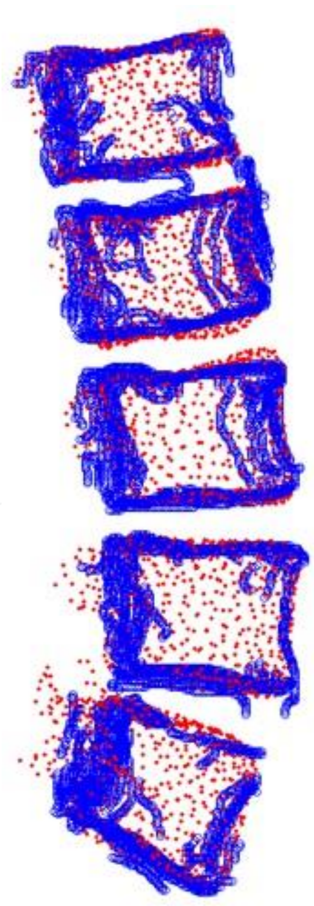
- Extract edges in the boxes around points clicked by user.



Extracted edges using Canny edge detection on three slices of the same volume

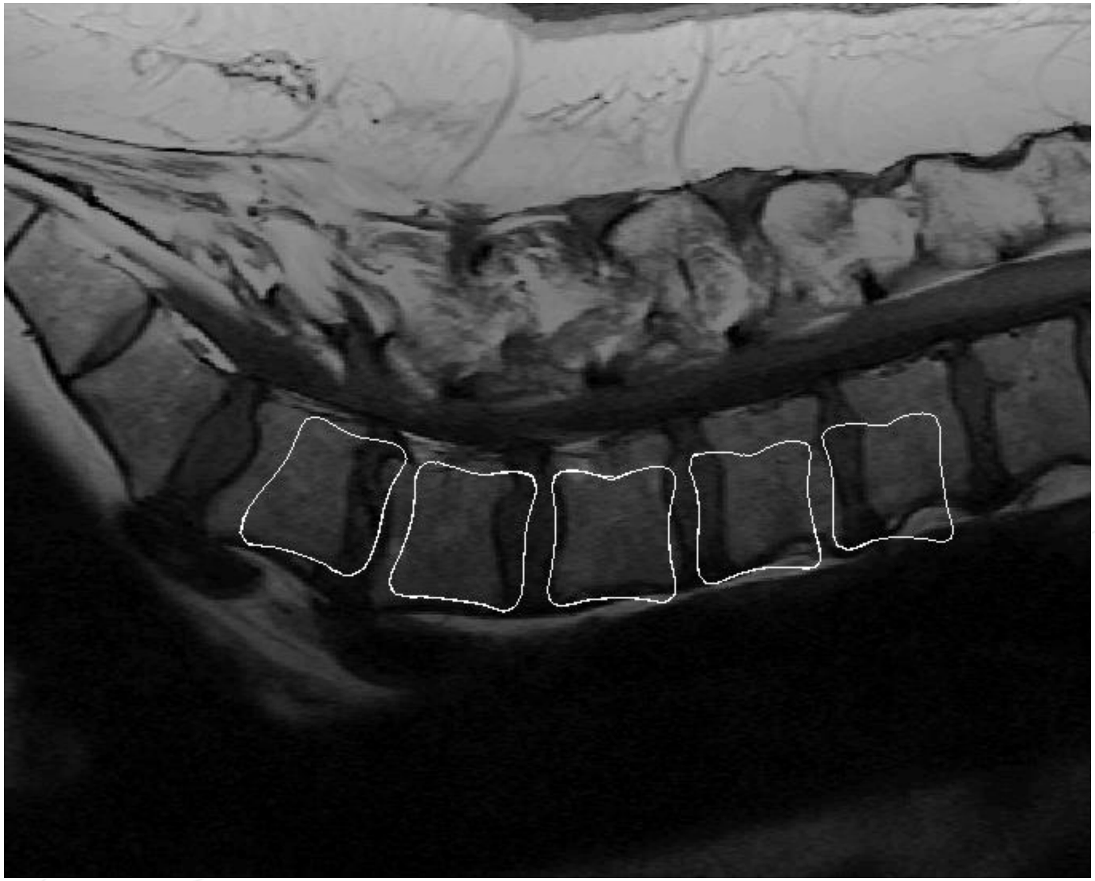
Registration

- Register the multi-vertebrae anatomical model to the edge map using an iterative Expectation Maximization (EM) method.
- Only vertebral body part of the model is used for registration.



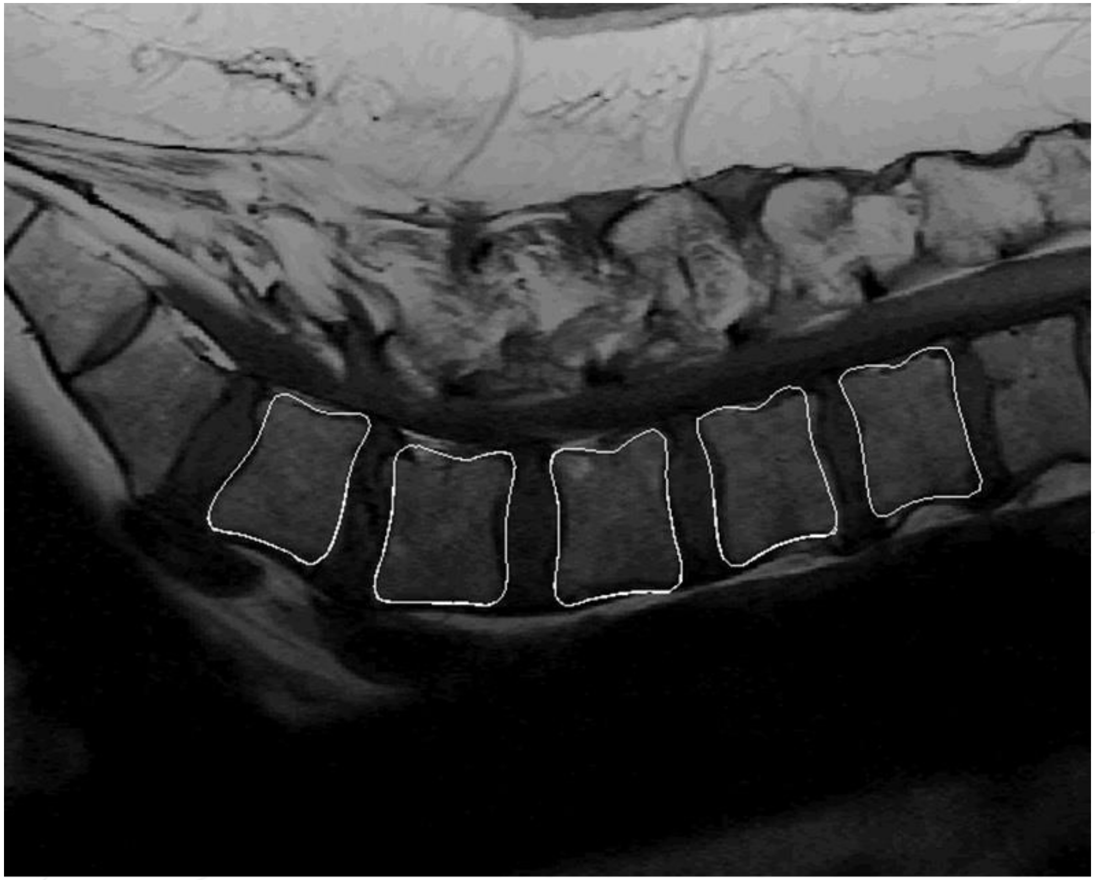
Registered model

Registration



Registration on mid-sagittal slice

Registration

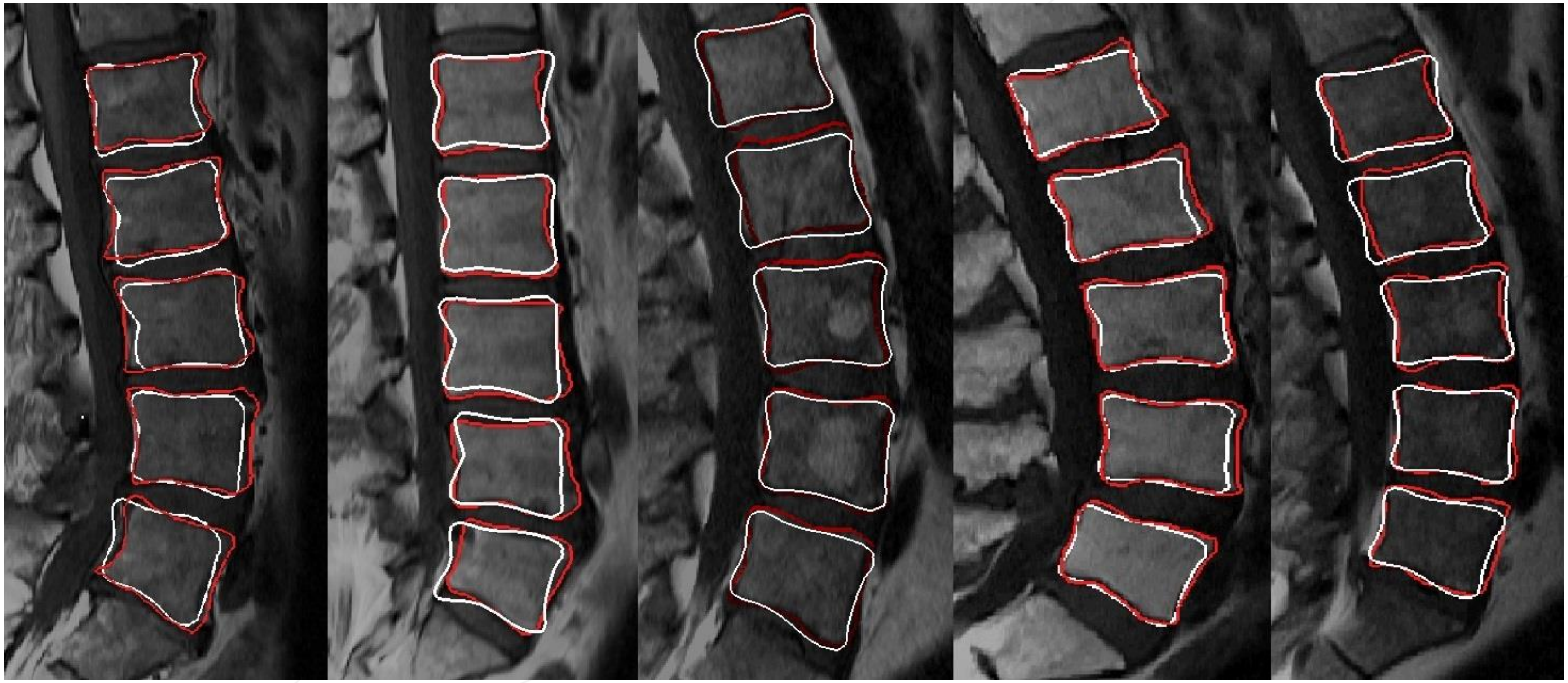


Registration on mid-sagittal slice

Segmentation Results

- Evaluated on nine multi-slice MR images.
- Inter-slice gaps in range of [3.3 mm 4.4 mm].
- Manual segmentation is used as ground truth.
- Computation time: less than 2 minutes on a 2.5 GHz Intel core i5 machine.
- 3D mean surface error $\cong 3 \pm 0.8$ mm.
- 2D mean error in mid-sagittal slices $\cong 1.9 \pm 0.4$ mm.

Segmentation Results



Examples of segmentation results in five different volumes

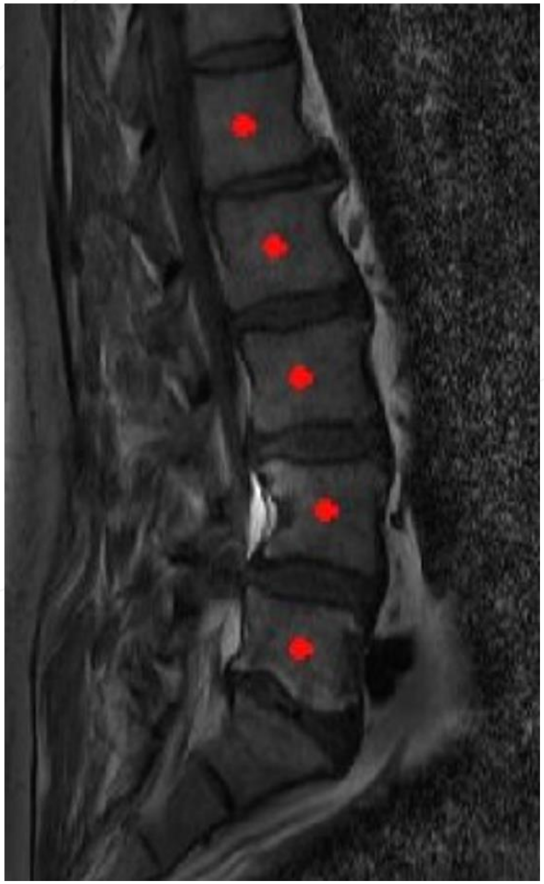
Conclusions

- A method for semi-automatic simultaneous segmentation of vertebral bodies in volumetric MR images is proposed.

- Future work includes
  - Segmentation of whole vertebrae.

Next Step

- Automatic localization of vertebrae instead of user interaction.



Automatically localized vertebrae

Acknowledgement

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CIHR IRSC

Thank you …