Deep Learning for Automatic Localization, Identification, and Segmentation of Vertebral Bodies in Volumetric MR Images

Amin Suzani, A. Rasoulian, A. Seitel,
S. Fels, R. N. Rohling
P. Abolmaesumi

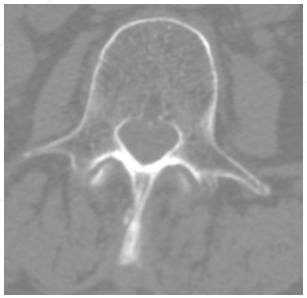
Robotics and Controls Laboratory,
University of British Columbia, Vancouver, Canada

Purpose

- Localization and identification of vertebrae.
  - Core requirement for computer-aided systems for spine.
- Segmentation of vertebral structures enables quantitative analysis of spine pathologies.
  - deformations caused by different pathologies

Challenges

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



CT

MR

Related Work in Localization

- Mostly make assumptions about which vertebrae are visible in the scan.
  - [Ma‘13], [Oktay’13], [Neubert’12], [Stern’11], [Naegel’07], [Schmidt’07].
- General methods are mostly developed for CT.
  - [Glocker’13], [Rasoulian’13], [Glocker’12], [Klinder’09].
- Mostly are not integrated with segmentation.
  - [Glocker’13], [Glocker’12].

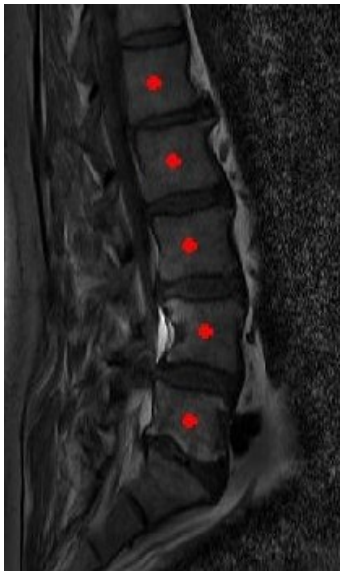
Related Work in Segmentation

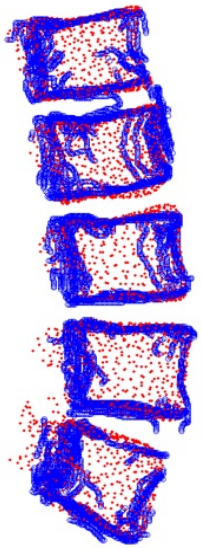
- Mostly require user interaction.
  - [Suzani'14], [Rasoulian'13], [Hoad'02].
- Most approaches are in 2D
  - [Egger'12], [Carballido-Gamio'04], [Shi'07], [Huang'09].
- 3D Methods are mostly evaluated on MR images with inter-slice gap of 1.2 mm or less.
  - [Kadoury'13], [Neubert'12], [Stern'11].
- Each vertebra is mostly segmented independently.
  - [Neubert'12], [Stern'11], [Hoad'02].

This Work

- We propose an automatic method for simultaneous localization and identification of vertebrae.
- The predictions are used for automating a registration-based segmentation technique.
- No assumptions are made about the visibility of specific vertebrae.
- Multiple vertebrae are registered simultaneously.

Method

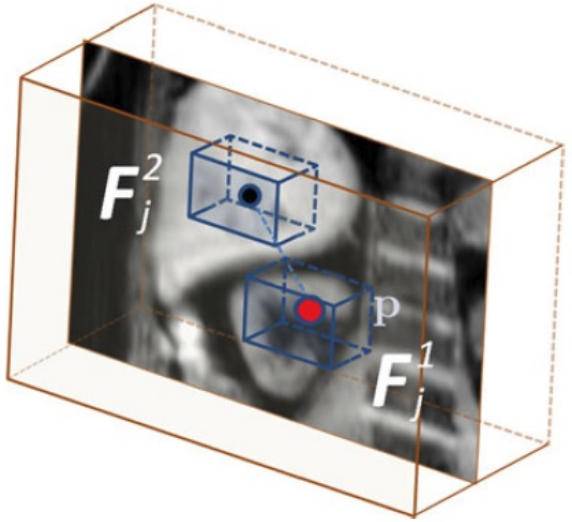




Automatic Localization → **Edge Detection** → **Model Registration**

Features

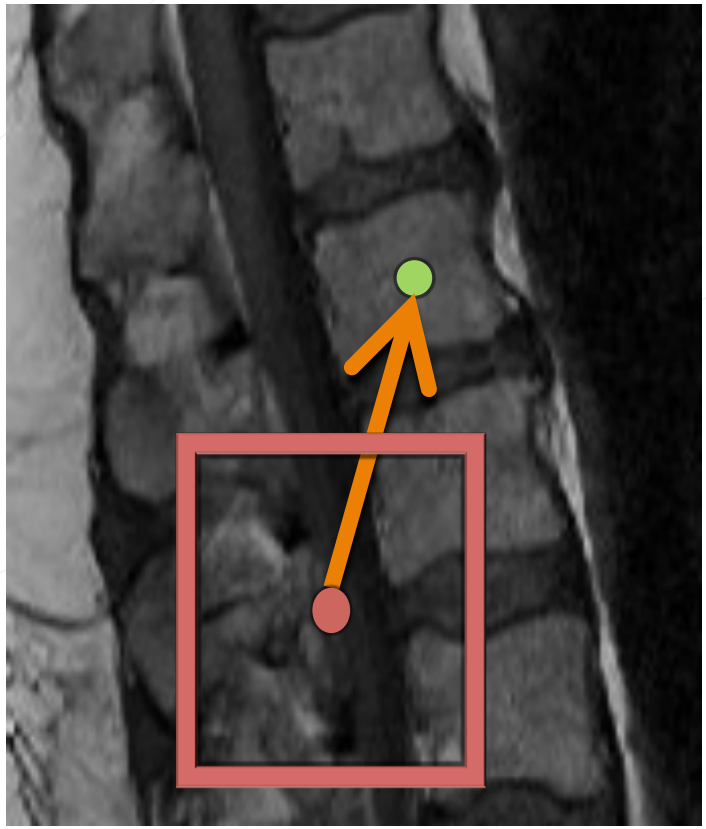
- 500 features are extracted for each voxel.
- Each feature: difference between the mean intensity over two cuboids displaced with respect to the reference voxel position.
- Feature dimensions and displacement are chosen randomly.



Intensity-based features

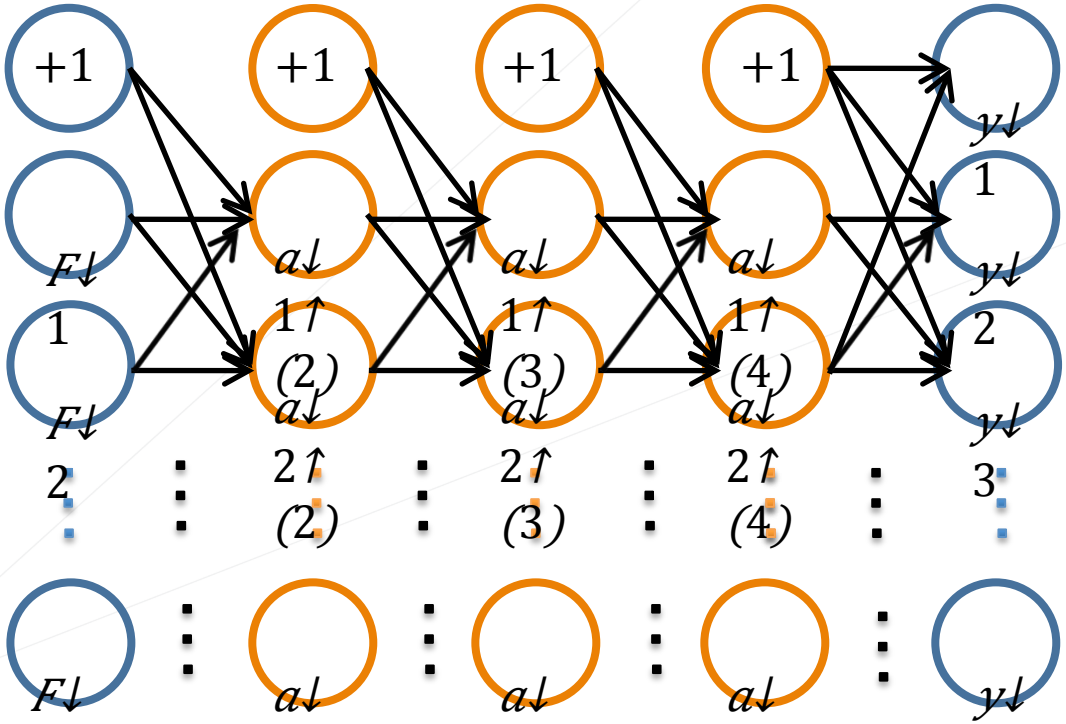
Problem Parameterization

- Vertebrae anatomy localization is parameterized as a multivariate regression problem.
- Each voxel votes for its relative distance to the centroid of each vertebral body.



Deep Neural Network

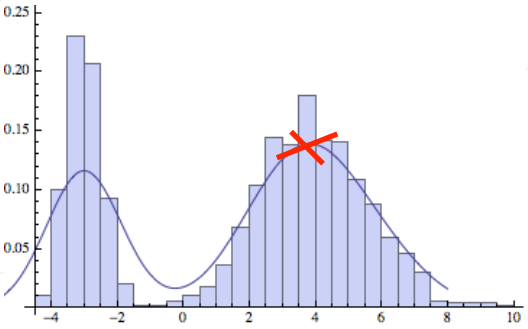
- Neural network is trained using stochastic gradient descent and layerwise pre-training.



Neural network structure

Centroid Estimation

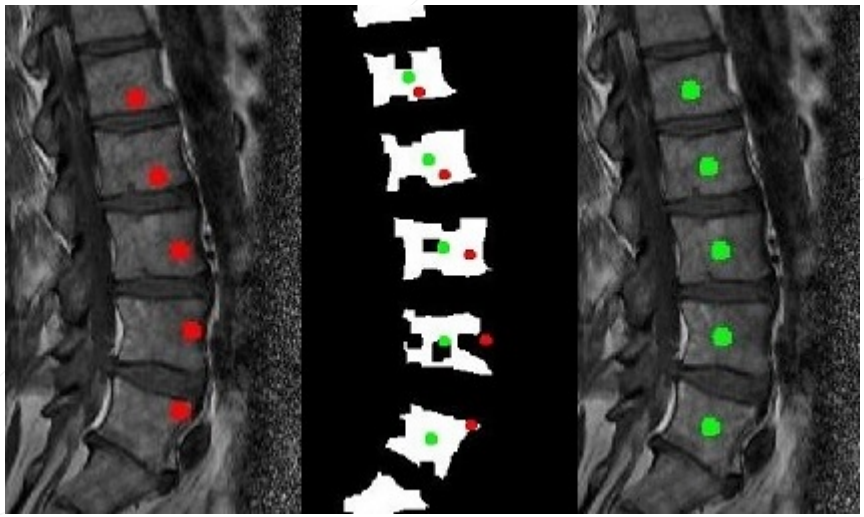
- Kernel Density Estimation is used for aggregating the votes of all voxels.



Centroid estimation

Refinement

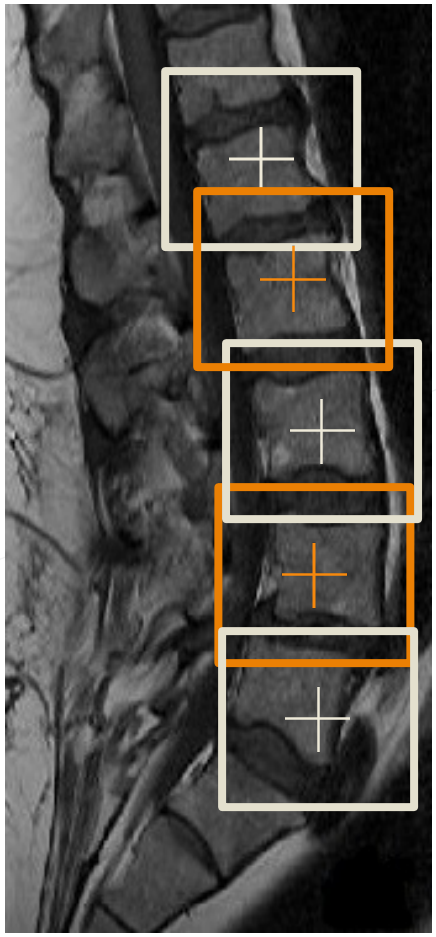
- Predicted points are refined by local Otsu thresholding. The points are replaced with the center of the closest large component.



Refinement step

Region of Interest

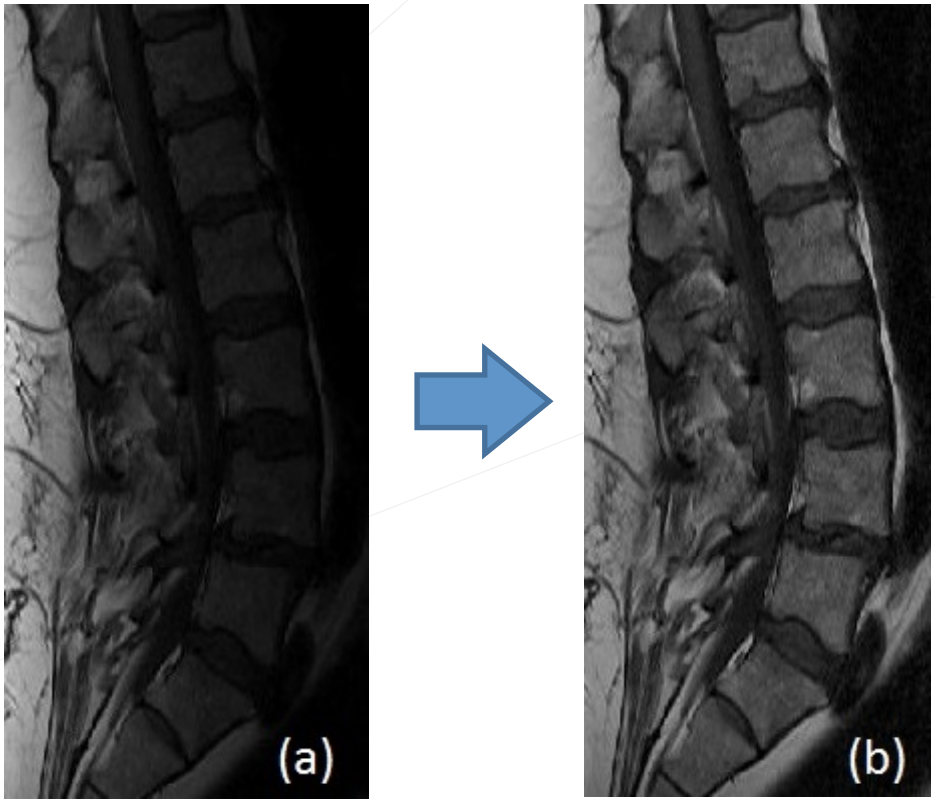
- Pre-processing steps and edge detection is only applied on boxes centered to the predicted points.



Predicted points and boxes

Pre-processing for Segmentation

- Intensity correction



Original image

Intensity-corrected image

Pre-processing for Segmentation

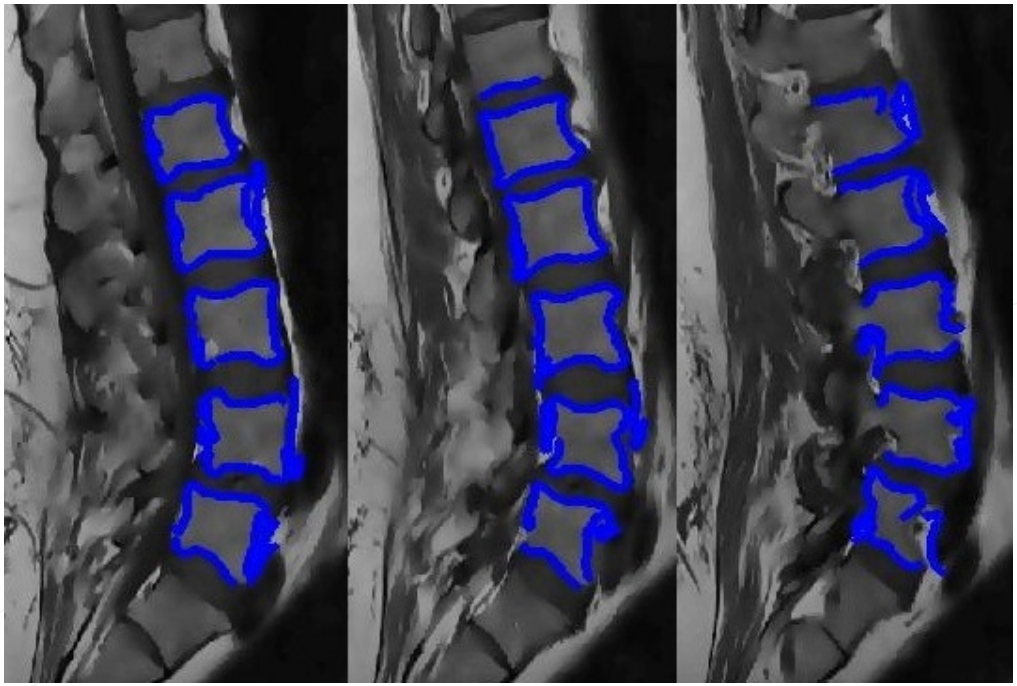
- Anisotropic diffusion

Intensity-corrected image

After anisotropic diffusion

Canny Edge Detection

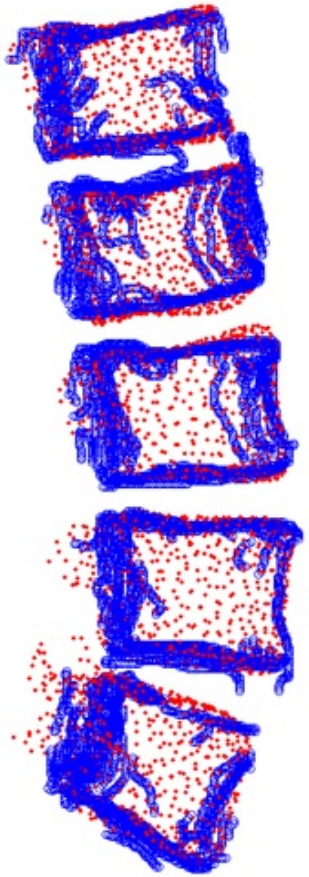
- Extract edges in the area of the predicted vertebrae.



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

Registration

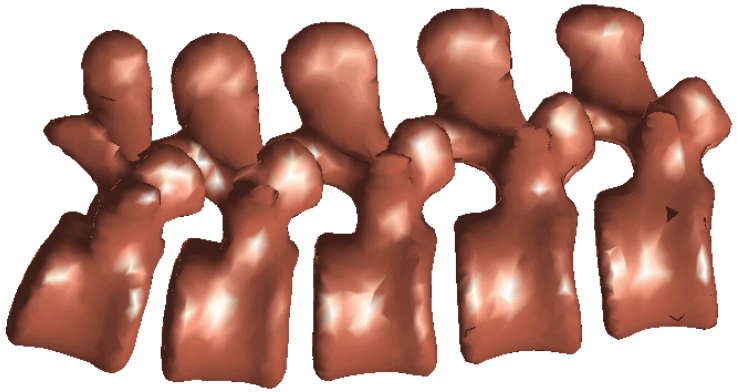
- Multi-vertebrae anatomical model is initialized by the predicted points from localization step.
- The model is registered to the edge map using an iterative expectation maximization method.
- Only vertebral body part of the model is used for registration.
- Correlation between shapes and poses of different vertebrae are taken into account.



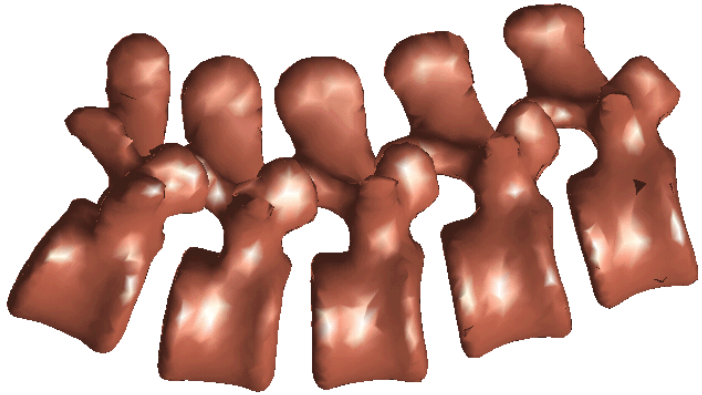
Registered model

Model Pose Variations

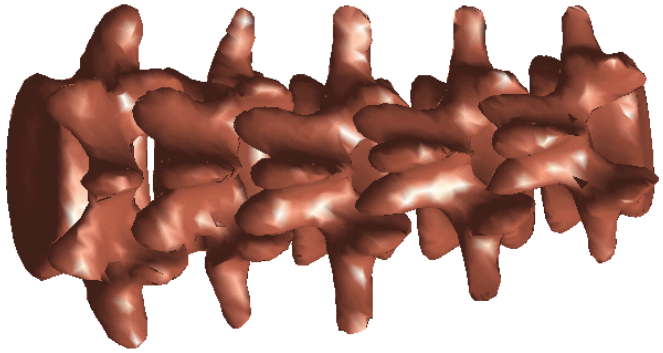
First Mode



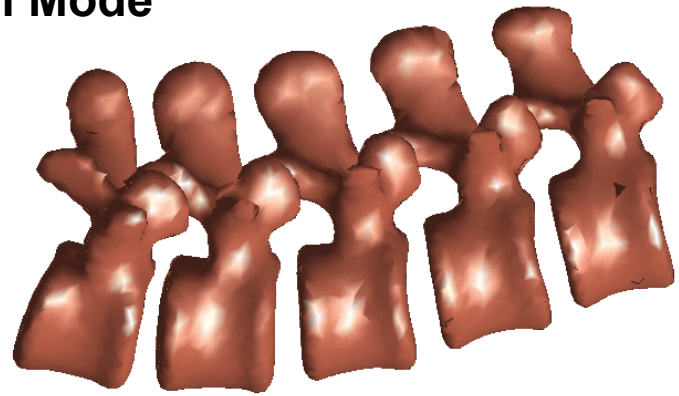
Second Mode



Third Mode

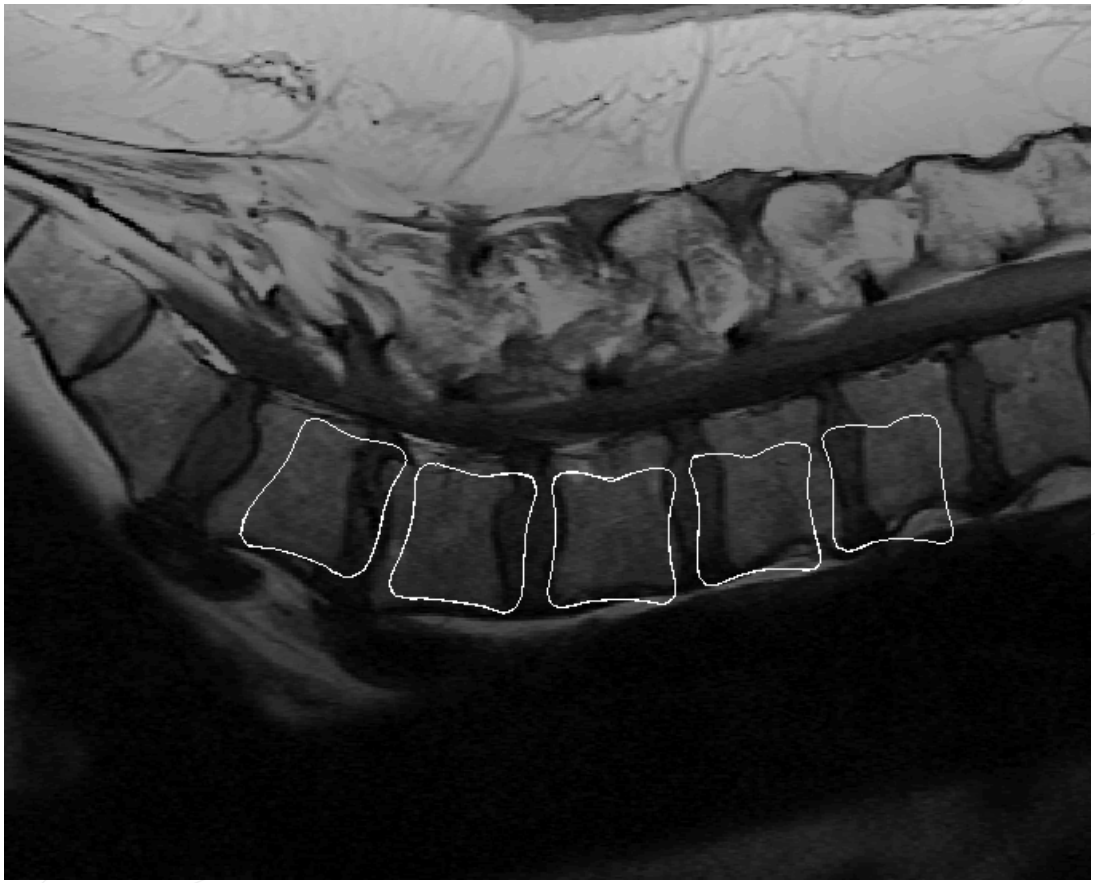


Fourth Mode



N=32

Registration



Registration on mid-sagittal slice

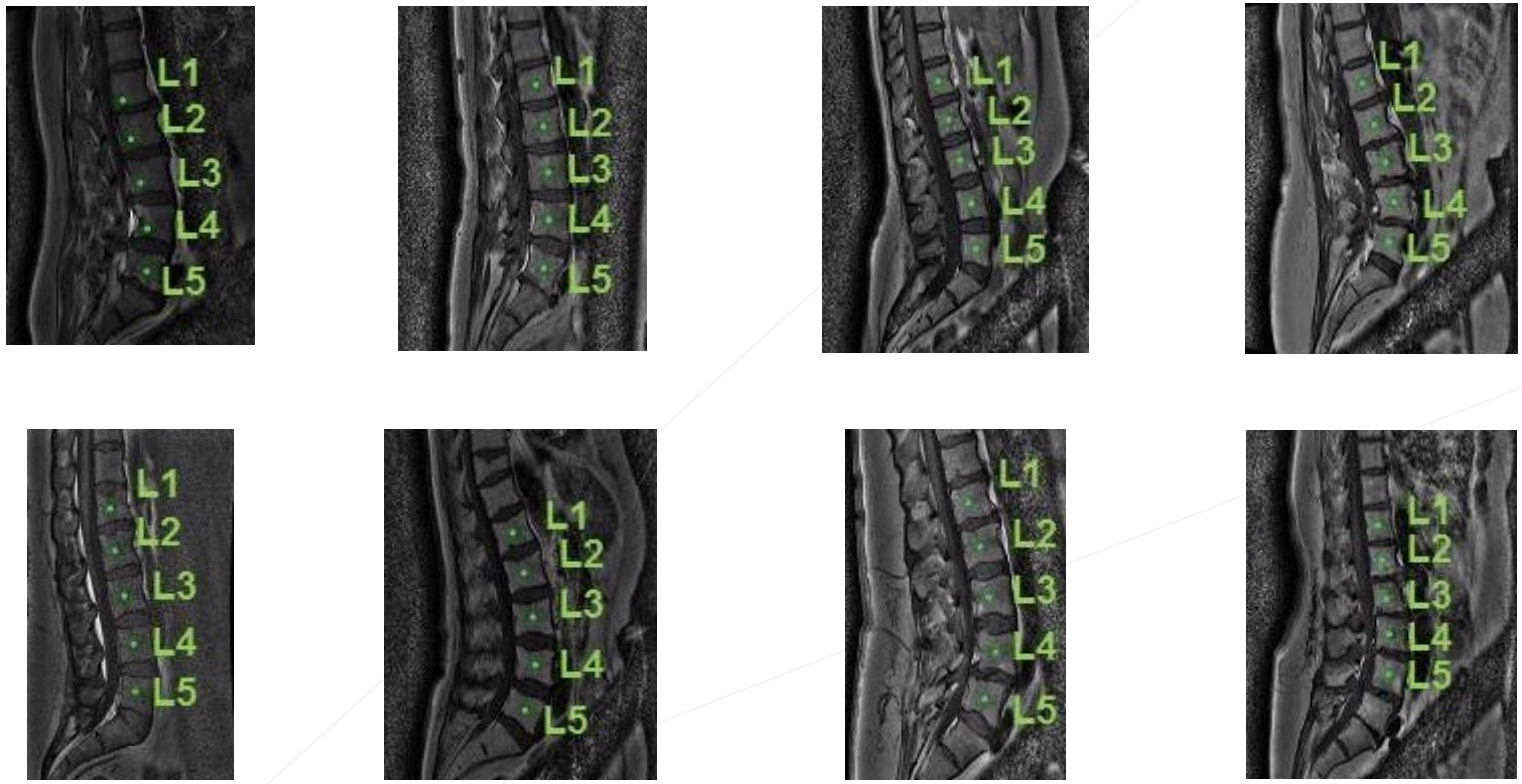
Results

- Evaluated on nine multi-slice MR images of lumbar spine.
- Inter-slice gaps in range of [3.3 mm 4.4 mm].
- Computation time: less than 3 minutes in total (on a 2.5 GHz Intel core i5 machine).

	Mean Error	Std	Identification
Deep learning localization	11.9 mm	6.3 mm	91 %
After refinement	3.0 mm	2.4 mm	100 %

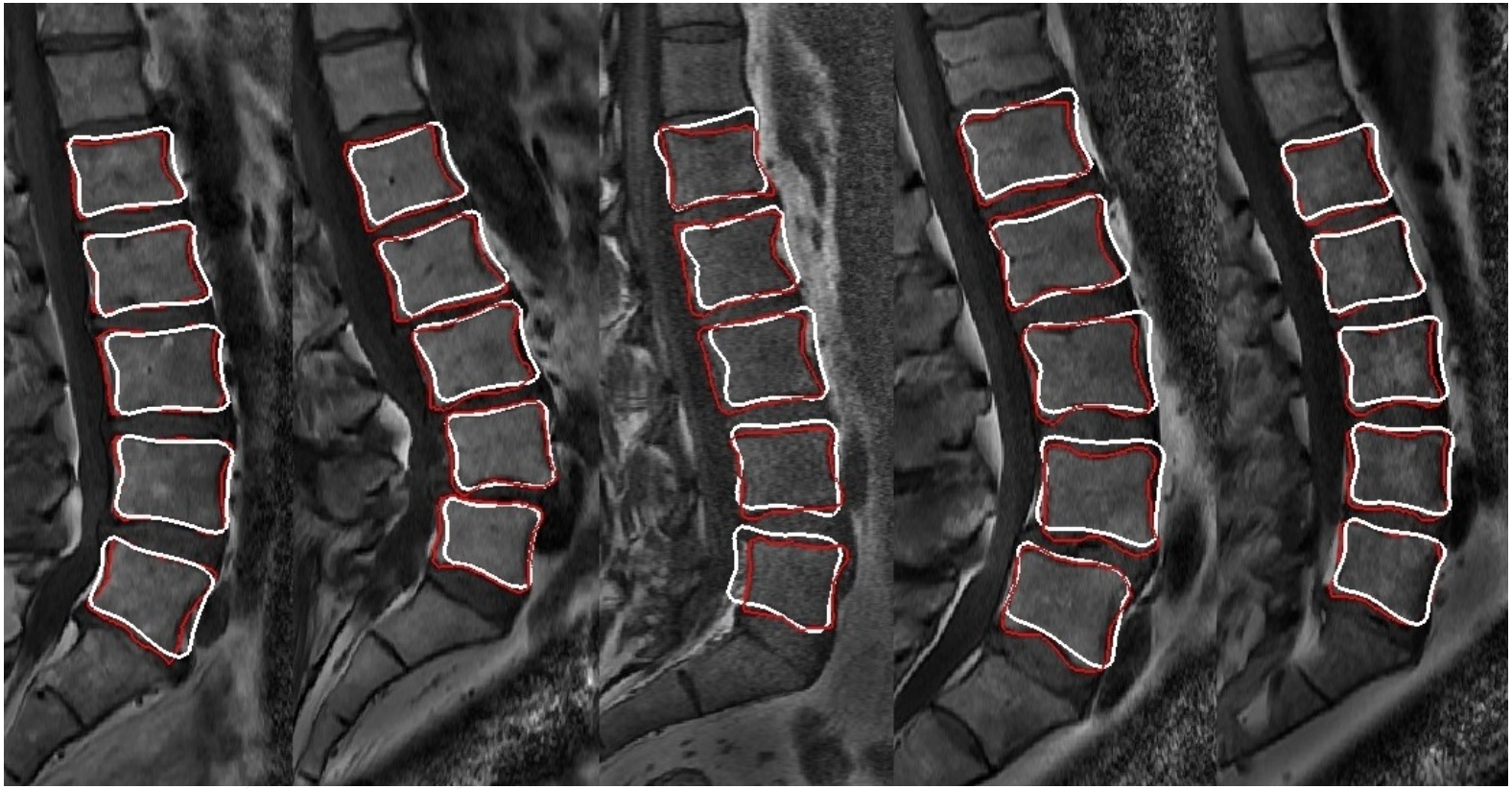
- Segmentation: 3D mean surface error $\cong 2.7 \pm 0.9$ mm.

Localization Results



Examples of localization and identification results.

Segmentation Results



Examples of segmentation result.

Our segmentation
Manual segmentation

Conclusion

- A method is proposed for Automatic localization, identification, and segmentation of vertebral bodies in volumetric MR images.

- Future work includes
  - Better evaluation on a large dataset of pathological cases.
  - Evaluation on other modalities like CT and Ultrasound.
  - Segmentation or sub-anatomical labeling of whole vertebrae.

Acknowledgement

Thank you …