Multi-modal registration for Adolescent Idiopathic Scoliosis subject specific avatar creation

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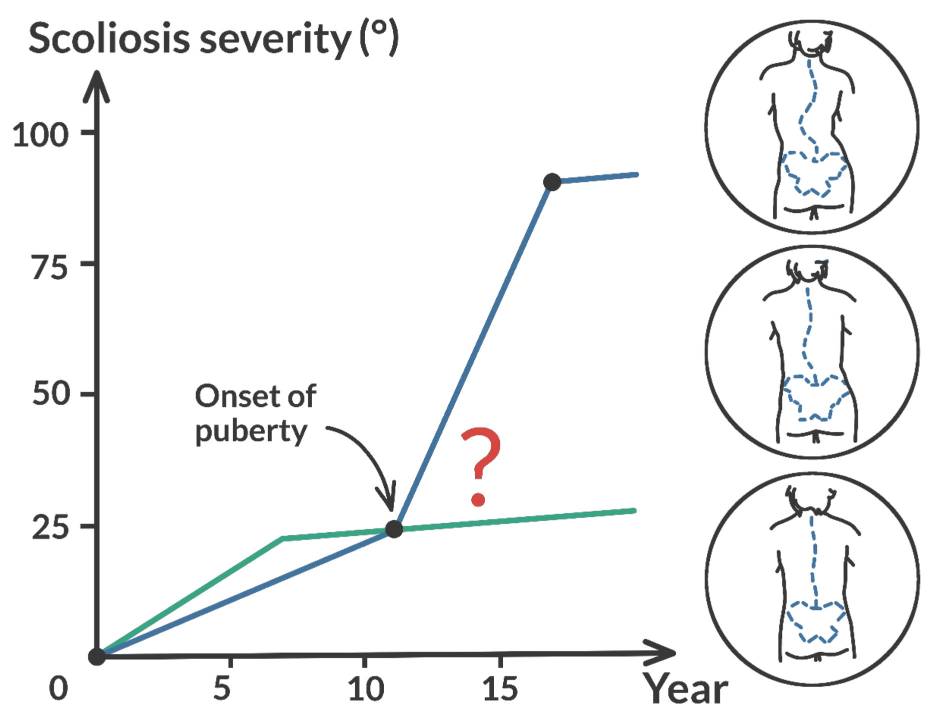
Summary

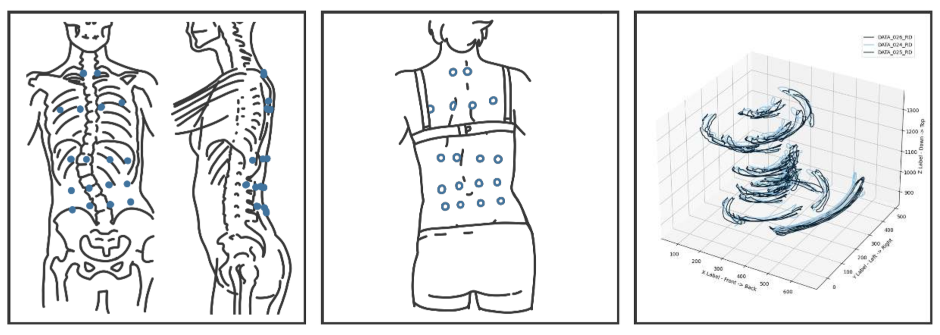
Long-term motivation

- Find predictive biomarkers of scoliosis evolution



Adaptated from the Duval-Beaupere diagram

Strategy



X-rays Surface scan Motion capture

- Hypothesis: information is in the patient
- Where ? we don't know, thus we capture different modalities
- Challenge: multi-modal data registration

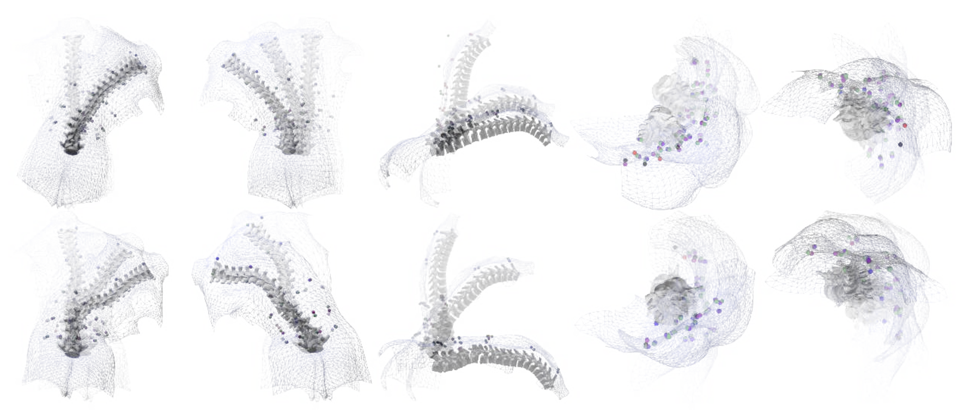
Contributions

- Workflow creating a subject-specific kinematic model of patients with Adolescent Idiopathic Scoliosis
- Preliminary evaluation: reconstruction of spine dynamics from motion capture

The kinematic model

- Set of 18 rigid-bodies (each bone)
- 17 spherical joints (6 DOFs) [2, 3]
- Meshes: skin and bones
- Linear Blend Skinning

Application to mocap



References

[1] Humbert et al. 3d reconstruction of the spine from biplanar x-rays using parametric models based on transversal and longitudinal inferences. *Medical Engineering & Physics*, 31(6):681–687, July 2009.

[2] Ignasiak et al. Thoracolumbar spine model with articulated ribcage for the prediction of dynamic spinal loading. *Journal of Biomechanics*, 49:959–966, 2016.

[3] Koutras et al. A Study of the Sensitivity of Biomechanical Models of the Spine for Scoliosis Brace Design. 2020.

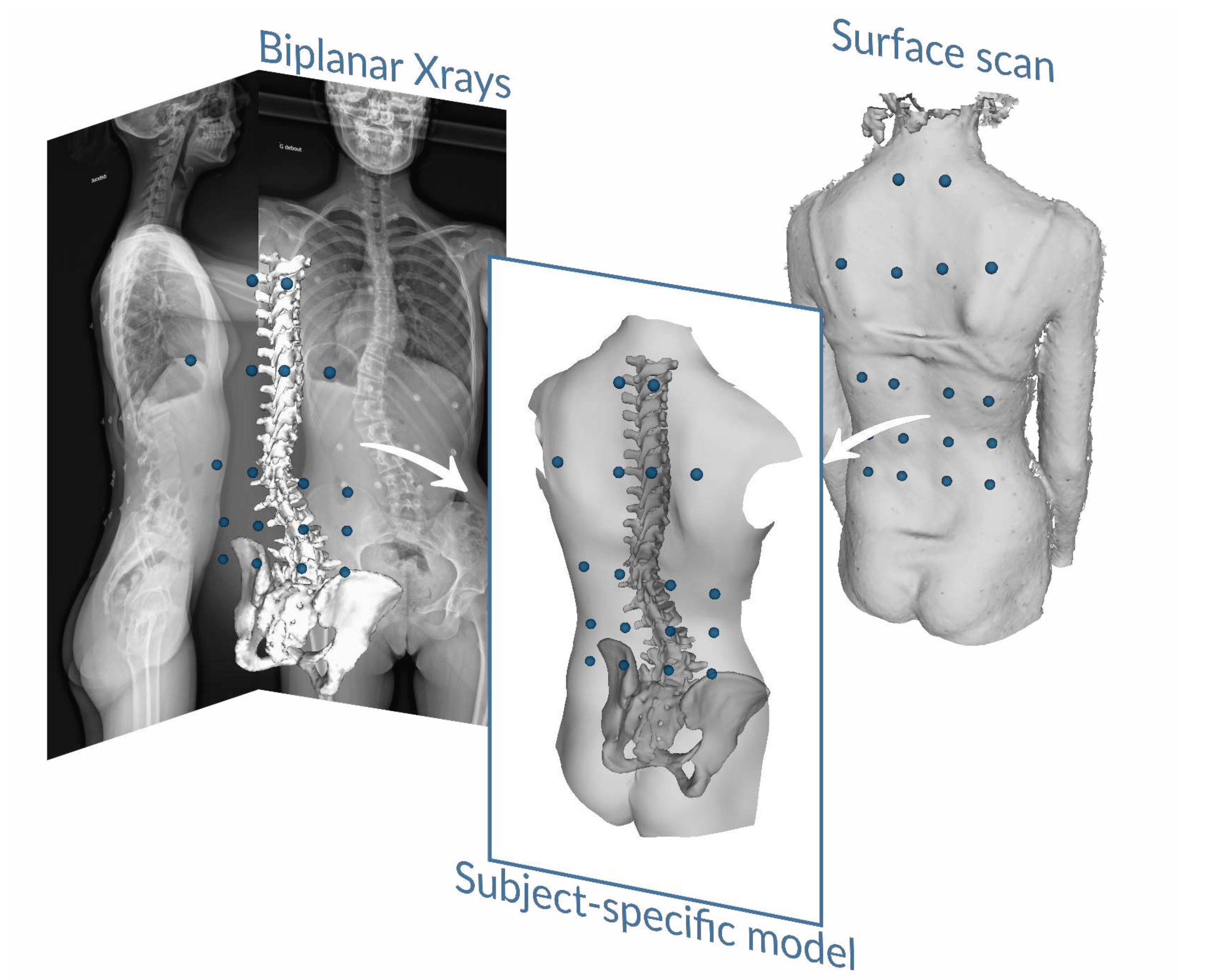
[4] Wu et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part i: ankle, hip, and spine. *Journal of Biomechanics*, 35(4):543–548, 2002.

Numerical twin creation

- Leverage radio-opaque markers (blue dots) present in all acquisitions

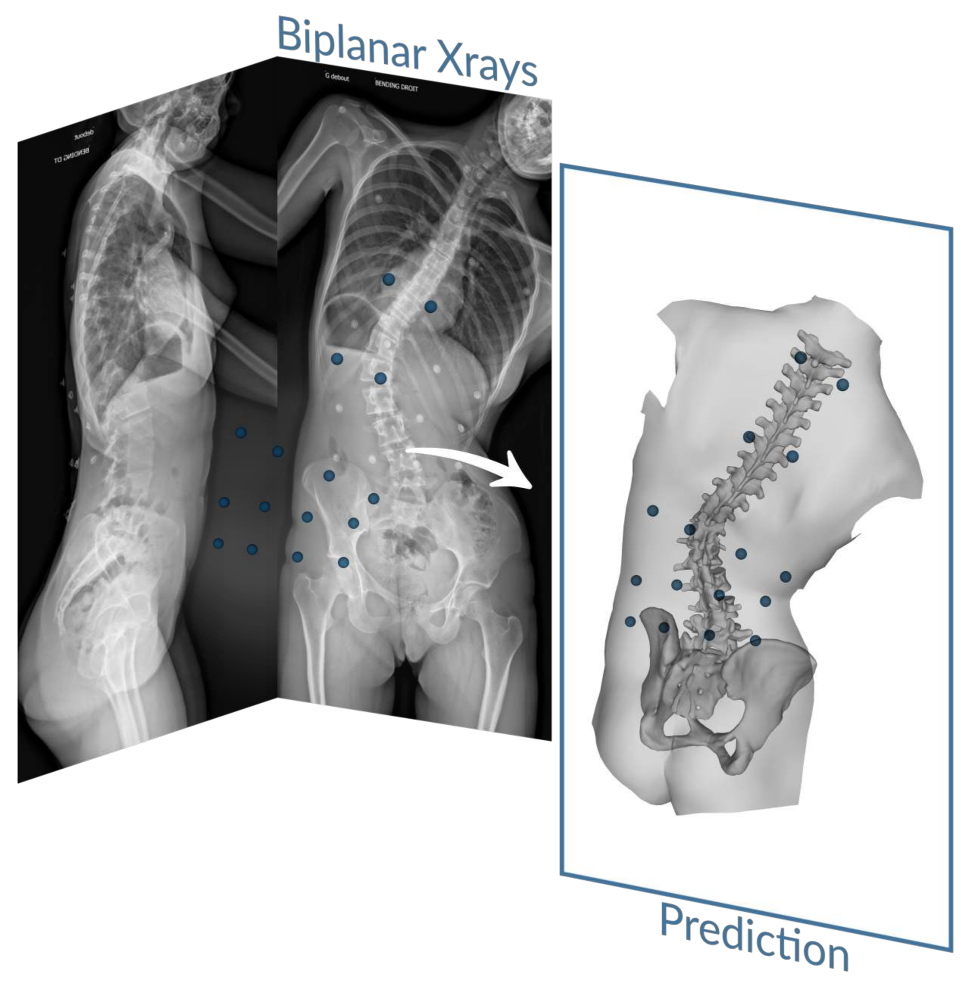
(1) Subject-specific avatar creation

- Inputs from two imaging systems:
  Spine biplanar X-rays + 3D reconstruction [1] using SterEOS (EOS imaging, Paris)
  Skin surface scan with the Structure Sensor Mark II (XRPro, LLC, Saratov)
- Rigid + elastic registration methods (Anatomy transfer, Anatoscope, Montbonnot-Saint-Martin)



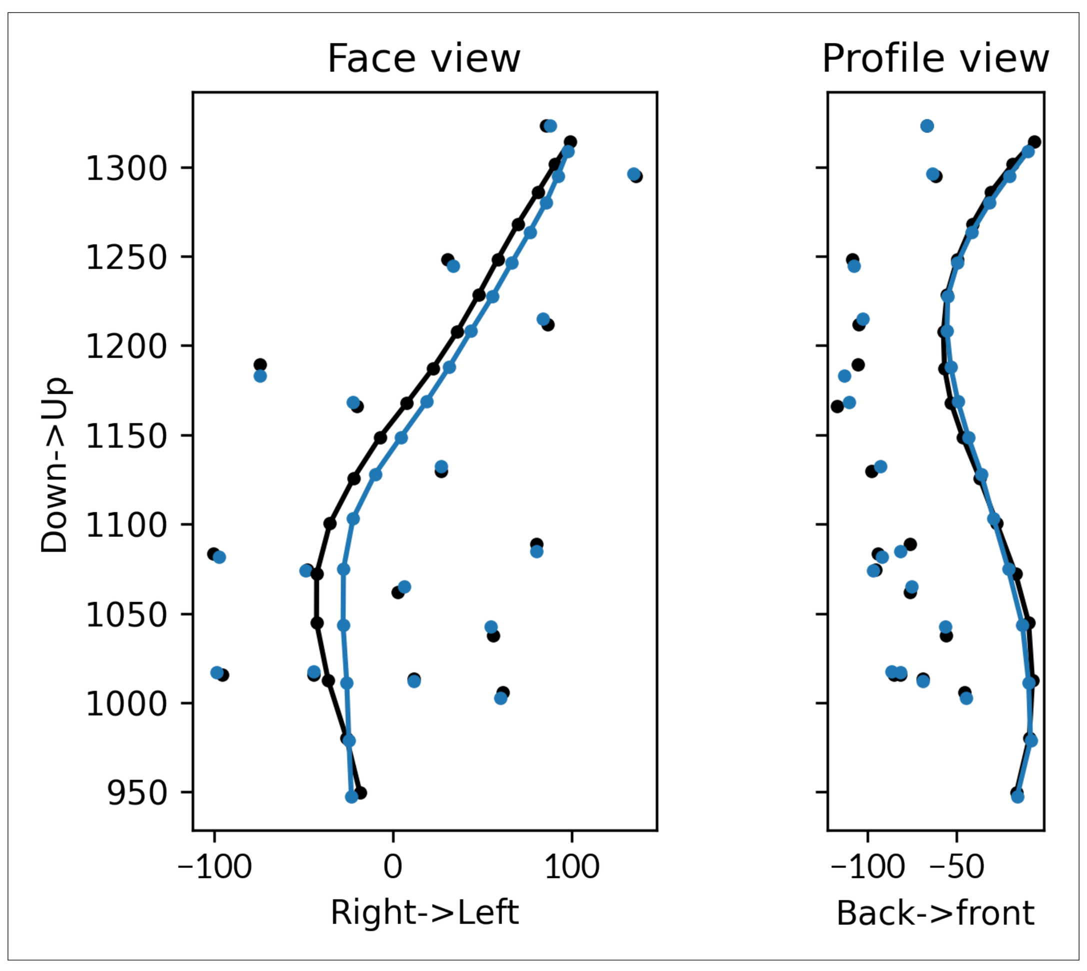
(2) Preliminary validation

- Prediction of the spine in lateral bendings
  Input 3D marker positions
  Output vertebrae 3D rigid transformations
- Validation against X-rays in lateral bending

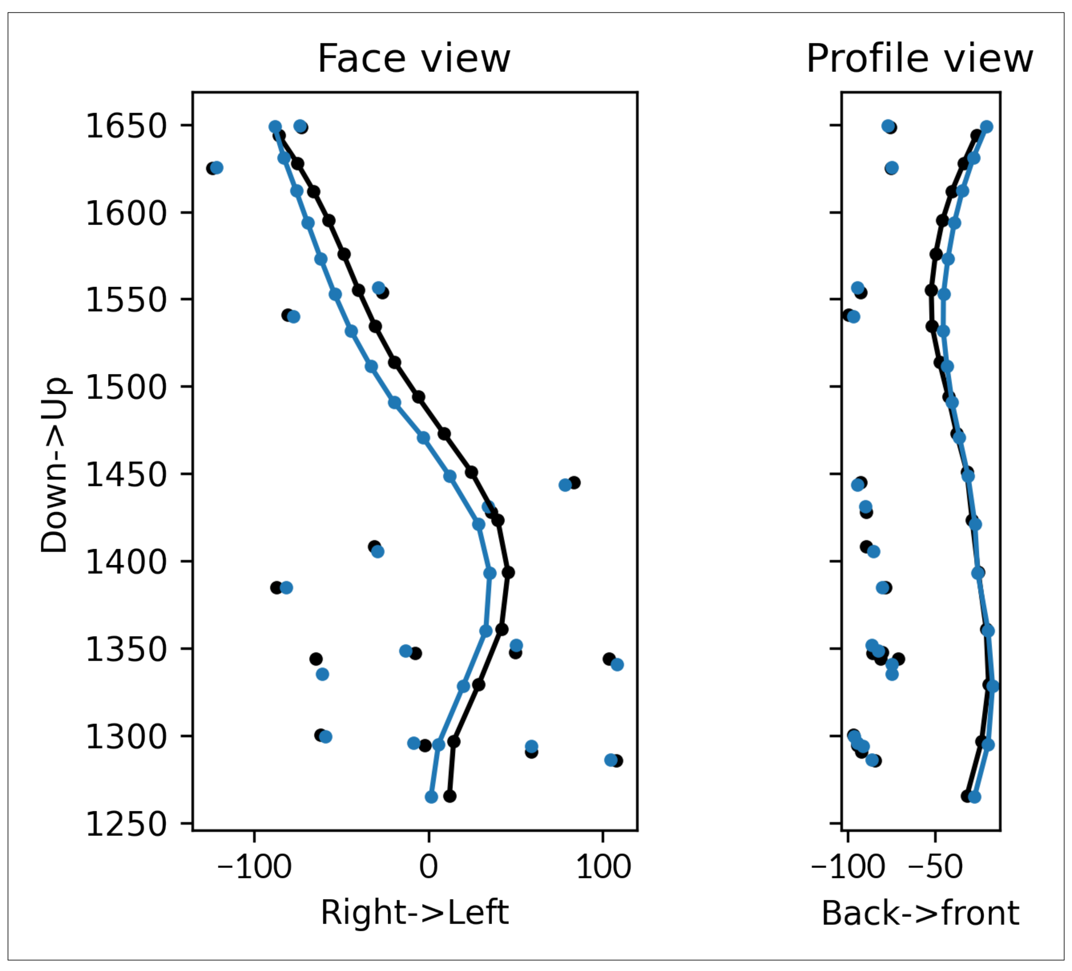


Results

Kinematic predictions (blue) vs Ground-truth (black)



Patient A in lat. bending left



Patient B in lat. bending right

Metrics

Model accuracy (Upright)

3D markers pos.	Point. to Surf. (bones)
4.5 (2.7)	0.3 (0.3)

Accuracy of the numerical twin in upright pose (8 patients)

- Skin: 3D distance (mm) between the radio-opaque markers from X-rays and the model
- Spine: mean absolute error of the point-to-surface distances (mm) between the model and the ground-truth vertebra meshes

Prediction accuracy (lat. bending)

	Vert. positions (mm)			Vert orientations (°)		
3D markers pos.	Post-ant.	Inf-sup.	Med-lat.	Cor.	Axial	Sagit.
4.7 (2.1)	4.4 (3.1)	1.8 (1.4)	8.5 (5.1)	4.6 (4.6)	5.1 (3.8)	2.6 (2.8)

Prediction accuracy in lat. bending (2 patients: 2 bend. left, 1 right)

- Vertebra positions (mm) given by the center of mass. Errors are reported as the mean absolute distances with standard deviation, on the three anatomical axis.
- Vertebra orientations (°) given by comparison of the intrinsic Euler rotations according to the sequence coronal-axial-sagittal (ISB [4]).

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