AN INNOVATIVE ENERGY METHOD TO INFORM SURGICAL PLANNING OF ADOLESCENT IDIOPATHIC SCOLIOSIS

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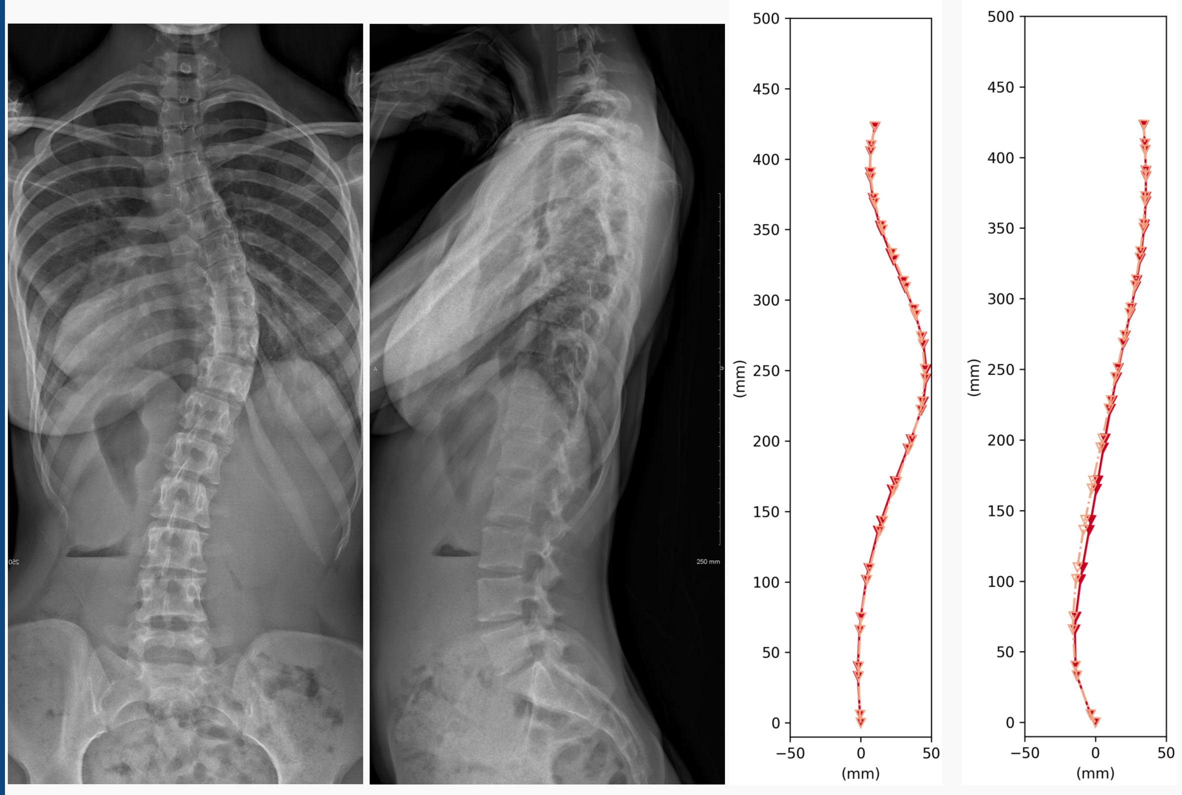
Context

- **Adolescent Idiopathic Scoliosis (AIS)** requires surgery in severe cases yet choosing the right **instrumented levels** and ensuring proper **sagittal balance** remain **clinical challenges** [1].
- **To reduce empiricism** in surgical planning, we developed **an image-driven, in silico energetic model**, implemented in our in-house simulation tool, **Spinergy®**, to **simulate post-surgery spinal alignment from pre-operative effective properties** [2], Fig. 1.



$\Delta_{frontal}$	$\Delta_{sagittal}$	α
0.89%	2.37%	4.17%

(a) Frontal pre-operative EOS® X-ray.

(b) Sagittal pre-operative EOS® X-ray.

(c) Simulated pre-operative geometry (orange) and **actual pre-operative geometry** (**red**), displayed in the **frontal and sagittal planes.**

(d) Quantitative comparison of the **simulated (orange)** and **actual (red) pre-operative geometries** using two error metrics: the **relative Cobb angle error α** and the **relative distance Δ**, from (c).

Figure 1 – Biplanar radiographs and pre-operative Spinergy® simulation

Objectives

Simulate the impact of the instrumentation length, ie. the choice of lower and upper instrumented vertebrae (LIV and UIV), on post-operative spinal alignment.

Mechanical Model Equation [2]

$$V(\mathbf{u},\mathbf{p}) = \frac{1}{2}\sum_i \mathbf{q}^{\top}_{i/\mathcal{R}_i}\cdot\mathbf{K}_i\cdot\mathbf{q}_{i/\mathcal{R}_i} + \frac{1}{2}\sum_i \mathbf{q}^{\top}_{i/\mathcal{R}_A}\cdot\mathbf{B}_i\cdot\mathbf{q}_{i/\mathcal{R}_A} - \sum_i \mathbf{G}_i\cdot\mathbf{q}_{i/\mathcal{R}_A}$$

The **local elastic** (**strain**) **energy** on vertebral segments — The **global elastic (strain) energy** on vertebral segments — **Gravitational potential energy**

Methodology

- **3D wire-frame model** of the spine
  - Based on **pre-operative biplanar EOS® X-rays, Fig.1a,b**
  - ***Inverse algorithm based on mechanical energy minimization*** (Fig.1c)
    -> Energy and effective tensors
- **Clinical balance** defined as:
  - Alignment of vertebral bodies along the **vertical axis** in the **frontal plane**
- **Surgery simulation inputs, Fig.2a,c**:
  - Pre-operative **effective parameters**
  - **Instrumented length** (range of UIV to LIV)
  - **Sagittal curvature**
  - **Spine curve reduction**
- **Surgery simulations, Fig.2e-h**:
  - **Residual area A: between non-instrumented vertebrae** and the **T1–S1 axis**
  - $\mathbf{Z_{max}}$**: absolute distance** between the **vertical axis** and the **apex of free (non-instrumented) vertebral segments**

Results

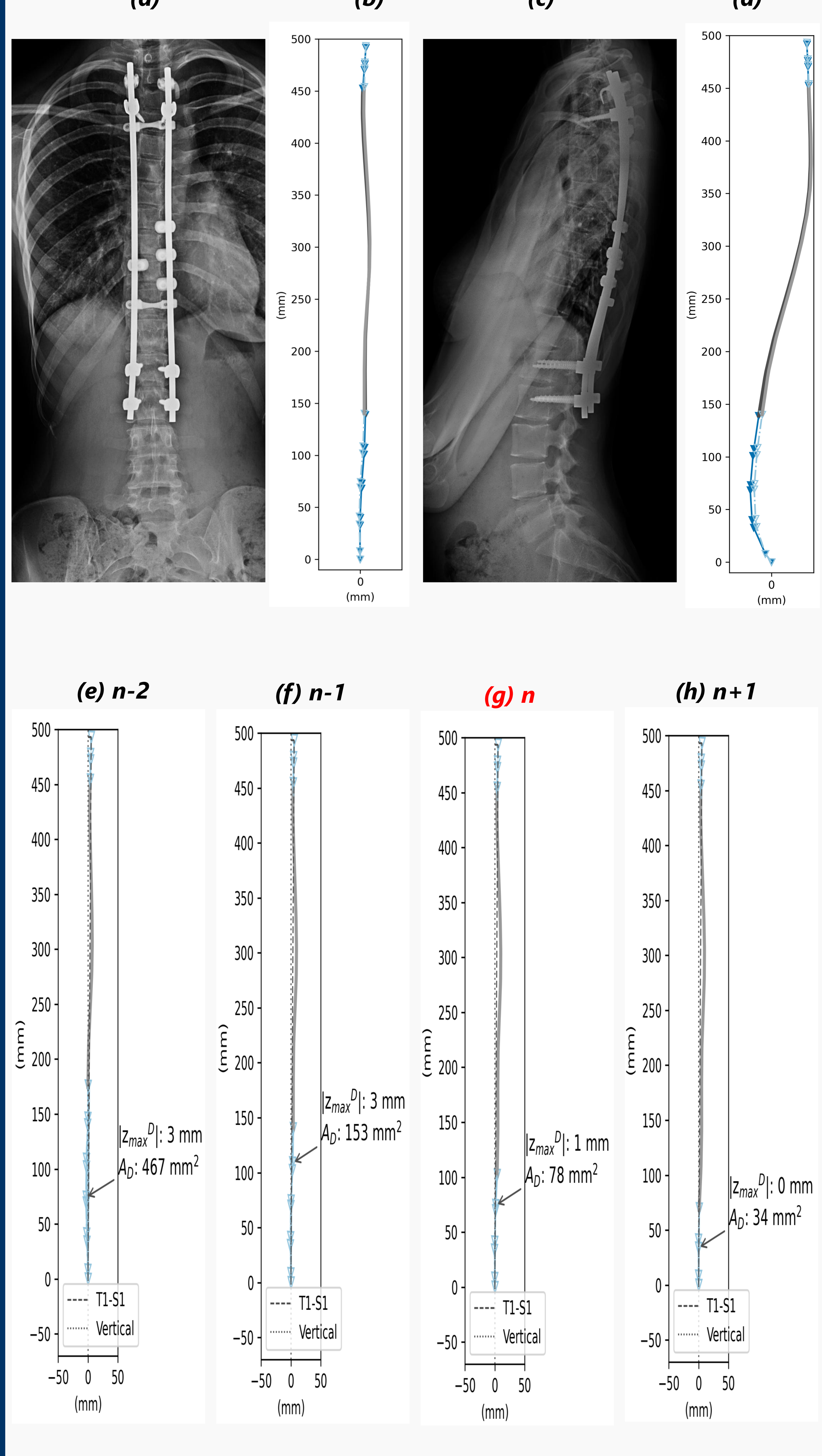


Figure 2 - Post-operative results and Spinergy® simulations

Discussion

- **Spinergy®** enables **fast** and **efficient simulations**:
  - **~1 hour to compute inputs** on 10 CPU cores
  - Simulation of **multiple instrumentation lengths in a few seconds**
- In Fig.2b,d: **simulated** (**blue**) and **post-operative** (**dark blue**) **distributions** based on Fig.2a,c show a **good agreement on the actual T3–L3** thoracic-lumbar instrumentation.
- **Fig. 2e–h** illustrates the impact of **varying instrumentation levels** (n−2 to n+1) **compared to the actual case** (**n = T3–L3**):

$$\downarrow L_{instrumentation} \Rightarrow \uparrow A_{residual} \text{ and } \equiv Z_{max}$$

UIV-LIV	$A_{residual}$ (mm^2)	Z_{max} (mm)
T3-L4 (n+1)	34	<0.5
T3-L3 (n)	78	1
T3-L2 (n-1)	153	3
T3-L1 (n-2)	467	3

Conclusion

- **Spinergy®** provides **efficient patient-specific simulations** that **enhance** and **personalize AIS surgical planning**. Expert-reviewed **results suggest that**, in the illustrative case, **a shorter instrumentation could have been appropriate**.
- This project contributes to the development of **Spinergy®** as a **decision-support tool** to:
  - Help surgeons choose **optimal** instrumentation levels
  - Improve **surgical outcomes** and **patient well-being**

References

[1] Compagnon, R. et al., Orthopaedics & Traumatology: Surgery & Research, Volume 108, Issue 6, 2022.

[2] Brun-Cottan, B. et al., Biomechanic and modeling in mecanobiology. 20, 359–370, 2021.