

Lumbar Apex Pelvic Angle (LaPA) as the Rosetta Stone of Spinal Shape: A PI-Based Predictive Cascade for Global Sagittal Reconstruction

Sleiman Haddad (Barcelona, Espagne), Lluís Vila (Barcelona, Espagne), Philippe Charles (Strasbourg, France), Susana Núñez-Pereira (Barcelona, Espagne), Alejandro Gomez-Rice (Madrid, Espagne), Anika Pupak (Barcelona, Espagne), Javier Pizones (Madrid, Espagne), Jeffrey M Hills (Sant Antonio, États-Unis), Michael P Kelly (San Diego, États-Unis), Ibrahim Obeid (Bordeaux, France), Frank Kleinstück (Zurich, Suisse), Ahmet Alanay (Istanbul, Turquie), Ferran Pellisé (Barcelona, Espagne), (Essg) European Spine Study Group (Barcelona, Espagne)

Introduction

Pelvic incidence (PI) governs sagittal spinal morphology, yet translating this patient-specific constant into individualized alignment targets remains challenging. Existing models anchored to fixed vertebrae (e.g., L1, T4) fail to account for inter-individual variation in curve apices and inflection points. We hypothesized that the lumbar apex pelvic angle (LaPA) is the key PI-dependent landmark linking pelvic morphology to global spinal shape. We also determined and could segregate individual PI-driven variables from universal PI-independent geometric constraints.

Materials and Methods

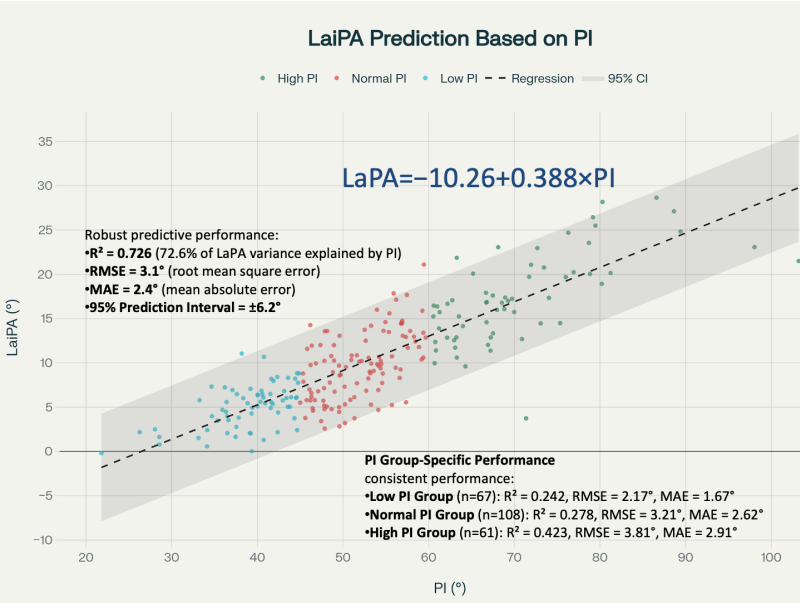
We analyzed 236 asymptomatic volunteers (age 20–50; PI 21.8–103.2°) using standardized standing full-spine radiographs. Pelvic angles (PA) were measured at regional landmarks: LaPA, LiPA (thoracolumbar inflection), TaPA (thoracic apex), and TiPA (cervicothoracic inflection), and compared with fixed vertebrae angles (L1PA, T4PA, C2PA). PI dependency was evaluated using Pearson correlation (r) and effect size (η^2), and heteroscedasticity quantified variability across the PI spectrum. Inter-parameter relationships were analyzed to establish a stepwise predictive cascade from pelvis to cranial regional landmarks.

Results

LaPA demonstrated the strongest PI dependency and enabled continuous prediction ($\text{LaPA} = -10.26 + 0.39 \times \text{PI}$; $r = 0.852$, $\eta^2 = 0.59$, $p < 0.001$), outperforming L1PA ($r = 0.784$, $\eta^2 = 0.47$). Mean LaPA increased from 5.0° (low PI) to 17.4° (high PI), with stable correlation across the PI spectrum, including extremes where fixed-vertebra angles were less reliable. A robust cascade was identified: LaPA predicted LiPA ($r^2 = 0.94$), which sequentially predicted TaPA ($r^2 = 0.97$), TiPA ($r^2 = 0.98$), and C2PA ($r^2 = 0.99$). Composite indices (TiLiPa & TaLaPa) were PI-independent ($r < 0.10$, $\eta^2 < 0.001$), suggesting universal alignment rules or “checkpoints” useful for planning and model validation. Variability increased with higher PI, supporting broader acceptable ranges or “tolerance” for high-PI individuals.

Conclusion

LaPA functions as the optimal Rosetta Stone for PI-concordant shape reconstruction offering greater accuracy than fixed points. Calculating target LaPA from PI allows reliable sequential derivation of ideal regional landmarks via a strong correlation chain - while PI-independent parameters (TiLiPa & TaLaPa) provide universal bounds for model validation. This combined approach of regional landmarks and universal bounds offers a comprehensive framework to individualize spinal shape planning. Validation in a surgical cohort is warranted.



Predictive Power of the Spinal Cascade: Stepwise R² and Prediction Error

Each step adds a spinal parameter, improving model accuracy

