Optimizing Cup Position with a Mathematical Model of the Hip-Spine Interaction

Kranti V Peddada[1], Christopher T Holland, Connor M Delman[2], Mauro Giordani, Gavin Pereira, Zachary Lum[3], Eric O Klineberg[4], John Patrick Meehan

[1]Orthopaedic Surgery, University of California, Davis Medical Center, [2]University of California Davis, [3]UC Davis Medical Center, [4]Univ of California Davis

INTRODUCTION:

Total hip arthroplasty (THA) cup orientation changes with pelvic tilt (PT). Spinal fusion to pelvis for sagittal malalignment may increase dislocation risk if changes in PT result in cup radiographic anteversion (RA) and/or inclination (RI) outside the intended safe zone. We sought to develop and validate a model quantifying changes in PT and cup parameters to optimize cup positioning in patients needing spinal deformity correction.

METHODS:

The model was derived mathematically and validated with a prospective case series of postoperative primary THA patients. Patients with bilateral THA implants and revision cups were excluded. Fifty patients were included in the sample based on *a priori* power analysis. Radiographic anteversion (RA) and radiographic inclination (RI) were measured on standing and sitting AP pelvis radiographs and ante-inclination (AI), PT, sacral slope, and pelvic incidence were measured on standing and sitting lateral radiographs. Measured and model-predicted values were correlated using linear regression analysis.

RESULTS:

Model-predicted sitting RA, RI, and AI were strongly correlated to measured sitting RA ($R^2 = 0.7686$, $p < 0.001$), RI ($R^2 = 0.9028$, $p < 0.001$), and AI ($R^2 = 0.9402$, $p < 0.001$), respectively. The model showed standing, sitting RA increased 0.7° for every 1° increase in PT. Standing, sitting RI increased 0.4° for every 1° increase in PT when ΔPT > 0° but was nearly unchanged when ΔPT < 0°. ΔPT and ΔAI were related in a 1:1 ratio. Based on these relationships, we added the following pelvic tilt correction factors for acetabular cup position: 15 ± 10° + [0.7 x (-ΔPT)] for RA, and 40 ± 10° + [0.4 x (-ΔPT)] when ΔPT > 0° and 40 ± 10° when ΔPT ≤ 0° for RI.

DISCUSSION AND CONCLUSION:

We quantified the relationship between pelvic mobility and cup orientation in a mathematical model. Our acetabular safe zone modification can enable safer cup placement when spinal deformity correction is anticipated.

Relationship Between Pelvic Tilt Change and Radiographic Anteversion

Relationship Between Pelvic Tilt Change and Radiographic Inclination
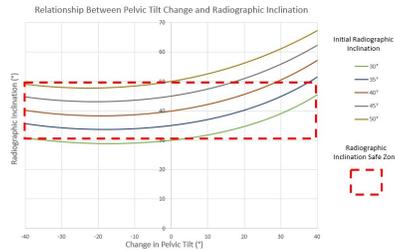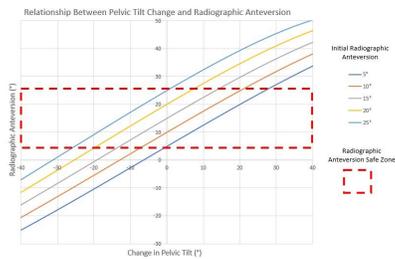
The Mathematical Relationships Between Cup Anteversion, Inclination, Ante-Inclination and Pelvic Tilt Change

Initial radiographic anteversion: α

Initial radiographic inclination: θ

Initial anatomic anteversion: ϕ, where $\phi = tan^{-1}\left(\frac{tan\alpha}{sin\theta}\right)$

Ante-inclination: σ

Change in pelvic tilt: δ

$$\alpha_{new} = tan^{-1}\left(\frac{\sqrt{tan^2\phi + cot^2\theta} * cos\left(tan^{-1}\left(\frac{-cot\theta}{tan\phi}\right) + \delta\right)}{\sqrt{1 + (tan^2\phi + cot^2\theta) * sin^2\left(tan^{-1}\left(\frac{-cot\theta}{tan\phi}\right) + \delta\right)}}\right)$$

$$\theta_{new} = sin^{-1}\left(\frac{tan(\alpha_{new})}{tan(\phi_{new})}\right)$$

$$\phi_{new} = tan^{-1}\left(\sqrt{tan^2\phi + cot^2\theta} * cos\left(tan^{-1}\left(\frac{-cot\theta}{tan\phi}\right) + \delta\right)\right)$$

$$\sigma_{new} = cos^{-1}\left(\frac{1}{\sqrt{sin^2\phi * tan^2\kappa + 1}}\right)$$

$$\kappa = \frac{\pi}{2} - tan^{-1}\left(\frac{\sqrt{tan^2\phi + cot^2\theta} * sin\left(tan^{-1}\left(\frac{-cot\theta}{tan\phi}\right) + \delta\right)}{\sqrt{1 + (tan^2\phi + cot^2\theta) * cos^2\left(tan^{-1}\left(\frac{-cot\theta}{tan\phi}\right) + \delta\right)}}\right)$$