Global Alignment and Proportion (GAP) Score: Development and Validation of a New Method of Analyzing Spinopelvic Alignment to Predict Mechanical Complications after Adult Spinal Deformity Surgery

Caglar Yilgor
Nuray Söğünmez
Yasemin Yavuz
Ibrahim Obeid

Frank S. Kleinstueck
Francisco Javier Sanchez Perez Grueso
Emre R. Acaroğlu
Anne F. Mannion

Ferran Pellisé
Ahmet Alanay

ESSG- European Spine Study Group
Background: Sagittal Plane Analysis

- **SRS-Schwab Classification – Sagittal Modifiers**
  - Have been used as alignment targets but addressing these
  - does not always prevent mechanical complications
    - Mechanical complication rate 31.7%
    - 52.6% of them revised!

- **Disadvantages of Schwab Parameters**
  - Based on HRQoL parameters, not mechanical complications
  - Do not include
    - Anteversion
    - Negative Malalignment
    - Shape and distribution of lumbar lordosis
  - Considering the whole spectrum of PI
    - when used as an absolute numeric value
    - in conjunction with previously reported
      - population-based average thresholds
    - Schwab criteria may be insufficient or misleading in quantifying
      - Normoversion of pelvis (PT)
      - Spinopelvic mismatch (PI-LL)

- There is a need for a new look into the ‘ideal’ sagittal plane

- Spinal curvatures and alignment must be viewed in light of each other
  - Chain of correlations
    - PI influences SS
    - SS influences LL
    - LL influences TK
    - TK influences CL

- **Pelvic incidence**
  - is a (relatively) constant morphological parameter
  - that describes the ‘pelvic size’ for any given person

- **PI = A signature**

- All sagittal plane parameters
  - Should be evaluated proportional to PI
  - rather than absolute numeric
  - to assess disproportion compared with the calculated ideal
Methods

• From the ESSG database
  – ≥4 levels posterior fusion
  – ≥2 years follow up
  – 222 patients (168F, 54M) were included

• Mechanical Complications
  – PJK / PJF
  – DJK
  – Rod breakage
  – Implant related complications
    • Screw loosening, fracture, pull out
    • Interbody, hook or set screw pull out

• 222 patients randomly assigned to
  – derivation (n = 148, 66.7%)
  – and validation (n = 74, 33.3%) cohorts

• Mean age
  – 52.2 ± 19.3 (range 18-84)

• Mean follow-up
  – 28.8 ± 8.2 (24-62) months
• Global Alignment & Proportion: GAP Score
  – New Method of Analyzing Sagittal Plane
  – Offers individualized sagittal plane analysis
    • Instead of population norms & mean values
  – Uses PI-based proportional radiographic parameters
    • Instead of absolute numerical values
  – Denotes “normal” and “pathologic”
    • standing sagittal alignment and shape
    • as a single score for every magnitude of pelvic incidence.

– Radiographic parameters
  • RPV: Relative Pelvic Version (Measured-Ideal SS)
  • RLL: Relative Lumbar Lordosis (Measured-Ideal LL)
  • LDI: Lordosis Distribution Index (L4-S1 / L1 – S1)
  • RSA: Relative Spinopelvic Alignment (Measured-Ideal GT)
  – Age Factor
### Results

<table>
<thead>
<tr>
<th>Mechanical Complication</th>
<th>- (n (%))</th>
<th>+ (n (%))</th>
<th>χ²</th>
<th>P</th>
<th>β regression coefficient (SE)</th>
<th>OR (95% CI)</th>
<th>P</th>
<th>Statistical Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RPV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anteversion</td>
<td>5 (62.5)</td>
<td>3 (37.5)</td>
<td></td>
<td></td>
<td>0.762 (0.790)</td>
<td>2.1 (0.5 – 10.1)</td>
<td>0.335</td>
<td>1</td>
</tr>
<tr>
<td>Aligned</td>
<td>50 (78.1)</td>
<td>14 (21.9)</td>
<td></td>
<td></td>
<td>- -</td>
<td>- -</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Moderate Retroversion</td>
<td>22 (44)</td>
<td>28 (56)</td>
<td></td>
<td></td>
<td>1.514 (0.415)</td>
<td>4.5 (2.0 – 10.3)</td>
<td>0.000</td>
<td>2</td>
</tr>
<tr>
<td>Severe Retroversion</td>
<td>3 (11.5)</td>
<td>23 (88.5)</td>
<td></td>
<td></td>
<td>3.310 (0.684)</td>
<td>27.4 (7.2 – 104.7)</td>
<td>0.000</td>
<td>3</td>
</tr>
</tbody>
</table>

| **RLL**                |           |           |    |   |                             |              |   |                     |
| Hyperlordosis          | 1 (16.7)  | 5 (83.3)  |    |   | 2.708 (1.124) | 15 (1.7 – 135.8) | 0.016 | 3 |
| Aligned                | 63 (75)   | 21 (25)   |    |   | - -                          | - -           | - | 0 |
| Moderate Hypolordosis  | 13 (36.1) | 23 (63.9) |    |   | 1.669 (0.429) | 5.3 (2.3 – 12.3) | 0.000 | 2 |
| Severe Hypolordosis    | 3 (13.6)  | 19 (86.4) |    |   | 2.944 (0.670) | 19 (5.1 – 70.7) | 0.000 | 3 |

| **LDI**                |           |           |    |   |                             |              |   |                     |
| Hyperlordotic Maldistribution | 3 (10.7) | 25 (89.3) |    |   | 3.022 (0.655) | 20.5 (5.7 – 73.5) | 0.000 | 3 |
| Aligned                | 69 (71.1) | 28 (28.9) |    |   | - -                          | - -           | - | 0 |
| Moderate Hypolordotic Maldistribution | 6 (37.5) | 10 (62.5) |    |   | 1.413 (0.563) | 4.1 (1.4 – 12.4) | 0.012 | 1 |
| Severe Hypolordotic Maldistribution | 2 (28.6) | 5 (71.4)  |    |   | 1.818 (0.866) | 6.2 (1.1 – 33.6) | 0.036 | 2 |

| **RSA**                |           |           |    |   |                             |              |   |                     |
| Negative Malalignment  | 2 (50)    | 2 (50)    |    |   | 1.219 (1.049) | 3.4 (0.4 – 26.4) | 0.245 | 1 |
| Aligned                | 44 (77.2) | 13 (22.8) |    |   | - -                          | - -           | - | 0 |
| Moderate Positive Malalignment | 30 (62.5) | 18 (37.5) |    |   | 0.708 (0.434) | 2.0 (0.9 – 4.7) | 0.103 | 1 |
| Severe Positive Malalignment | 4 (10.3) | 35 (89.7) |    |   | 3.388 (0.615) | 29.6 (8.8 – 98.9) | 0.000 | 3 |

| **Age**                |           |           |    |   |                             |              |   |                     |
| <60 years              | 51 (66.2) | 26 (33.8) |    |   | - -                          | - -           | - | 0 |
| ≥60 years              | 29 (40.8) | 42 (59.2) |    |   | 1.044 (0.341) | 2.8 (1.4 – 5.5) | 0.002 | 1 |
The GAP score, calculated by adding the scores for relative pelvic version, relative lumbar lordosis, lordosis distribution index, relative spinopelvic alignment, and the age factor, ranged from 0 to 13 points.

A GAP score of 0 to 2 was categorized as indicating a proportioned spinopelvic state; 3 to 6, as moderately disproportioned; and ≥7, as severely disproportioned.
# GAP Score

**Parameters**

### Relative Pelvic Version (RPV = Measured - Ideal Sacral Slope)

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe Retroversion</td>
<td>-15°</td>
</tr>
<tr>
<td>Moderate Retroversion</td>
<td>-7°</td>
</tr>
<tr>
<td>Aligned</td>
<td>0°</td>
</tr>
<tr>
<td>Anteversion</td>
<td>+5°</td>
</tr>
</tbody>
</table>

### Relative Lumbar Lordosis (RL = Measured - Ideal Lumbar Lordosis)

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe Hypolordosis</td>
<td>-25°</td>
</tr>
<tr>
<td>Moderate Hypolordosis</td>
<td>-14°</td>
</tr>
<tr>
<td>Aligned</td>
<td>0°</td>
</tr>
<tr>
<td>Hyperlordosis</td>
<td>+11°</td>
</tr>
</tbody>
</table>

### Lordosis Distribution Index (LDI = L4-S1 Lordosis / L1-S1 Lordosis x100)

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe Hypolordotic</td>
<td>40%</td>
</tr>
<tr>
<td>Moderate Hypolordotic</td>
<td>50%</td>
</tr>
<tr>
<td>Aligned</td>
<td>80%</td>
</tr>
<tr>
<td>Hyperlordotic</td>
<td></td>
</tr>
</tbody>
</table>

### Relative Spinopelvic Alignment (RSA = Measured - Ideal Global Tilt)

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe Positive</td>
<td>+18°</td>
</tr>
<tr>
<td>Moderate Positive</td>
<td>+10°</td>
</tr>
<tr>
<td>Aligned</td>
<td>0°</td>
</tr>
<tr>
<td>Negative</td>
<td>-7°</td>
</tr>
</tbody>
</table>

### Age Factor

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly</td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>60</td>
</tr>
</tbody>
</table>

**Scoring**

### RPV Subgroups

- Score: 0 - 2
- Total Score: 0 - 2
- Proportioned

### LLD Subgroups

- Score: 0 - 2
- Total Score: 3 - 6
- Moderately Disproportioned

### LDI Subgroups

- Score: 0 - 2
- Total Score: 3 - 6
- Severe ≥ 7
- Severely Disproportioned

### RSA Subgroups

- Score: 0 - 2
- Total Score: 0 - 2
- Severely Disproportioned

### Age Subgroups

- Score: 0 - 2
- Total Score: 0 - 2
- Elderly

---

**Categorization**

- GAP Score includes a scale-based view of the subgroups of each parameter using the cutoff points.
- The scoring column includes the statistical weights of the parameter subgroups.
- The categories column includes the categorization of the GAP score.
**Pelvic Incidence** 79

**Age** 61

**Age Factor** 1

<table>
<thead>
<tr>
<th>Sacral Slope</th>
<th>49</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal Sacral Slope</td>
<td>55.61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pelvic Proportion</th>
<th>Aligned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Pelvic Version</td>
<td>-6.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L1-S1 Lordosis</th>
<th>66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal Lordosis</td>
<td>77.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lordosis Proportion</th>
<th>Aligned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Lumbar Lordosis</td>
<td>-12.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L4-S1 Lordosis</th>
<th>42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lordosis Distribution Proportion</td>
<td>Aligned</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Global Tilt</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal Global Tilt</td>
<td>22.92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spino-Pelvic Proportion</th>
<th>Aligned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Sagittal Alignment</td>
<td>3.08</td>
</tr>
</tbody>
</table>

**No Mechanical complications**

Pre-op 6w

2y

PT ‘++’ = 34
PI-LL ‘++’ = 21
SVA ‘0’ = -2.3 cm

Age Adjustment

PT under
PI-LL under
SVA over

Age Adjustment

PT under
PI-LL under
SVA over

**PI=79°**
Pre-op 6w

PI = 26°

Pelvic Incidence | 26
--- | ---
GAP Score | 13

<table>
<thead>
<tr>
<th>Age</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Factor</td>
<td>1</td>
</tr>
</tbody>
</table>

Sacral Slope | 9
Ideal Sacral Slope | 24.34

Pelvic Proportion | Severe Retroversion | 3

L1-S1 Lordosis | 17
Ideal Lordosis | 45.12

Lordosis Proportion | Severe Hyplordosis | 3

L4-S1 Lordosis | 20

Lordosis Distribution Index | 118%

Global Tilt | 18
Ideal Global Tilt | -2.52

Spino-Pelvic Proportion | Severe Positive Alignment | 3

Relative Pelvic Version | -15.3
Relative Lumbar Lordosis | -28.1
Relative Sagittal Alignment | 20.52

Age Adjustment
PT '0' = 19
PI-LL '++' = 24
SVA '+' = 5.4 cm

PT '0' = 17
PI-LL '0' = 9
SVA '0' = 2.3 cm

Age Adjustment
PT matched
PI-LL matched
SVA matched

PJK & Rod Breakage
Mechanical Complication & Revision Rates

GAP Score

GAP Categories

GAP Score in predicting mechanical complications

HRQoL Scores

<table>
<thead>
<tr>
<th>HRQoL Scores</th>
<th>Proportioned Mean ± SD</th>
<th>Moderately Disproportioned Mean ± SD</th>
<th>Severely Disproportioned Mean ± SD</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODI</td>
<td>21.3 ± 13.4</td>
<td>35 ± 17.9</td>
<td>36.3 ± 19.9</td>
<td>F(1,70)=11.496, p=0.001</td>
</tr>
<tr>
<td>COMI</td>
<td>3.1 ± 2.0</td>
<td>4.2 ± 2.1</td>
<td>4.8 ± 2.8</td>
<td>F(1,62)=6.169, p=0.016</td>
</tr>
<tr>
<td>SRS-22 Subtotal</td>
<td>3.7 ± 0.6</td>
<td>3.2 ± 0.7</td>
<td>3.3 ± 0.8</td>
<td>F(1,70)=4.393, p=0.040</td>
</tr>
<tr>
<td>SF-36 PCS</td>
<td>43.2 ± 7.7</td>
<td>39.5 ± 9.2</td>
<td>37.9 ± 8.8</td>
<td>F(1,70)=5.699, p=0.020</td>
</tr>
<tr>
<td>SF-36 MCS</td>
<td>49.1 ± 8.5</td>
<td>42.4 ± 9.3</td>
<td>44.3 ± 12.9</td>
<td>F(1,70)=3.326, p=0.072</td>
</tr>
</tbody>
</table>
Conclusion

• GAP score
  – is a new PI-based proportional method of analyzing
  – the individualized sagittal plane

• GAP score
  – is an all-inclusive single score
  – that offers a ‘one-size fits all’ solution
  – for every size of pelvic incidence

• Preoperative planning & setting surgical goals in the sagittal plane
  – on the basis of the individualized proportional indices reflected by the GAP score
  – may decrease the rate of mechanical complications.
Disclosures

- Caglar Yilgor: None
- Nuray Sogunmez: Grants/Research Support: Depuy Synthes
- Yasemin Yavuz: None
- Ibrahim Obeid: Grants/research support: Depuy Synthes
  Consultant: Depuy Synthes, Medtronic
  Royalties: Alphatec, Spineart
- Frank Kleinstück: Grants/Research Support: Depuy Synthes
  Speaker’s Bureau: Depuy Synthes
- FJS Pérez-Grueso: Grants/research support: Depuy Synthes
  Consultant: Depuy Synthes
- Emre Acaroglu: Grants/Research Support: DePuy Synthes, Medtronic, Stryker Spine
  Speaker’s Bureau: AO Spine, Medtronic, Stryker Spine, Zimmer Biomet
  Advisory Board or Panel: AO Spine
  Stock/Shareholder: IncredX (self-managed)
- Ferran Pellise: Grants/research support: Depuy Synthes, K2M, Medtronic
  Consultant: Depuy Synthes, Zimmer Biomet
- Ahmet Alanay: Grants/research support: Depuy Synthes
  Consultant: Depuy Synthes, Stryker Spine, Medtronic
- ESSG: Grants/research support: Depuy Synthes