

Partial Intraoperative Global Alignment and Proportion Scores Do Not Reliably Predict Postoperative Mechanical Failure in Adult Spinal Deformity Surgery

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Abstract

Study Design: Retrospective radiographic review.

Objectives: The Global Alignment and Proportion (GAP) score allows sagittal plane analysis for deformity patients and may be predictive of mechanical complications. This study aims to assess the effectiveness of predicting mechanical failure based on partial intraoperative GAP (iGAP) scores.

Methods: A retrospective radiographic review was performed on 48 deformity patients between July 2015 to January 2017 with a 2-year follow-up. Using the same methodology as the original GAP study, the partial iGAP score was calculated with the sum of the scores for age, relative lumbar lordosis (RLL), and lordosis distribution index (LDI). Therefore, the iGAP score (0-7) was grouped into proportional (0-2), mildly disproportionate (3-5), and severely disproportionate (6-7). Logistic regression was performed to assess the ability of the partial iGAP score to predict postoperative mechanical failure.

Results: The mean iGAP for patients with a mechanical failure was 3.54, whereas the iGAP for those without a mechanical failure was 3.46 ($P = .90$). The overall mechanical failure rate was 27.1%. The mechanical failures included 8 proximal junctional kyphosis, 7 rod fractures, and 1 rod slippage from the distal end of the construct. Logistic regression analysis revealed that the partial iGAP score was not able to predict postoperative mechanical failure ($\chi^2 = 1.4$; $P = .49$).

Conclusion: The iGAP scores for RLL or LDI did not show any significant correlation to postoperative mechanical failure. Ultimately, the proposed partial iGAP score did not predict postoperative mechanical failure and thus, cannot be used as an intraoperative alignment assessment to avoid postoperative mechanical complications.

Keywords

lordosis, kyphosis, postoperative period, follow-up studies, retrospective studies

Introduction

Balanced global spine alignment is a combination of adequate spinal and pelvic positioning.¹ Sagittal balance has a large impact on maintaining the global spine alignment and is considered one of the main issues to solve in adult spine deformity.^{2,3} Inability to restore sagittal balance has been correlated with mechanical failure, pain, and poorer functional outcomes.⁴⁻⁷ The SRS (Scoliosis Research Society)-Schwab classification is a widely known method of examining radiographic parameters to predict postoperative mechanical failure.^{2,4} Despite previous published reports on the validity of the classification, it is not

unusual to observe poor outcomes, mechanical complications, and subsequent revision surgeries even after ideal corrections are achieved based on these criteria.^{8,9}

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The Global Alignment and Proportion (GAP) score is a recently developed score assessing sagittal balance and predicting mechanical complications.^{10,11} The GAP score is a pelvic incidence based proportional method of analyzing the sagittal alignment that assigns a cumulative score obtained from the patient's age and 4 different radiographic parameters. The GAP score is divided into 3 categories: proportioned (total score 0-2), moderately disproportioned (total score 3-6), and severely disproportioned (total score 7 and more), which reliably predicted increasing mechanical failure rates for groups with higher scores.

This study aimed to evaluate a partial version of this GAP score to use in the intraoperative setting using intraoperative spine films to predict postoperative mechanical failure. An intraoperative GAP (iGAP) score has not yet been evaluated and would be a useful tool to judge the spinal deformity correction intraoperatively as well as potentially avoiding mechanical complications.

Methods

Study Design

Following institutional review board approval, we conducted a retrospective review of adult spinal deformity surgical patients operated on by a single surgeon between July 2015 and January 2017. Inclusion criteria were patients older than 18, a minimum of 2-year follow-up (or a mechanical failure at any time point), full-length intraoperative radiographs, over 4 levels of instrumented fusion, and any one of the following preoperative radiographic criteria: coronal Cobb angle of $>20^\circ$, sagittal vertical axis of >5 cm, pelvic tilt of $>25^\circ$, or thoracic kyphosis of $>60^\circ$ (the same deformity criteria as the original GAP study).¹² Patients were not excluded based on comorbidities, demographics, or age.

Basic demographic data collected included age, diagnosis, gender, history of prior spine surgery, and postoperative follow-up. Surgical data included 3-column osteotomy performed, number of levels instrumented, and pelvic fixation. Intraoperative radiographic data of L1-S1 lumbar lordosis (LL), L4-S1 LL, pelvic incidence (PI), was measured by a senior orthopedic surgery resident and a spine fellow using validated software (PACS). The final measurement used for the study were the averaged numbers obtained from the 2 observers. Mechanical complication outcomes were identified as proximal or distal junctional kyphosis or failure (PJK/PJF, DJK/DJF), rod breakage, interbody graft dislodgement, set screw dislodgment, screw breakage, loosening, or pullout, and revision surgery due to any mechanical complication.

GAP Score

A modified iGAP score was calculated according to the original methodology defined by Yilgor et al¹⁰: ideal LL = $(0.62 \times \text{PI})$. PI was measured using preoperative films as theoretically, the PI does not change with surgery and is more reliable

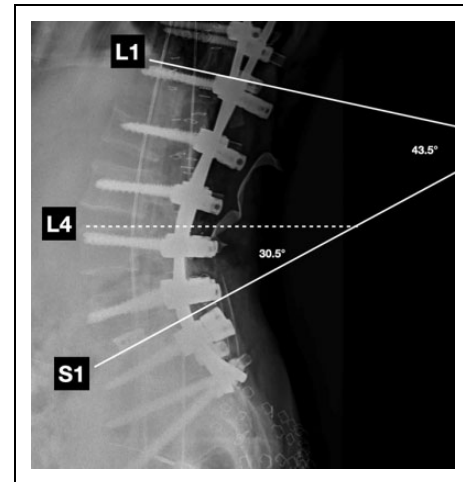


Figure 1. Example of an intraoperative sagittal lumbar spine x-ray with L1-S1 and L4-S1 lordosis measured.

to measure than intraoperative films. L1-S1 lordosis and L4-S1 lordosis were then measured from the postinstrumentation intraoperative radiographs (Figure 1). Given the inability to accurately incorporate the sacral slope and the global tilt from the limitation of inadequate intraoperative films, the relative pelvic version (RPV) and relative spinopelvic alignment (RSA) were omitted from the partial iGAP score. Using the radiographic measurements and the ideal values, we then calculated the following 3 out of original 5 domains of the GAP score:

1. Intraoperative relative lumbar lordosis (iRL) = (measured LL – ideal LL). Less than -25° was severe hypolordosis (3 points), -25° to -14.1° was moderate hypolordosis (2 points), -14° to 11° was aligned (0 points), and $>11^\circ$ was hyperlordosis (3 points).
2. Intraoperative lordosis distribution index (iLDI) = $[(\text{measured L4-S1 LL})/(\text{measured L1-S1 LL})] \times 100$. An LDI of $<40\%$ was severe hypolordotic maldistribution (2 points), 40% to 49% was moderate hypolordotic maldistribution (1 point); 50% to 70% was aligned (0 points), and $>80\%$ was hyperlordotic maldistribution (3 points).
3. Age was dichotomized to those older than 60 years (1 point) and those younger than 60 years (0 points).¹²

Statistical Analysis

Basic descriptive analysis included Student's *t* test and chi-square for continuous and categorical variables, respectively. Results are presented as mean (\pm standard deviation) for continuous variables and n (%) for categorical variables. After calculation of the GAP scores, patients were categorized into 1 of 3 groups: Proportioned (P) for a score of 0 to 2, moderately disproportioned (MD) for a score of 3 to 5, or severely disproportioned (SD) for a score of 6 to 7. Logistic regression was

Table 1. Preoperative and Operative Variables (N = 48).

Variable	Mean \pm SD or n (%)
<i>Preoperative</i>	
Age, years	52.6 \pm 17.5
Follow-up (range)	2.0 (0.1-3.3)
Female	37 (77.1)
Prior surgery	24 (54.2)
Decompression	19 (43.8)
Fusion	23 (52.1)
<i>Diagnosis</i>	
Idiopathic	22 (45.8)
Degenerative	18 (37.5)
Neuromuscular	4 (8.3)
Congenital	2 (4.2)
Posttraumatic	2 (4.2)
<i>Operative</i>	
Levels instrumented	14.9 \pm 4.5
3CO	12 (25)
Pelvic fixation	39 (81.3)
<i>Intraoperative</i>	
L1-S1 lordosis, deg	43.8 \pm 12.9
L4-S1 lordosis, deg	31.5 \pm 9.7
PI, deg	53.4 \pm 13.9
RLL	1.8 \pm 1.2
LDI	1.2 \pm 1.4
iGAP score	3.5 \pm 2.0
<i>iGAP classification</i>	
P	13 (27.1)
MD	24 (50.0)
SD	11 (22.9)

Abbreviations: 3CO, 3-column osteotomy; PI, pelvic incidence; iGAP, intraoperative Global Alignment and Proportion score; P, proportioned; MD, moderately disproportionate; SD, severely disproportionate.

used to identify if a modified intraoperative GAP score could predict postoperative mechanical complications. Statistical significance was set at $P < .05$. SAS Version 9.0 (SAS Institute Inc) was used for all statistical analyses.

Results

A total of 48 patients were identified who fit the inclusion criteria; 37 (77.1%) were female with an average age of 52.6 (± 17.3) years. Diagnoses include adult idiopathic scoliosis (22; 45.8%), degenerative scoliosis (18; 37.5%), neuromuscular scoliosis (4; 8.3%), posttraumatic (2; 4.2%), and congenital scoliosis (2; 4.2%). 23 patients (47.9%) had prior spine surgery; of these, 22 (45.8%) had a prior spinal fusion and 19 (39.6%) had a prior spinal decompression (Table 1).

Patients with and without mechanical complications, respectively, had similar levels instrumented (15.0 vs 14.7; $P = .84$), 3-column osteotomies (22.9% vs 30.7%; $P = .83$), and instrumentation to the pelvis (77.1% vs 92.3%; $P = .44$) (Table 2). The raw scores of the iGAP showed that patients with and without mechanical complications, respectively, had similar lumbar lordosis (43.5° vs 44.6°; $P = .79$), L4-S1 lordosis (31.9° vs 30.5°; $P = .67$), pelvic incidence (52.9° vs 54.7°; $P = .70$). This resulted in statistically insignificant

changes in RLL (1.7 vs 2.1; $P = .36$) and LDI (1.4 vs 0.8; $P = .19$) in patients with and without mechanical complications.

The overall mechanical complication rate was 27.1% (13/48) and included 16.7% (8/48) with PJK, 14.5% (7/48) with rod fracture, and 2.1% (1/48) with a rod slippage from the distal end of the construct. A total of 76.9% (10/13) of patients with mechanical complications had reoperations for correction of the mechanical failure. None of the patients without mechanical complications had reoperations thus, there was a 20.8% reoperation rate in the entire cohort (Table 3).

Intraoperative LDI, RLL, and partial GAP (iLDI, iRLL, iGAP) scores were calculated for patients stratified into those with and without postoperative mechanical complications. Overall average iGAP was 3.48 (± 2.0); while those with mechanical complications had an average 3.53 (± 2.1) iGAP and those without mechanical complications had an average iGAP of 3.45 (± 2.0) ($P = .90$). There were 13 (27.1%) patients in the P group, 24 (50.0%) in the MD group, and 11 (22.9%) in the SD group. Three (6.3%) patients in the P group experienced a mechanical complication, 7 (14.6%) in the MD group, and 3 (6.3%) in the SD group. Logistic regression analysis revealed that iGAP did not successfully predict postoperative mechanical complications ($\chi^2 = 0.2$, $P = .92$).

Discussion

Mechanical failures, including but not limited to PJK, PJF, DJK, and implant breakage, after spine deformity surgery occur in 12% to 47% of postoperative patients.¹¹⁻¹³ Given the high rates of mechanical failures, there has been a conscientious effort to limit such postoperative complications by screening and optimizing patients preoperatively, utilizing newly designed instrumentation, and developing new radiographic parameters to predict postoperative failures.^{2,4,12} The recently developed GAP score is an example of a proposed way to predict postoperative mechanical complications using new radiographic parameters.¹⁰ Our study aimed to evaluate the use of a partial intraoperative version of this GAP score to predict postoperative mechanical failures. Unfortunately, we found that neither the partial iGAP score predicted the postoperative mechanical failure nor did the iGAP raw scores for the iRLL or iLDI show any significant association with postoperative mechanical failure.

The partial iGAP scores were similar for both the complications group (3.53 \pm 2.0) and no-complications group (3.45 \pm 2.1) in our cohort. Therefore, discerning impending postoperative complications based on a partial iGAP score is unreliable since both groups had similar preoperative variables, operative fixation methods in length of instrumented levels, and rate of 3CO. A potential reason behind the similarity of iGAP scores between the 2 groups may be secondary to the inherent operative goal to achieve consistent lumbar lordosis for all surgical patients with the use of different surgical techniques ranging from vertebral osteotomies to interbody cage insertion. Our result shows consistent lumbar lordosis for the 2 groups with

Table 2. Preoperative and Operative Variables by Mechanical Complication.

Variable	No complication (n = 35)	Complication (n = 13)	P
<i>Preoperative</i>			
Age, years, mean \pm SD	50.6 \pm 16.6	57.8 \pm 18.1	.21
Female, n (%)	29 (82.9)	9 (69.2)	.53
Prior surgery, n (%)	17 (48.6)	7 (53.8)	.09
Decompression	13 (37.1)	6 (46.2)	
Fusion	16 (45.7)	7 (53.8)	
<i>Diagnosis, n (%)</i>			
Idiopathic	12 (34.3)	10 (76.9)	
Degenerative	16 (45.7)	2 (1.5)	
Neuromuscular	3 (8.6)	1 (1.0)	
Congenital	1 (2.9)	1 (1.0)	
Posttraumatic	2 (5.7)	0 (0.0)	
<i>Operative</i>			
Levels instrumented, mean \pm SD	15.0 \pm 4.4	14.7 \pm 4.8	.84
3CO, n (%)	8 (22.9)	4 (30.7)	.83
Pelvic fixation, n (%)	27 (77.1)	12 (92.3)	.44
<i>Intraoperative GAP measurements, mean \pm SD</i>			
L1-S1 lordosis, deg	43.5 \pm 12.8	44.6 \pm 13.4	.79
L4-S1 lordosis, deg	31.9 \pm 10.2	30.5 \pm 8.1	.67
PI, deg	52.9 \pm 12.7	54.7 \pm 16.6	.70
RLL	1.7 \pm 1.2	2.1 \pm 1.0	.36
LDI	1.4 \pm 1.4	0.8 \pm 1.2	.19
iGAP score	3.5 \pm 2.1	3.5 \pm 2.0	.90
<i>iGAP Classification, n (%)</i>			
P	10 (20.8)	3 (6.3)	.08
MD	17 (35.4)	7 (14.6)	
SD	8 (16.7)	3 (6.3)	

Abbreviations: 3CO, 3-column osteotomy; PI, pelvic incidence; iGAP, intraoperative Global Alignment and Proportion score; P, proportioned; MD, moderately disproportionate; SD, severely disproportionate.

Table 3. Mechanical Complications.

Variable	n (%)
Mechanical complication	13 (27.1)
Proximal junction kyphosis	8 (16.7)
Rod fracture	7 (14.5)
Rod slippage	1 (2.0)
Reoperation	
Of patients with mechanical complication	10 (76.9)
Of patients without mechanical complication	0 (0.0%)
Of all patients in the cohort	10 (20.8)

less than 2° of difference in both the L1-S1 lordosis and L4-S1 lordosis, which is within realms of measurement errors.

The iRLL and iLDI scores also showed minimal correlation to mechanical complication. The iRLL score was slightly higher in the complication group (1.7 vs 2.1), but the iLDI score was slightly lower in the complication group (1.4 vs 0.8), which were all statistically insignificant. Furthermore, the iGAP classification of P, MD, and SD showed poor reliability in both no complications and complications group (Figures 2 and 3). In the complications group, both the P and SD group had the same rate of mechanical complication (6.3%) and the MD group had the highest complication rate (14.6%). This suggests that the iGAP classification may need more parameters to further assess

the different risk factors for each patient as the 3 variables used in this study (age, iRLL, iLDI) showed insufficient power to differentiate the probability for postoperative mechanical complications. This may be due to a narrow range of angular differentiation between each individual raw score of the iRLL and iLDI. For example, a patient with iRLL measuring -15° will have an iRLL raw score of 2 and a patient with iRLL measuring -14° will have an iRLL raw score of 0 based on the current definition of the GAP score. With a difference of 1° in lumbar lordosis, these 3 hypothetical patients will have an iGAP score that is ± 2 , which may place one patient in the P group while the other in the MD group. Noh et al¹⁴ comment that the GAP score's predictive model may still incompletely encompass preoperative risk factors for postoperative mechanical failure and suggests adding body mass index and bone mineral density to further strengthen the GAP score model, which may play a role in augmenting a partial iGAP score.

The type of mechanical complications sustained by the patients may be another reason for poor correlation between the partial iGAP score and mechanical failure. The partial iGAP score relies mostly on the lumbar lordosis to predict mechanical failure disregarding the proximal spine since the RSA is omitted in the calculation. The inability to accurately assess the proximal spinal alignment may have resulted in the partial iGAP score's unreliable prediction of PJK, which was

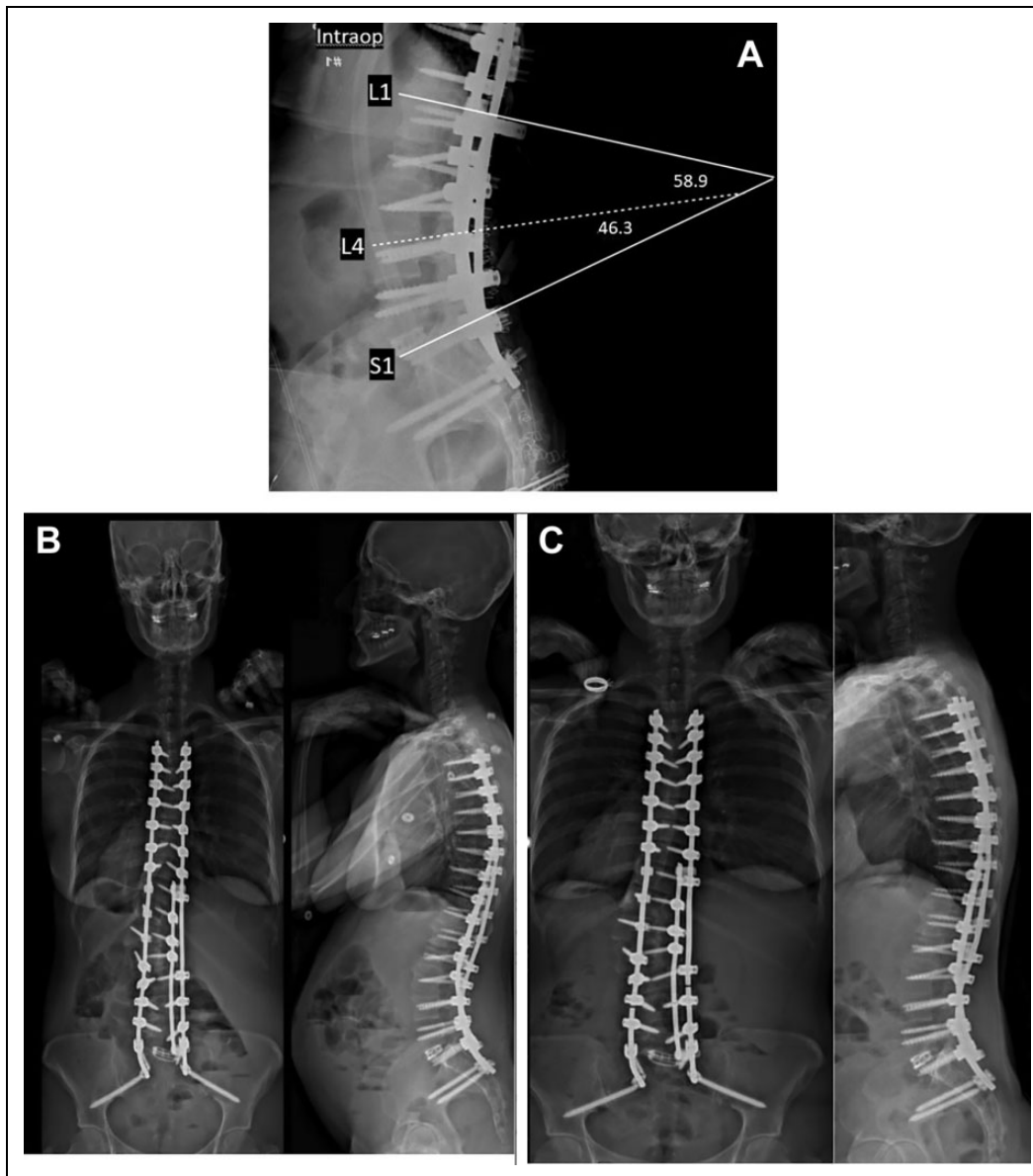


Figure 2. Patient with a proportioned spine based on the iGAP score with mechanical complication. (A) Intraoperative film demonstrating L1-S1 lordosis 58.9° of and L4-S1 lordosis of 46.3° with an iGAP score of 1. (B). Postoperative day 5 full-length standing anteroposterior (AP) and lateral spine films. (C). 2 years postoperative full-length standing AP and lateral spine films demonstrating mechanical complication: Fracture of right rod at L3-L4 and left rod at L4-L5. iGAP, intraoperative Global Alignment and Proportion.

the most frequent mechanical complication (61.5%). Another factor to consider for the inability of the iGAP score to predict PJK may be based on the patient cohort used in the original GAP score. The original GAP article does not mention the surgical approach or operative details, which does not allow us to assess if our patient population and surgeries are comparable and may also contribute to the inability to predict mechanical complications in this patient sample.

Inferentially, the role of RSA and RPV in standing films may be critical in accurately portraying the global alignment of the spine based on the inability for the iGAP to predict mechanical failure in this study. Jacobs et al¹⁵ reported that the GAP score was more predictive of mechanical complications than

the SRS-Schwab classification in their cohort of 39 patients with a minimum 2-year follow-up.¹⁵ Interestingly, they pointed out that the GAP score was most dependent on the RSA, RLL, and RPV. The LDI had a weaker correlation, and the age showed poor correlation with the GAP score. Their findings may explain the reason behind our results as the iGAP is based on age, iRLL, and iLDI. Similarly, Ohba et al⁸ suggest that the global tilt is the more important spinopelvic parameter to assess for potential predictors of poor postoperative GAP scores in their group of 128 patients with a minimum 2-year follow-up. This finding further implies that the GAP score variables we used for the iGAP score (age, iRLL, and iLDI) may paint a less than complete picture of the global spinal alignment.

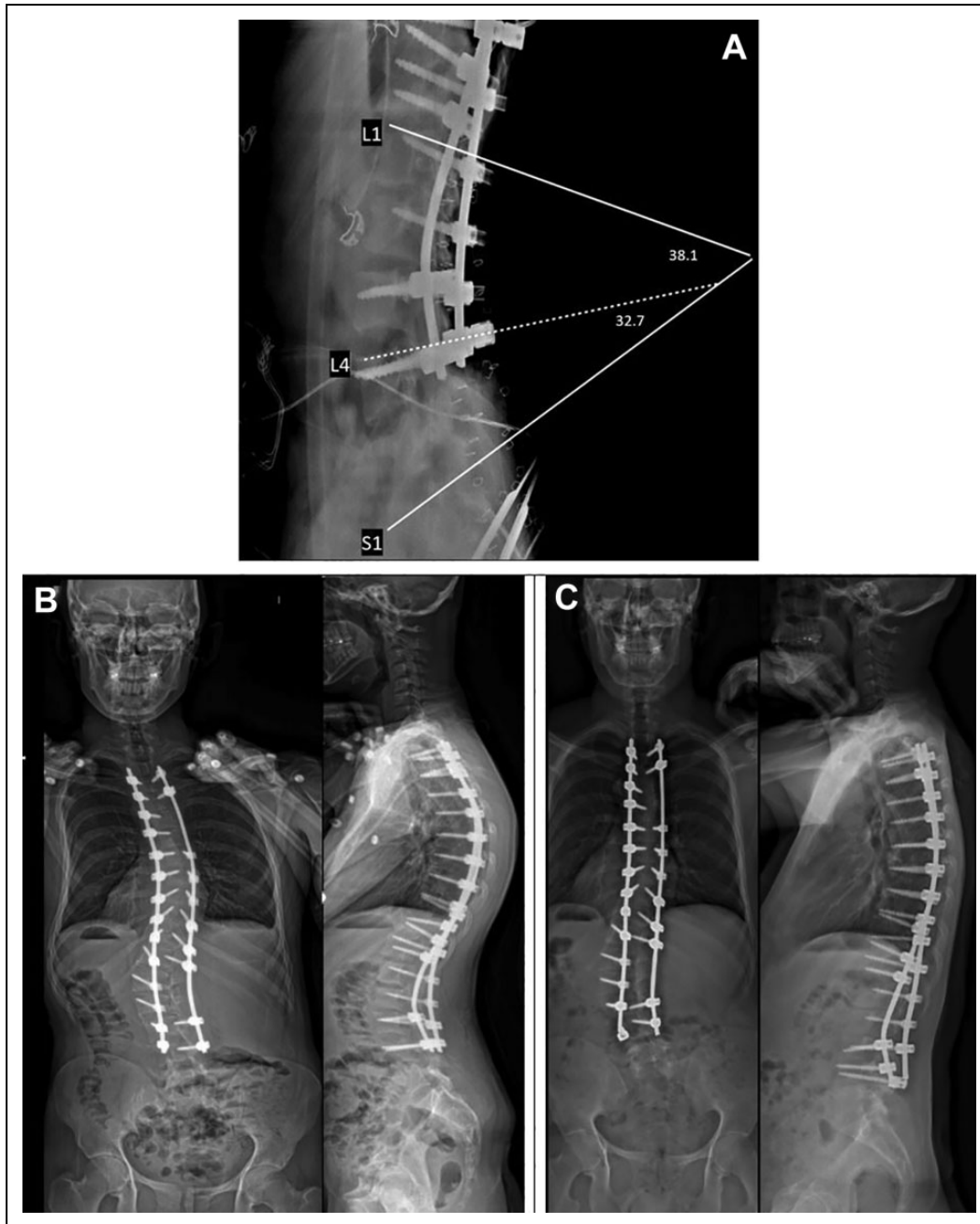


Figure 3. Patient with a severely disproportioned spine based on the iGAP score without mechanical complication. (A) Intraoperative X-ray demonstrating 38.1° of L1-S1 lordosis and 23.7° of L4-S1 lordosis with iGAP of 7. (B) Postoperative day 5 full-length standing anteroposterior (AP) and lateral spine films. (C) Two years postoperative full-length AP and lateral spine films demonstrating no mechanical complication. iGAP, intraoperative Global Alignment and Proportion.

Despite some promising recent literature on the validity of the GAP score, there have also been reports on the GAP score's inability to accurately predict mechanical complications. Bari et al reports no significant correlation between postoperative GAP scores and mechanical failure in their cohort of 149 patients with minimum 2-year follow-up, which questions the validity of the GAP score even with the presence of all 4 radiographic parameters.¹⁶ Similarly, Baum et al¹⁷ recently reported that the predicted rate of mechanical complications from the

GAP score overestimated the observed rate in patients with disproportioned alignment. The current literature has mixed results on the validity of the GAP score and a further simplification of this score to use as an intraoperative tool may not be feasible.

One of the limitations to this study is the poor quality of the intraoperative spine films used to obtain measurements. The intraoperative full-length spine films are obtained after reconstructing 2 or more radiographs into one using computer

software. The final film may inadvertently shift the spine alignment based on imperfect reconstitution of multiple radiographs. Also, many of the spinal radiographic measurements from the intraoperative films were difficult given the inadequate radiation penetration of the portable X-ray machine compared with the imaging obtained in the postoperative setting. We were unable to obtain intraoperative pelvic incidence because most of the intraoperative films did not show the entirety of the femoral heads and instead used the preoperative pelvic incidence, which theoretically should not deviate far from the actual intraoperative pelvic incidence.

The mechanical complication predictive model for spine deformity surgery is still in its early stages. The GAP score presents a tool based on published data to predict potential spinal deformity postoperative mechanical complications, but its use is currently limited in the pre- and postoperative setting. There is still a lack of reliable predictive models that can be used intraoperatively to predict postoperative complications. The partial iGAP score for our cohort of patients was unable to consistently predict future complications with the information obtained in the operating room. There may be more utility of the iGAP score if we could reliably obtain the RSV and RPV in the operating room setting to recreate the full original GAP score. However, it may be difficult to accurately account for the RSV and RPV when the patient is in the prone position with surgical paddings and cervical traction. This further confirms that there is yet a reliable intraoperative tool to assess postoperative mechanical complications in adult spine deformity surgery.

Conclusion

The success of spinal deformity surgery hinges on minimizing postoperative complications while obtaining satisfactory spinal global alignment. The GAP score is a useful tool that allows reliable prediction of postoperative mechanical failures based on sagittal plane analysis. The iGAP raw scores for RLL or LDI did not show any significant correlation to postoperative mechanical failure. Ultimately, the proposed partial iGAP score did not predict postoperative mechanical failure and thus, cannot be used as an intraoperative alignment assessment to avoid postoperative mechanical complications. Further studies are needed to find a reliable intraoperative radiographic predictor for postoperative mechanical failure.

Authors' Note

This study does not have any prior or duplicate submissions or publications elsewhere of any part of the work.


Declaration of Conflicting Interests

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References

1. Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. *Eur Spine J*. 2002;11:80-87. doi:10.1007/s005860000224
2. Diebo BG, Varghese JJ, Lafage R, Schwab FJ, Lafage V. Sagittal alignment of the spine: what do you need to know? *Clin Neurol Neurosurg*. 2015;139:295-301. doi:10.1016/j.clineuro.2015.10.024
3. Faundez A, Roussouly P, Le Huec JC. Sagittal balance of the spine: a therapeutic revolution [in French]. *Rev Med Suisse*. 2011;7:2470-2474.
4. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. *Spine (Phila Pa 1976)*. 2005;30:2024-2029. doi:10.1097/01.brs.0000179086.30449.96
5. Harroud A, Labelle H, Joncas J, Mac-Thiong JM. Global sagittal alignment and health-related quality of life in lumbosacral spondylolisthesis. *Eur Spine J*. 2013;22:849-856. doi:10.1007/s00586-012-2591-6
6. Makhni MC, Shillingford JN, Laratta JL, Hyun SJ, Kim YJ. Restoration of sagittal balance in spinal deformity surgery. *J Korean Neurosurg Soc*. 2018;61:167-179. doi:10.3340/jkns.2017.0404.013
7. Rajnic P, Templier A, Skalli W, Lavaste F, Illés T. The association of sagittal spinal and pelvic parameters in asymptomatic persons and patients with isthmic spondylolisthesis. *J Spinal Disord Tech*. 2002;15:24-30. doi:10.1097/00024720-200202000-00004
8. Ohba T, Ebata S, Oba H, Koyama K, Yokomichi H, Haro H. Predictors of poor global alignment and proportion score after surgery for adult spinal deformity. *Spine (Phila Pa 1976)*. 2019;44:E1136-E1143. doi:10.1097/BRS.0000000000003086
9. Polly DW Jr. Align the spine—it's not just the pelvis! Commentary on an article by Caglar Yilgor, MD, et al: 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. *J Bone Joint Surg Am*. 2017;99:e104. doi:10.2106/JBJS.17.00676
10. Yilgor C, Sogunmez N, Boissiere L, et al. 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. *J Bone Joint Surg Am*. 2017;99:1661-1672. doi:10.2106/JBJS.16.01594
11. Inoue S, Khashan M, Fujimori T, Berven SH. Analysis of mechanical failure associated with reoperation in spinal fusion to the sacrum in adult spinal deformity. *J Orthop Sci*. 2015;20:609-616. doi:10.1007/s00776-015-0729-1
12. Hyun SJ, Rhim SC. Clinical outcomes and complications after pedicle subtraction osteotomy for fixed sagittal imbalance patients: a long-term follow-up data. *J Korean Neurosurg Soc*. 2010;47:95-101. doi:10.3340/jkns.2010.47.2.95

13. Hallager DW, Karstensen S, Bukhari N, Gehrchen M, Dahl B. Radiographic predictors for mechanical failure after adult spinal deformity surgery: a retrospective cohort study in 138 patients. *Spine (Phila Pa 1976)*. 2017;42:E855-E863. doi:10.1097/BRS.0000000000001996
14. Noh SH, Ha Y, Obeid I, et al. Modified Global Alignment and Proportion Scoring with body mass index and bone mineral density (GAPB) for improving predictions of mechanical complications after adult spinal deformity surgery. *Spine J*. 2020;20:776-784. doi:10.1016/j.spinee.2019.11.006
15. Jacobs E, van Royen BJ, van Kuijk SMJ, et al. Prediction of mechanical complications in adult spinal deformity surgery—the GAP score versus the Schwab classification. *Spine J*. 2019;19:781-788. doi:10.1016/j.spinee.2018.11.013
16. Bari TJ, Ohrt-Nissen S, Hansen LV, Dahl B, Gehrchen M. Ability of the Global Alignment and Proportion score to predict mechanical failure following adult spinal deformity surgery—validation in 149 patients with two-year follow-up. *Spine Deform*. 2019;7:331-337. doi:10.1016/j.jspd.2018.08.002
17. Baum GR, Ha A, Cerpa M, et al. Does the Global Alignment and Proportion score overestimate mechanical complications after adult spinal deformity correction? Paper presented at: Scoliosis Research Society 54th Annual Meeting; September 18-21, 2019; Montréal, Canada.