



Original Article

Corresponding Author

Kyung Hyun Kim

<https://orcid.org/0000-0002-1338-5523>

Department of Neurosurgery, Spine and Spinal Cord Institute, Gangnam Severance Hospital, Yonsei University College of Medicine, 211 Eonju-ro, Gangnam-gu, Seoul 06273, Korea
Email: NSKHK@yuhs.ac

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Modified Global Alignment and Proportion Scoring With Body Mass Index and Bone Mineral Density Analysis in Global Alignment and Proportion Score of Each 3 Categories for Predicting Mechanical Complications After Adult Spinal Deformity Surgery

Sung Hyun Noh^{1,2}, Yoon Ha³, Jeong Yoon Park⁴, Sung Uk Kuh³, Dong Kyu Chin⁴, Keun Su Kim⁴, Yong Eun Cho⁴, Hye Sun Lee⁵, Kyung Hyun Kim⁴

¹Department of Neurosurgery, Ajou University College of Medicine, Suwon, Korea

²Department of Neurosurgery, Yonsei University College of Medicine, Seoul, Korea

³Department of Neurosurgery, Spine and Spinal Cord Institute, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea

⁴Department of Neurosurgery, Spine and Spinal Cord Institute, Gangnam Severance Hospital, Yonsei University College of Medicine, Seoul, Korea

⁵Biostatistics Collaboration Unit, Yonsei University College of Medicine, Seoul, Korea

Objective: This study aimed to analyze the prediction rate of the modified Global Alignment and Proportion (GAP) scoring system with body mass index and bone mineral density (GAPB) in each GAP of the 3 categories.

Methods: Between January 2009 and December 2016, 203 consecutive patients with adult spinal deformity (ASD) underwent corrective fusion of more than 4 levels and were followed-up for more than 2 years. As a validation of the GAPB, the GAPB was divided into tertiles (Q1, Q2, Q3) for each section of the GAP score. Each patient's GAP score and GAPB system complication rate were examined.

Results: Of the 203 patients, 89 patients (44%) developed mechanical complications after ASD surgery. A GAP score analysis of the patients found that 42 patients were proportioned, 85 patients were moderately disproportioned, and 76 patients were severely disproportioned. Mechanical complications occurred with increasing GAPB in the proportioned group, but were not statistically significant ($p = 0.0534$). However, mechanical complications occurred in a statistically significant manner in the moderately disproportioned and severely disproportioned groups as GAPB increased ($p < 0.001$).

Conclusion: The GAPB system showed improved predictability for mechanical complications after surgery for ASD in each category of the GAP score.

Keywords: Adult spinal deformity, Mechanical complication, Body mass index, Bone mineral density, Retrospective study, Global alignment and proportion scoring

INTRODUCTION

The incidence of spinal deformities in adults has been increasing with the age of the population. Currently, the incidence of spinal deformities ranges from 29% in adults who are 54 years of age to over 65% in adults who are over 65 years of age.¹ Comprehensive surgical planning of adult spinal deformity (ASD) is possible with a better understanding of the sagittal alignment of the spine, which is key to achieving optimal surgical alignment and improved results. A recent study of outcomes after ASD surgery reported high rates of complications (8.4%–42%) and revision rates (9%–17.6%).^{2–5} Among complications, proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) are common, and morbidity has been reported at 20%–40%.⁶ Furthermore, revision surgery is often performed because of pseudoarthrosis, implant failure, adjacent segment disease, or infection, resulting in increased medical costs.⁷

Many studies have presented optimal radiologic targets and reported formulas for predicting mechanical complications. The Scoliosis Research Society (SRS)-Schwab classification, age-adjusted alignment goals, the Global Alignment and Proportion (GAP) score, modified GAP scoring system with body mass index (BMI) and bone mineral density (GAPB) have been reported as formulas related to surgery for ASD. In particular, the recently introduced GAPB system adds BMI and BMD to the GAP score to combine the characteristics of the patient.⁸ In a study by Noh et al.,⁸ compared to the GAP score, the modified GAPB system improved the predictive value of mechanical complications after surgery for ASD. However, the prediction rates of GAPB in the 3 categories of the GAP score (proportioned, moderately disproportioned, severely disproportioned) have not been analyzed. Therefore, this study aims to analyze the prediction rate of GAPB in each of the 3 categories of the GAP score.

MATERIALS AND METHODS

1. Patient Population

The current study is a 2-center cohort review of patients suffering from ASD using posterior spinal fusion and instrumentation between January 2009 and December 2016. The inclusion criteria were as follows: (1) patients who underwent surgical deformity surgery for ASD; (2) patients who had a coronal spinal curvature $> 20^\circ$, sagittal vertical axis > 5 cm, pelvic tilt (PT) $> 25^\circ$, or thoracic kyphosis (TK) $> 60^\circ$ as indicated by radiologic examinations; (3) patients who underwent surgery for posterior instrumented fusion of ASD for more than 4 levels;

and (4) those with a follow-up period of more than 2 years. The exclusion criteria were as follows: (1) ASD patients secondary to syndromic, infectious, tumor, autoimmune, or other pathologic conditions; (2) those who underwent surgery for ASD at level 4 or below; and (3) patients with a follow-up period less than 2 years. From January 2009 to December 2016, 456 patients with ASD underwent spinal surgery at Gangnam Severance Hospital. We excluded 253 patients with a follow-up period of less than 2 years, those who were not indicated for correction surgery for ASD, or those with a surgical level below level 3. From January 2009 to December 2016, 203 patients who underwent surgery for ASD were contained. The study was approved by each hospital's Institutional Review Board and all participants provided written consent.

2. Radiographic Measurements and Scoring

All radiographs were analyzed using validated software (Sur-gimap, Nemaris Inc., New York, NY, USA). The measured pelvic parameters were pelvic incidence (PI), PT, and sacral slope (SS). Local spinal parameters contained PI–LL, L1–S1 Lordosis, L4–S1 lordosis, and TK. The sagittal alignment was evaluated by T1 pelvic angle and global tilt. All radiographic evaluations were performed 4 weeks after surgery.

GAP scoring was conducted according to the formula by Yilgor et al.⁹ The GAP score consists of relative pelvic version, relative lumbar lordosis, lumbar distribution index, relative sagittal alignment, and age. The GAP score ranges from 0 to 13 points. The selected GAP score cutoff point was consistent with the cutoff value determined by the report of Yilgor et al.⁹ Relative pelvic versions of $< 15^\circ$ (with measured SS minus ideal SS) were considered to be severe retroversion; -15° to -7.1° , moderate retroversion, -7° to 5° , aligned; and $> 5^\circ$, anteversion. Relative lumbar lordosis $< -25^\circ$ (measured lumbar lordosis minus ideal lumbar lordosis) were considered severe hypolordosis; -25° to -14.1° , moderate hypolordosis; -14° to 11° aligned; and $> 11^\circ$, hyperlordosis. Less than 40% of the lumbar distribution index (L4–S1 lordosis divided by L1–S1 lordosis multiplied by 100 loadsheets) was considered to be a severe hypolordotic maldistribution; 40%–49%, moderate hypolordotic maldistribution; 50%–80%, aligned; and $> 80\%$, hyperlordotic maldistribution. Relative spinopelvic alignment $> 18^\circ$ (measured global tilt minus ideal global tilt) was considered a severe positive malalignment; 10.1° – 18° , moderate positive malalignment; 10° to -7° aligned; $< -7^\circ$, negative malalignment. A GAP score of 0–2 was classified as indicating the state of the proportional spinopelvic state; 3–6, moderately disproportioned; > 6 , severely disproportioned.

The modified predictive model included the GAP score, BMI, and BMD (GAPB). As described above, GAP scores were ob-

Table 1. Adult spinal deformity surgery patients' demographics (n = 203)

Variable	Value
Sex	
Female	170 (84)
Male	33 (16)
Age (yr)	66.8 ± 12.28
Prior spine surgery	55 (27)
BMI (kg/m ²)	23.75 ± 2.57
BMD (T-score)	-1.95 ± 0.98
Diagnosis	
Idiopathic	0 (0)
Degenerative	196 (97)
Neuromuscular	1 (0.1)
Posttraumatic	6 (2.9)
Type of mechanical complication	89 (44)
PJK/PJF	60
DJK/DJF	3
Rod fracture	22
Implant-related complications	4
No. of levels fused	8.42 ± 2.01
3-Column osteotomy	52 (26)
UIV level	
T7/T8/T9	7/8/70
T10/T11/T12	55/5/7
L1/L2	18/33
Pelvic fixation	
Yes	138 (68)
No	65 (32)

Values are presented as number (%) or mean ± standard deviation. BMI, body mass index; BMD, bone mineral density; PJK, proximal junctional kyphosis; PJF, proximal junctional failure; DJK, distal junctional kyphosis; DJF, distal junctional failure; UIV, upper instrumented vertebra.

Table 2. Range of GAPB by GAP score group

Group	Total		Q1		Q2		Q3	
	No.	No.	No.	Range	No.	Range	No.	Range
Proportioned	42	14	0.012	0.036	14	0.038–0.133	14	0.136–0.928
Moderately disproportioned	85	28	0.008	0.114	29	0.117–0.482	28	0.485–0.999
Severely disproportioned	76	25	0.175	0.617	26	0.632–0.883	25	0.886–0.993

GAPB, Modified Global Alignment and Proportion scoring with body mass index and bone mineral density; GAP, Global Alignment and Proportion.

tained, and BMI and BMD were measured before surgery. The standards of the World Health Organization (WHO) using BMD measured by double energy x-ray absorption measurements are the most widely used in the diagnosis of osteoporosis. The BMD was measured according to the WHO criteria to use the worst of the spine and femur measurements. The mechanical complication rate was calculated through the nomogram of the GAPB as described by Noh et al.⁸

3. Mechanical Complications

Mechanical complications were defined as PJK or PJF, distal junctional kyphosis (DJK) or distal junctional failure (DJF), rod fracture, and implant-related complications. Implant-related complications were defined as screw loosening, breakage, pull-out or interbody graft, hook, or set-screw dislodgement.

4. Statistical Analysis

As a validation of the GAPB score, the GAPB score (predicted probability) was divided into tertiles (Q1, Q2, Q3) for each section of the GAP score: proportioned, 0–2 points; moderately disproportioned, 3–6 points, and severely disproportioned, 7–13 points. In addition, the Cochran-Armitage trend test was conducted to determine whether the probability of actual replication increased. A p-value < 0.05 was considered to indicate statistical significance. All statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

RESULTS

1. Patients Demographics

Two hundred three patients underwent surgery for ASD (170 women [84%], 33 men [16%]). Their demographic data are listed in Table 1. The average age of the patients was 66.8 ± 12.28 years (range, 54–83 years), and the average follow-up duration was 30.54 ± 6.25 months (range, 24–118 months). The number of prior cases of spine surgery was 55 cases (27%), the mean BMI was 23.75 ± 2.57 kg/m², and the mean BMD was -1.95 ±

0.98. Among the diagnoses, there were 196 degenerative cases (97%), 6 posttraumatic cases (2.9%), and 1 neuromuscular case

(0.1%). Mechanical complications occurred in a total of 89 cases (44%), among which 60 cases occurred in the PJK and PJF, and 22 cases in the rod fracture. Implant-related complications occurred in 4 cases, and DJK/DJF occurred in 3 cases.

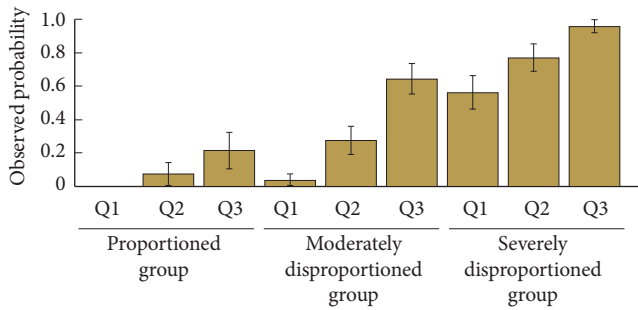


Fig. 1. The observed probability of complications (observed probability ± standard error) of Q1, Q2, Q3 were 0.000 ± 0.000, 0.071 ± 0.069, and 0.214 ± 0.110, respectively, in the proportioned group; 0.036 ± 0.035, 0.276 ± 0.083, and 0.643 ± 0.091, respectively, in the moderately disproportioned group; and 0.560 ± 0.099, 0.769 ± 0.083, and 0.960 ± 0.039, respectively, in the severely disproportioned group.

2. Range of GAPB by GAP Score Group

There were a total of 203 cases. Each count was converted back to the GAPB score system. Then, each group was divided into Q1, Q2, and Q3 groups. The minimum and maximum values of Q1, Q2, and Q3 are shown in Table 2 and Fig. 1. The proportioned group had 42 cases, resulting in 14 cases each in the Q1 (0.012–0.036), Q2 (0.038–0.133), and Q3 (0.136–0.928). The moderately disproportioned group had 85 cases, with 28, 29, and 28 cases in the Q1 (0.008–0.114), Q2 (0.117–0.482), and Q3 (0.485–0.999) groups, respectively. The severely disproportioned group had 76 cases, with 25, 26, and 25 cases divided Q1 (0.175–0.617), Q2 (0.632–0.883), and Q3 (0.886–0.993) groups, respectively.

Table 3. Observed probability of complication by GAP score group

Group	Total		Q1		Q2		Q3			
	No.	No.	Observed probability	Standard error	No.	Observed probability	Standard error	No.	Observed probability	Standard error
Proportioned	42	14	0.000	0.000	14	0.071	0.069	14	0.214	0.110
Moderately disproportioned	85	28	0.036	0.035	29	0.276	0.083	28	0.643	0.091
Severely disproportioned	76	25	0.560	0.099	26	0.769	0.083	25	0.960	0.039

GAP, Global Alignment and Proportion.

Table 4. Cochran-Armitage trend test

Group	Total	Q1	Q2	Q3	p-value
Proportioned					0.0534
Total	42 (100)	14 (100)	14 (100)	14 (100)	
Complication (-)	38 (90.48)	14 (100)	13 (92.86)	11 (78.57)	
Complication (+)	4 (9.52)	0 (0)	1 (7.14)	3 (21.43)	
Moderately disproportioned					<0.0001*
Total	85 (100)	28 (100)	29 (100)	28 (100)	
Complication (-)	58 (68.24)	27 (96.43)	21 (72.41)	10 (35.71)	
Complication (+)	27 (31.76)	1 (3.57)	8 (27.59)	18 (64.29)	
Severely disproportioned					<0.0001*
Total	76 (100)	25 (100)	26 (100)	25 (100)	
Complication (-)	18 (23.68)	11 (44.00)	6 (23.08)	1 (4.00)	
Complication (+)	58 (76.32)	14 (56.00)	20 (76.92)	24 (96.00)	

Values are presented as number (%).

*p < 0.05, statistically significant differences.

3. Observed Probability of Complication by GAP Score Group

Table 3 shows the observed probability of complications by the GAP score group. The observed probability of complications (observed probability ± standard error) of Q1, Q2, Q3 were 0.000 ± 0.000, 0.071 ± 0.069, and 0.214 ± 0.110, respectively, in the proportioned group; 0.036 ± 0.035, 0.276 ± 0.083, and 0.643 ± 0.091, respectively, in the moderately disproportioned group; and 0.560 ± 0.099, 0.769 ± 0.083, and 0.960 ± 0.039, respectively, in the severely disproportioned group

4. Cochran-Armitage Trend Test

Table 4 shows the frequencies of mechanical complications in each group using the Cochran-Armitage trend test. As the score was converted to GAPB in each group of the GAP scoring system increased, the number of mechanical complications increased. In addition, there were statistically significant findings in the moderately disproportioned and severely disproportioned groups (p < 0.0001).

5. Subgroup Analysis: Pelvic Fixation (+) / (-)

The trend of GAPB in the GAP of each group was analyzed

Table 5. Cochran-Armitage trend test (no pelvic fixation group)

Group	Total	Q1	Q2	Q3	p-value
Proportioned					> 0.9999
Total	13 (100)	4 (100)	5 (100)	4 (100)	
Complication (-)	12 (90.31)	4 (100)	4 (80.00)	4 (100)	
Complication (+)	1 (7.69)	0 (0.00)	1 (20.00)	0 (0)	
Moderately disproportioned					0.0009*
Total	29 (100)	9 (100)	10 (100)	10 (100)	
Complication (-)	20 (68.97)	9 (100)	8 (80.00)	3 (30.00)	
Complication (+)	9 (31.03)	0 (0)	2 (20.00)	7 (70.00)	
Severely disproportioned					0.0156*
Total	23 (100)	7 (100)	8 (100)	8 (100)	
Complication (-)	7 (30.43)	4 (57.14)	3 (37.50)	0 (0)	
Complication (+)	16 (69.57)	3 (42.86)	5 (62.50)	8 (100)	

Values are presented as number (%).

*p < 0.05, statistically significant differences.

Table 6. Cochran-Armitage trend test (pelvic fixation group)

Group	Total	Q1	Q2	Q3	p-value
Proportioned					0.029*
Total	29 (100)	9 (100)	10 (100)	10 (100)	
Complication (-)	26 (89.66)	9 (100)	10 (100)	7 (70.00)	
Complication (+)	3 (10.34)	0 (0.00)	0 (0.00)	3 (30.00)	
Moderately disproportioned					0.0007*
Total	56 (100)	18 (100)	19 (100)	19 (100)	
Complication (-)	38 (67.86)	17 (94.44)	13 (68.42)	8 (42.11)	
Complication (+)	18 (32.14)	1 (5.56)	6 (31.58)	11 (57.89)	
Severely disproportioned					0.0097*
Total	53 (100)	17 (100)	18 (100)	18 (100)	
Complication (-)	11 (20.75)	7 (41.18)	3 (16.67)	1 (5.56)	
Complication (+)	42 (79.25)	10 (58.82)	15 (83.33)	17 (94.44)	

Values are presented as number (%).

*p < 0.05, statistically significant differences.

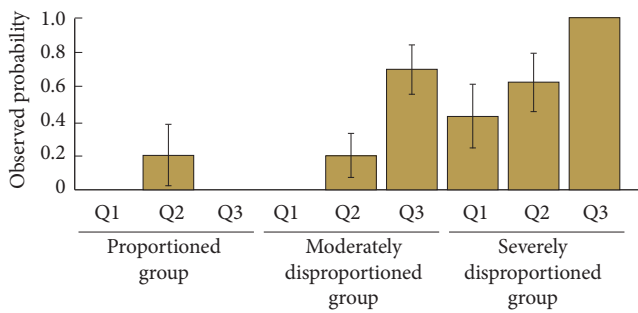


Fig. 2. No pelvic fixation group. The observed probability of complications (observed probability ± standard error) of Q1, Q2, Q3 were 0.000 ± 0.000, 0.2 ± 0.179, and 0.000 ± 0.000, respectively, in the proportioned group; 0.000 ± 0.000, 0.2 ± 0.126, and 0.7 ± 0.145, respectively, in the moderately disproportioned group; and 0.429 ± 0.187, 0.625 ± 0.171, and 1.0 ± 0.000, respectively, in the severely disproportioned group.

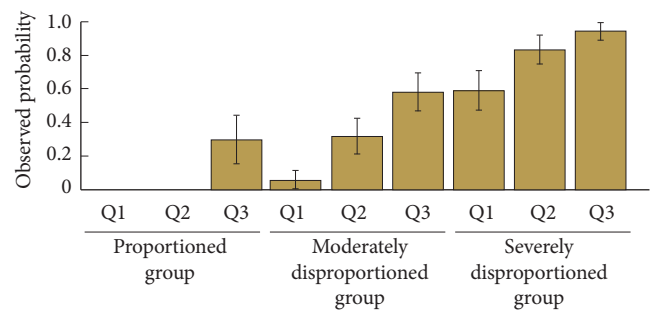


Fig. 3. Pelvic fixation group. The observed probability of complications (observed probability ± standard error) of Q1, Q2, Q3 were 0.000 ± 0.000, 0.000 ± 0.000, and 0.3 ± 0.145, respectively, in the Proportioned group; 0.056 ± 0.054, 0.316 ± 0.107, and 0.579 ± 0.113, respectively, in the Moderately disproportioned group; and 0.588 ± 0.119, 0.833 ± 0.088, and 0.944 ± 0.054, respectively, in the Severely disproportioned group.

by dividing the group with and without pelvic fixation. Tables 5 and 6 show the frequencies of mechanical complications in each group using the Cochran-Armitage trend test. In pelvic fixation (-) group, there were statistically significant findings in the moderately disproportioned and severely disproportioned groups ($p < 0.05$). In pelvic fixation (+) group, there were statistically significant findings in all of groups ($p < 0.05$) Figs. 2 and 3 show the observed probability of complications by the GAP score group in pelvic fixation (-) and pelvic fixation (+) group.

DISCUSSION

Many studies have been performed to reduce mechanical complications in surgery for ASD, and several studies have suggested ideal targets.^{3,9-11} Schwab et al.¹¹ proposed a clinically relevant classification for surgery for ASD, which may be advantageous because the surgeon can then treat the disease by highlighting the patient's sagittal alignment. Although it was corrected according to the Schwab classification, there have been many cases of mechanical complications.¹² Lafage et al.¹³ proposed an ideal target by considering changes in radiologic parameters with age. However, this was also incomplete.

Yilgor et al.⁹ reported the GAP scoring system. The proportional parameter according to the PI was related to the rate of mechanical complications, and the mechanical complication rate was lower in the proportioned group. In contrast to absolute values such as SRS-Schwab classification's target and age-adjusted alignment goals, these parameters fit well with individual variability in human anatomy.⁹ According to the PI-based global alignment and "ratio concept," the spine pelvic alignment

can be used to set up separate radiologic targets for surgical planning.⁹ In addition, the shape/alignment, which is not ideal, can be recognized early after surgery, so treatment of osteoporosis, rehabilitation, and correction of activity can be performed as needed. However, the disadvantage of this formula is that only patient-specific factors other than radiologic parameters are included. In this formula, there was a limitation of simply dividing by 60 and more. Furthermore, the GAP study group consisted of subjects who were 18 years of age or older, and the age range was too wide for use in the ASD group.

Therefore, a new model that included BMI and BMD that was suitable for the ASD group, is characteristic of patients, and affects ASD surgery was needed. The GAPB system, including BMI and BMD, showed improved predictability for forecasting mechanical complications compared to the GAP scoring system [(8)]. Many studies have reported that osteoporosis and obesity are important risk factors for PJK, PJE, and other mechanical complications.¹⁴⁻¹⁷ In surgery for ASD, BMI and osteoporosis are essential when discussing mechanical complications because most elderly patients have low muscle mass and severe osteoporosis.

Noh et al.⁸ reported that the area under the curve of the GAPB system is more than that of GAP score system. But the prediction rates of the GAPB system for the 3 categories of the GAP score (with severe imbalances in the middle of the proportion) were not analyzed. Because the GAP score was used to predict the possibility of complications within the three categories, there was no difference between 3 and 6 points in the GAP score, and there was no difference between 7 and 13 points. According to the GAP score, the incidence of mechanical complications was only 6% in patients in the proportioned group, but not 47% and

95% in the moderately and severely disproportioned group.⁹ However, since GAPB can be used to predict the possibility of mechanical complications in each case, it can provide accurate information to the surgeon. In our study, the incidence of mechanical complications increased as the GAPB score increased in the 3 categories of the GAP scoring system. Especially in the moderate disproportioned and severely disproportioned groups, there was a statistically significant increase ($p < 0.0001$). In predicting mechanical complications using GAPB, the fact that it came out meaningfully within the 3 categories of GAP suggests that GAPB can provide more accurate information than GAP to the surgeon.

There are some limitations to this study. This was a retrospective study, and the possibility of mechanical complications can only be evaluated based on the immediate postoperative results. Therefore, the possibility of mechanical complications before surgery cannot be predicted. Furthermore, the reason for mechanical complications after ASD correction is multifactorial. The focus was on postoperative radiation alignment and recovery of patient factors. Many factors, such as surgical method, upper instrument level, muscle volume, and various underlying diseases that the patient may have will influence the outcome of the operation.

The GAPB system is meant to more accurately predict mechanical complications compared to other scoring systems and to present ideal surgical goals. There is evidence demonstrating that patient bone quality and obesity are also important factors in mechanical complications. Even if the risk of failure is expected to be high, there are some things that must be done in patients at high risk. We believe that this system will help the patient in consultation with the surgeon about the prognosis.

CONCLUSION

The GAPB system, which includes BMI and BMD, showed improved predictability for mechanical complications after surgery for ASD in each category of the GAP scoring system. In particular, the GAPB system was more meaningful in the moderately disproportioned and severely disproportioned groups. These results require the surgeon to keep in mind the quality and proportionality of bone quality and BMI when planning surgery for ASD.

CONFLICT OF INTEREST

The authors have nothing to disclose.

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