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ORIGINAL ARTICLE

Global alignment and proportion (GAP) scores in an asymptomatic, nonoperative cohort: a divergence of age-adjusted and pelvic incidence-based alignment targets

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Abstract

Purpose To investigate GAP scores in an asymptomatic cohort of adults, including older adults with age-expected changes in spinal alignment.

Methods One hundred and twenty asymptomatic volunteers underwent full-body radiographic scans. Demographics and sagittal radiographic parameters (pelvic incidence, sacral slope, L1-S1 lordosis, L4-S1 lordosis, and global tilt) were measured and GAP scores calculated (www.gapcalculator.com). Mann–Whitney *U* test compared groups.

Results Eighty-five individuals (65 female, average age 48 ± 16 years, BMI 27 ± 6 kg/cm^2) were analyzed. The median GAP score was that of a proportioned spine (0, range 0–10). 20% were moderately disproportioned and 6% were severely disproportioned. The mean relative pelvic version, relative lumbar lordosis (RLL), lumbar distribution index (LDI), and relative spinopelvic alignment were all considered aligned, although the mean RLL and LDI scores were both greater than 1. When categorized by age (< 60 years, ≥ 60 years), the median GAP score of the younger group was 0 (normal), while the median GAP score of the older cohort was 1 (normal) and different from the younger group ($p < 0.001$).

Conclusion Most patients in this asymptomatic, nonoperative cohort were normally proportioned. However, a large percentage of asymptomatic volunteers were moderately or severely disproportioned. Older patients had higher scores, indicating some disproportion. There was also a small number of severely sagittally misaligned and poorly proportioned, yet asymptomatic, volunteers. Further refinement of individualized targets is needed to determine the effect on mechanical complications and quality of life given the divergent recommendations of age-adjusted targets and GAP targets.

Keywords Alignment · Sagittal plane · GAP · Age-adjusted · Adult deformity

Introduction

Complications are common after adult spinal deformity (ASD) surgery [1, 2]. These complications can be costly and have a significant influence on long-term quality of life [3, 4]. One predictor of mechanical complications and quality of life may be alignment of the spine after fusion. However, the ideal alignment of the fused spine after ASD surgery to minimize complications and maximize outcomes has yet to be defined.

Sagittal alignment is considered to be one of the most important driver of health-related quality of life (HRQOL) after ASD surgery [5]. The sagittal alignment targets proposed by Schwab et al. (PI-LL ± 9, sagittal vertical axis (SVA) < 5, pelvic tilt (PT) < 20) were based on correlations, with disability measured by HRQOL [6]. The global alignment and proportion (GAP) score expanded on this concept in an attempt to predict mechanical complications after adult spinal deformity surgery [7]. The predictions are based on pelvic incidence (PI) as the driver of sacral slope (SS), lumbar lordosis (L1-S1), low lumbar lordosis (L4-S1), global tilt (GT). There is an age component, as older patients were

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found to be less tolerant of malalignment. Recently proposed age-adjusted alignment goals hope reduce the occurrence of proximal junctional kyphosis (PJK) but maintaining some age-related malignment [8]. Many sagittal parameters change with age in asymptomatic individuals [9], which have spurred the concept of age-adjusted alignment goals in ASD surgery. There is, however, a divergence between the concepts of GAP-guided alignment and age-related alignment targets.

The ideal sagittal alignment remains an elusive target. As predictive algorithms improve, we may move toward more individualized alignment goals based on the morphology of an individual's spine and pelvis. The GAP score attempts to predict complications based on sagittal alignment after surgery, using a database of patients treated with ASD surgery. To our knowledge, it has not been measured in a population of asymptomatic individuals. We measured GAP scores from full length EOS radiographs of a normal asymptomatic population and hypothesize that the GAP scores of asymptomatic volunteers are proportioned.

Methods

Subject enrollment

After institutional review board approval, 120 asymptomatic volunteers ages 18–79 were recruited as previously described [9–11]. Exclusion criteria were coronal cobb angle > 10°, a history of spine surgery, knee or hip surgery or any realignment surgery of the lower extremities, neck or back pain that resulted in missed work, affected activities of daily living, participation in recreational activities, or required opiates, spine condition that warranted physician intervention (appointment or epidural steroid injection), non-ambulatory patients, history of neuromuscular disorder, inflammatory arthritis, or congenital anomaly, and pregnancy. Standing AP and lateral skull to feet radiographs (EOS Imaging SA, Paris, France) were obtained. Oswestry disability index (ODI) and demographics such as age, gender, and body mass index (BMI) were collected. Eighty-five patients were included for analysis.

Radiographic measurements and gap scores

All radiographic analysis was performed using Surgimap Spine (Nemaris, New York, NY). Lumbar lordosis (L5-S1), pelvic incidence, pelvic tilt, sacral slope, low lumbar lordosis (L4-S1) and global tilt were obtained as previously described and verified by an orthopedic surgeon (Fig. 1) [9, 10]. GAP scores, individual components of the GAP score (relative pelvic version (RPV), relative lumbar lordosis (RLL), lumbar distribution index (LDI) and relative

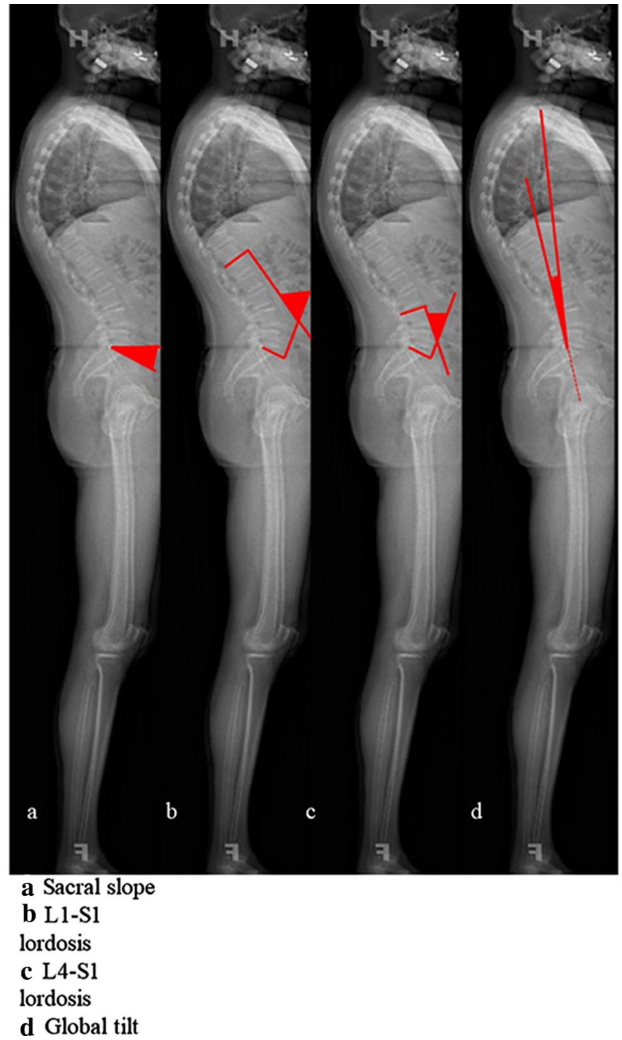

Fig. 1 Angular measurements of the GAP score. **a** Sacral slope, **b** L1-S1 lordosis, **c** L4-S1 lordosis, **d** global tilt

spinopelvic alignment (RSA)), and differences from ideals were calculated using an online calculator (www.gapcalculator.com). GAP scores range from 0 to 11. Scores are categorized as follows: 0–2 proportioned, 3–6 moderately disproportioned, and ≥ 7 severely disproportioned.

Statistical analysis

Means and standard deviations for continuous variables (age, BMI, sagittal radiographic parameters) and median and interquartile range (IQR, middle 50% of data) for ordinal variables (GAP scores and GAP score components) were calculated for the entire cohort as well as the groups of volunteers < 60 years old and ≥ 60 years old. The original GAP score paper stratified patients into < 60 years old and ≥ 60 years old, determining that patients ≥ 60 years old had a higher risk of mechanical complications [7]. A

Mann–Whitney *U* Test compared GAP scores and student's *t* test compared individual sagittal parameters. Statistical significance was defined as $p < 0.05$.

Funding

Direct support was received from EOS-Imaging for volunteer honoraria and enrollment support. No funds were paid to any authors.

Results

Five volunteers never completed imaging and 30 had insufficient imaging, so 85 were included for analysis (Table 1). The median GAP score for the entire cohort was 0 (IQ range 0–3, range 0–10), or proportioned. Mean Oswestry Disability Index (ODI) was 1 ± 4. The means and ranges of the individual sagittal parameters required to calculate GAP scores, the medians of individual components of the GAP score and mean differences from the "ideal" alignment of each parameter are in Table 1.

We stratified the asymptomatic patients with the same age cutoff as the original GAP score paper. The median GAP score of patients < 60 years old was 0 (IQ range 0–2) and ≥ 60 years old was 1 (IQ range 1–6). The older cohort had less L4-S1 lordosis (37.2 ± 7.2° versus 31.6 ± 8.1°, $p = 0.002$) and had greater global tilt (7.3 ± 9.0° versus 13.6 ± 9.4°, $p < 0.001$). Total lumbar lordosis was not different between the age groups. See Table 1 for characteristics and sagittal parameters stratified by age. Pelvic tilt and global tilt were significantly higher in the older cohort and low lumbar lordosis was lower. Distribution of proportioned, moderately disproportioned, and severely disproportioned volunteers by age is shown in Fig. 2. The percentage of moderately disproportioned volunteers is constant, but the percentage of severely disproportioned is higher in the volunteers ≥ 60.

Discussion

The GAP score and alignment targets are proposed to reduce mechanical complications after spinal fusion by promoting the restoration of lumbopelvic harmony. While some components of the score come from asymptomatic individuals, the classification was devised from a cohort of ASD surgical patients. No analysis of an asymptomatic cohort has been performed. In a cohort including a breadth of ages, we found

Table 1 Demographic and radiographic data with GAP Score components for asymptomatic volunteers

	< 60 Years Old		≥ 60 Years Old		*p* value
N	58		27		
Male/female	11/47		9/18		
	Mean ± SD	Range	Mean ± SD	Range	
Age (years)	39 ± 11	22–59	67 ± 5	60–77	
Body Mass Index (kg/cm^2)	28 ± 7	19–45	27 ± 3	22–35	
GAP score	1	0–6	2	0–10	< 0.001
Thoracolumbar sagittal parameters					
Pelvic incidence (°)	50.1 ± 11.6	29–80	52.1 ± 10.2	30–74	0.45
Sacral slope (°)	37.7 ± 7.9	21–60	35.2 ± 7.6	21–55	0.18
L1-S1 lordosis (°)	59.8 ± 10.7	32–81	54.9 ± 12.1	32–75	0.07
L4-S1 lordosis (°)	37.2 ± 7.2	24–53	31.6 ± 8.1	14–45	0.002
Global tilt (°)	7.3 ± 9.0	− 14–29	13.6 ± 9.4	− 14–31	< 0.001
Gap score components					
Age	0	0–0	1	1–1	
Relative Pelvic Version (°)	− 0.5 ± 6.0	− 13.3–23.7	− 4.4 ± 5.6	− 16.3–7.6	
Median RPV score	0	0–2	0	0–3	
Relative lumbar lordosis (°)	0.4 ± 9.7	− 19.3–35.4	− 4.0 ± 13.1	− 28.5–16.7	
Median RLL score	0	0–3	0	0–3	
Lumbar Distribution Index (%)	63 ± 10	36–87	57 ± 18	3–89	
Median LDI score	0	0–3	0	0–3	
Relative spinopelvic alignment (°)	0.5 ± 6.3	-13.0 – 20.1	3.5 ± 7.2	-13.4 – 15.3	
Median RSA score	0	0–1	0	0–1	

For continuous variables, means and standard deviations are reported. For ordinal measures, median values and interquartile ranges are presented

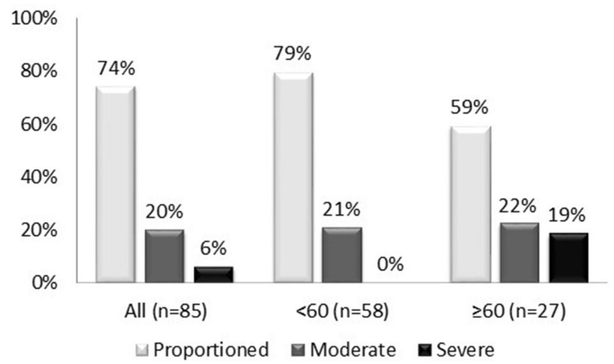

Fig. 2 Distribution of GAP score categories for all patients and as divided by age less than 60 or 60 and older

that the majority of normal asymptomatic volunteers were classified as proportioned by GAP score (0, IQ range 0–3). However, the range was from 0 to 10, with 26% of GAP scores being moderately or severely disproportioned, with all severely disproportioned volunteers being over 60 years old. Thus, age-adjusted alignment targets are distinctly opposite to targets proposed by the GAP theory.

A prior radiographic analysis of asymptomatic patients found a loss of low lumbar lordosis with a maintained sagittal vertical axis with increasing age [12]. There was an increase in segmental lordosis as one progressed distally in the lumbar spine, a precursor to the concept of L4-S1 lordosis in the GAP score. More recently, the International Spine Study Group has proposed age-adjusted alignment parameters in ASD surgery. In a comparison of ASD patients under 35 versus over 75, the older group had higher PT, more PI-LL mismatch, and higher SVA [13]. A subsequent study found that PJK rates were higher in patients who were overcorrected relative to age-adjusted sagittal targets [8].

Age-adjusted alignment goals are a matter of debate, however, as undercorrection based on age-adjusted targets may result in lower HRQOL improvement [14]. While the GAP score does include an age component, age does not change target alignment [7]. In fact, the age component was added due to the intolerance of older patients for malalignment in the original study. The validity of the GAP score has been questioned however, with other cohorts of ASD patients failing to confirm the predictive capabilities of the classification system [15]. Our results confirm that older, unfused patients tend to have different sagittal profiles with some patients living with asymptomatic lumbopelvic malalignment. Age-adjusted alignment targets may, in this case, aim to fuse patients with lumbopelvic malalignment. Thus, a dichotomy exists between the concepts of GAP and age-adjusted targets, as both are offered to improve results and decrease complications in ASD surgery.

A criticism of the GAP score is that it was developed and validated on the same population [7]. Bari et al. demonstrated no relationship between GAP score and mechanical complications, questioning the external validity of the system [15]. The GAP score more reliably predicts mechanical complications than the Schwab classification, highlighting the controversy that still exists in this arena [16]. Thus, further investigations into appropriate alignment targets are needed to determine the roles of restoring “ideal” alignment while balancing the influence of age on outcomes. This is particularly true when one considers that a balance of reduced complication rates with lower potential HRQOL may be the most appropriate option in older general [17]. Thirty-five Patients had radiographs not appropriate for measurement and the sample size of the cohort, particularly older (≥ 60 years) patients, was small. This may cause underestimation or overestimation of alignment scores. Our findings of more malalignment in the older population are consistent with prior publications; however, and we believe our results would be stable with a larger cohort [12, 18]. Finally, the volunteers for this study were drawn from an urban tertiary care center in North America, so the broad applicability of this study to other regions or ethnicities is unknown. However, several other studies suggest that any difference attributed to ethinicity is small and likely inconsequential [18–21]. ASD patients.

A limitation of this study is that no longitudinal data were available for the individual subjects. Thus, we assume that age-related progression occurs. It is possible that changes in alignment occurred at a distant time point and then remained unchanged. Similarly, we do not know if subjects became symptomatic or required treatment for spine disease. Another limitation is that the population recruited for this study was predominantly female (65/85) because gender was not a screening criterion for volunteers, though this reflects the ASD surgical population in.

Conclusion

In summary, we have calculated the GAP score for a sample of normal asymptomatic adult volunteers. Overall, the mean GAP score was proportioned, but there were many volunteers with GAP scores that were moderately or severely disproportioned, with all those severely disproportioned being over 60 years old. Age-adjusted targets may intentionally result in lumbopelvic malalignment. Thus, further refinement of individualized alignment targets and their implications for mechanical and quality of life outcomes is needed given the divergent recommendations of age-adjusted alignment and GAP alignment targets.

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Compliance with ethical standards

Conflicts of interest Dr. Lenke reports being a consultant for Medtronic (money donated to charity); receiving royalties from Medtronic and Quality Medical Publishing; receiving reimbursement for airfare and hotels from Broadwater, the Seattle Science Foundation, Stryker Spine, the Spinal Research Foundation, AOSpine, and the Scoliosis Research Society; receiving grant support from the Scoliosis Research Society (money to his institution), EOS Imaging (money to his institution), and the Setting Scoliosis Straight Foundation (money to his institution); being an expert witness for Fox Rothschild, LLC, in a patent-infringement case; receiving philanthropic research funding from the Evans family; and receiving grant and fellowship support from AOSpine (money to his institution). Dr. Kim acts as a consultant to Zimmer Biomet, K2M/Styrker and receives royalty payments from Zimmer Biomet, K2M/Stryker. Dr. Kelly receives research support paid to his institution from the Setting Scoliosis Straight Foundation and the International Spine Study Group Foundation; honoraria from The Journal of Bone and Joint Surgery.

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