Lack of joint hypermobility increases the risk of surgery in adolescent idiopathic scoliosis

Gabe Haller[a,*], Hannah Zabriskie[a,*], Shelby Spehar[a], Timothy Kuensting[a], Xavier Bledsoe[a], Ali Syed[a], Christina A. Gurnett[a,b,c] and Matthew B. Dobbs[a]

Generalized joint hypermobility (GJH) is a risk factor for developing adolescent idiopathic scoliosis (AIS); however, it is not known whether joint hypermobility influences the risk of progression to surgery. Beighton joint hypermobility scores were assessed in 570 female AIS patients. Multivariate analysis was carried out to determine whether Beighton hypermobility scores were predictors of surgical intervention. In this female AIS cohort, 24.7% (141/570) had GJH (Beighton score ≥ 4). Multivariate analysis showed that GJH did not influence the risk of surgery, although having no joint hypermobility (Beighton score = 0) increased risk (odds ratio: 1.89; $P = 0.003$). Females who had no hypermobility (score = 0) had significantly larger curves than individuals who scored at least one point on the Beighton scale [50° (interquartile range: 26) vs. 42° (interquartile range: 24), $P = 0.001$]. Evaluation of specific measures of joint hypermobility indicated that females who could not touch their palms to the floor were 2.1-fold more likely to have surgery than patients who could perform this task ($P = 0.001$). None of the other features measured on the Beighton score correlated with surgical risk. The lack of joint hypermobility increases the odds of surgery in females with AIS. Specifically, inability to touch the palms to the floor is an indicator of progression to surgery. *J Pediatr Orthop B* **27:152–158**

Journal of Pediatric Orthopaedics B 2018, **27**:152–158

Keywords: adolescent, fusion, hypermobility, juvenile, scoliosis

Departments of [a]Orthopaedic Surgery, [b]Neurology and [c]Pediatrics, Washington University, St Louis, Missouri, USA

Correspondence to Matthew B. Dobbs, MD, One Children's Place, Suite 4S60, Washington University School of Medicine, St Louis 63110, Missouri, USA
Tel: +1 314 454 4814; fax: +1 314 454 4817;
e-mail: dobbsm@wudosis.wustl.edu

*Gabe Haller and Hannah Zabriskie contributed equally to the writing of this article.

Introduction

Adolescent idiopathic scoliosis (AIS) is characterized by a lateral curvature of the spine of greater than 10°. Approximately 0.3% of adolescents have scoliosis greater than 20° requiring specialist treatment and more than one in 10 000 children have severe spine deformity requiring surgical correction [1]. Several factors influence AIS risk and/or severity, including sex, age of onset, menarcheal status, curve type/characteristics, and skeletal maturity [2–4]. However, factors responsible for curve progression are incompletely understood, and it remains difficult to predict which patients will ultimately require surgery.

Joint hypermobility is a risk factor for developing scoliosis. In females with AIS, generalized joint hypermobility (GJH) is increased compared with controls (23.2 vs. 13.4%) [5]. Joint hypermobility is a common feature of many hereditary disorders of connective tissues and measures of joint hypermobility are part of the diagnostic criteria for Marfan syndrome [6], Ehlers–Danlos syndrome [7], and many other related disorders [8]. Scoliosis, clubfoot, hip dysplasia, and other musculoskeletal complaints are common in these disorders [9,10]; therefore, orthopedic surgeons encounter these patients frequently in clinical practice.

The increased prevalence of joint hypermobility in AIS suggests a role for extracellular matrix and connective tissues in the pathogenesis of idiopathic scoliosis, which has been confirmed in genome-wide association studies of rare genetic variants [11,12]. Consistent observations that joint hypermobility is more common in females [13,14] also support the possibility that these factors contribute toward the sex imbalance of severe scoliosis.

Although joint hypermobility is a risk factor for scoliosis, few studies have addressed the relationship between joint hypermobility and scoliosis curve progression. To determine the effect of joint hypermobility and its individual components on AIS curve severity and the risk of surgery, we assessed Beighton hypermobility scores in a large cohort of AIS patients.

Patients and methods

Patients

Patients were recruited prospectively from orthopedic surgery clinics at St Louis Children's Hospital and Shriners Hospital for Children, St Louis over a 10-year period (2005–2015). Three trained research coordinators (H.Z., S.S., T.K.) carefully prescreened the scoliosis clinics at both hospitals each week to generate lists of potential study participants. Then, in partnership with

1060-152X DOI: 10.1097/BPB.0000000000000489

Table 1 Demographics of female adolescent idiopathic scoliosis patients

	Total ($N=570$)	Nonsurgical females ($N=340$)	Surgical females ($N=230$)	P
Cobb angle				
Mean (SD)	44.65° (19.0)	33.05° (11.36)	61.8° (14.5)	**<0.0001**
Median (IQR)	45° (26)	32.0° (15.5)	59° (12)	
Beighton				
Mean (SD)	2.17 (2.0)	2.39 (1.96)	1.85 (2.02)	**0.0001**
Median (IQR)	2 (3)	2 (3)	2 (3)	
Age				
Mean (SD)	16.48 (2.77)	15.7 (2.3)	17.64 (3.0)	**<0.0001**
Median (IQR)	16.01 (3.9)	15.2 (3.35)	17.4 (4.11)	

IQR, interquartile range.
Bold values means statistically significant ($P > 0.05$).

scoliosis providers in the clinics, potential study participants were approached, eligibility was confirmed, and patients were recruited. Beighton joint hypermobility scores were measured on 821 AIS patients. To minimize confounding of sex and age, which are known to affect Beighton scores, males and patients younger than 12 and older than 25 years of age were excluded. These exclusions left a total of 570 females (Table 1). Over this period of time, not all participants who fulfilled the inclusion criteria were recruited because of large numbers of patients and the inability of coordinators to be at every clinic. More than 90% of those who fulfilled the inclusion criteria and were approached agreed to participate in the study. Hereafter, all data referring to 'patients' will refer to this female age-restricted cohort.

This study was approved by the Institutional Review Board and consent was obtained from all participants and/or their parents. All patients had juvenile or AIS with spinal curves measuring greater than or equal to 10°. Curve measurements are reported for the maximum lateral spinal curve using the Cobb method [15]. Patients with developmental delay, multiple congenital anomalies, or known underlying genetic disorders (e.g. Ehlers–Danlos syndrome, Marfan syndrome) were excluded from this study. Of the 570 participants, 230 had either already undergone spinal fusion at the time of enrollment or undergone surgery at some point during the time frame of the study because of curve progression. Of the remaining 340 nonsurgical patients, most had nonprogressive curves, although 63 patients had curves greater than 45° Cobb angle, but were never surgically treated. The ethical committee at the Washington University School of Medicine has approved this study.

Beighton joint hypermobility scoring

Joint hypermobility was assessed once by one of the three trained research coordinators during an evaluation with an orthopedic surgeon using the Beighton scoring system [13]. The Beighton score assesses the ability to touch the palms to the floor with straight knees (one point) and hyperextension of the knees (two points), elbows (two points), thumb (two points), and little finger (two points), for a total possible score of nine points (Fig. 1). GJH was diagnosed for scores of 4 or higher on the nine-point Beighton score [16].

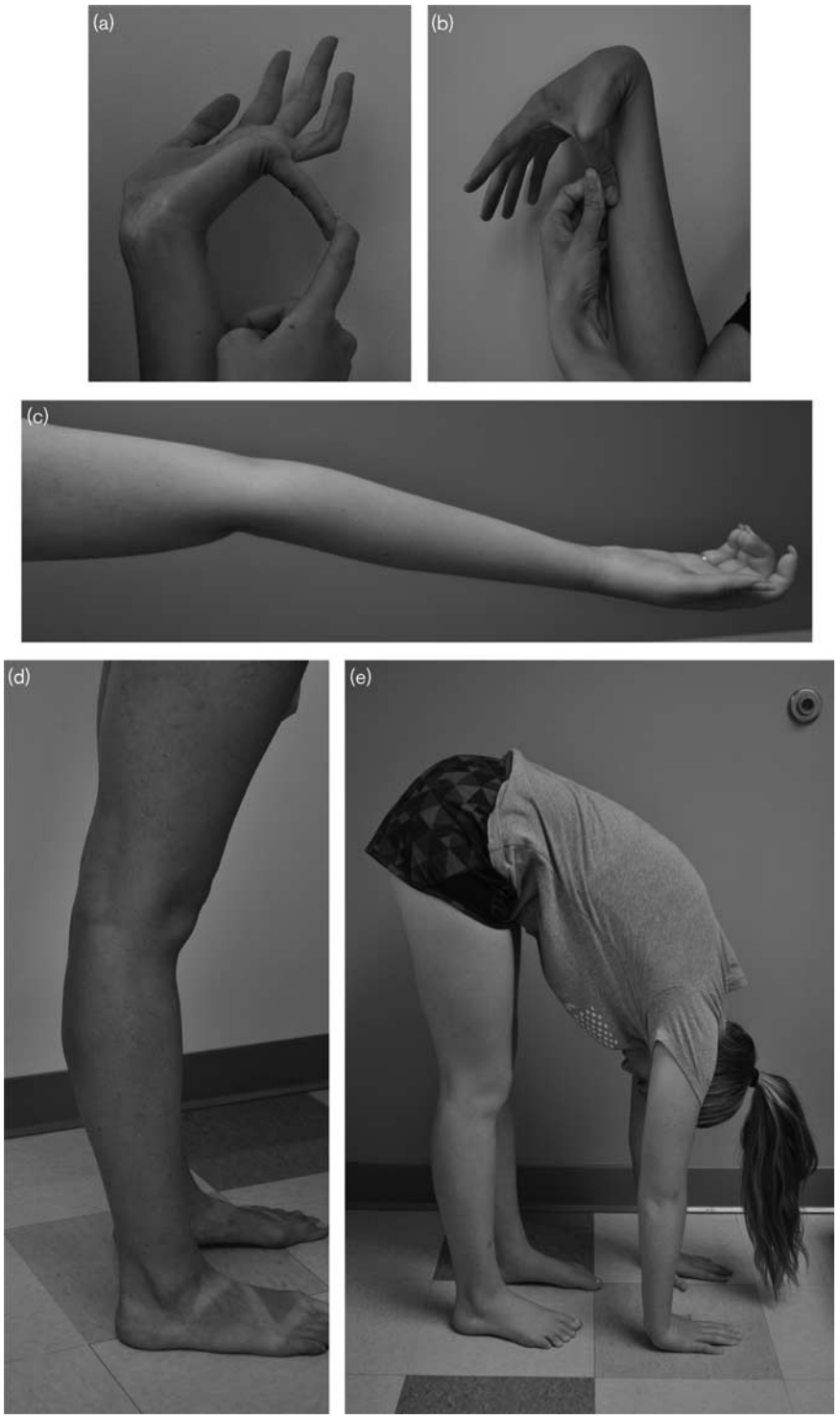
Statistical analysis

All analyses were carried out in SAS 9.4 software. Patients were divided into two groups for analysis on the basis of whether or not they had surgical treatment. Correlations and partial correlations were calculated using Spearman's rank correlation. Comparisons between the Cobb angle and the Beighton score between the two groups were performed using Wilcoxon's rank sum tests because of skewed data. Two-sample t-tests were used for comparisons between ages among groups. Linear and logistic regressions were also used.

Results

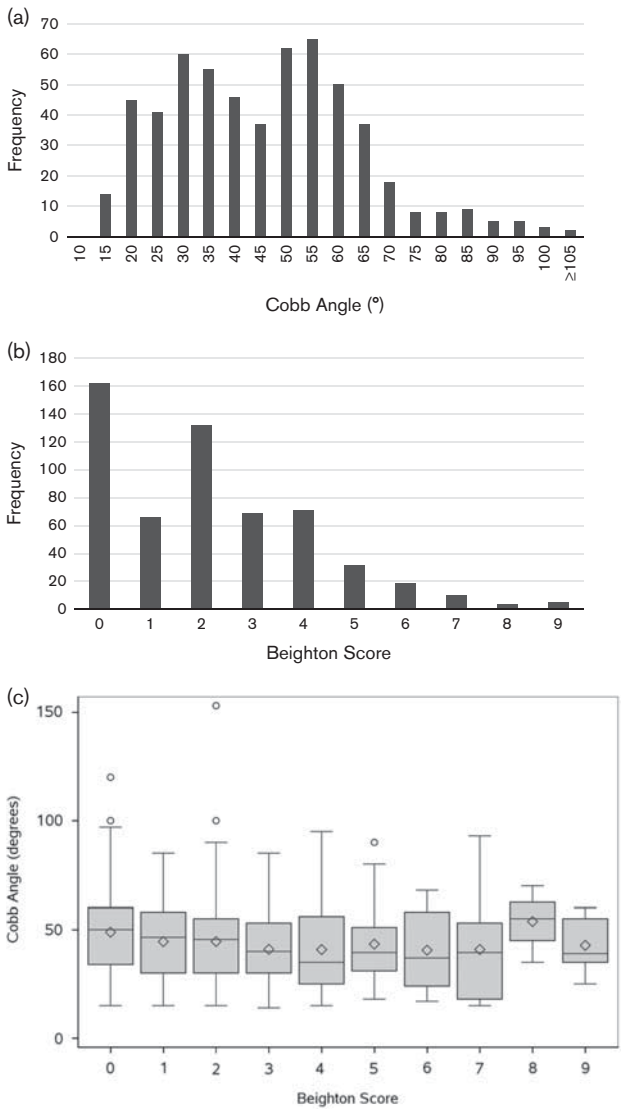
This patient cohort consisted of 570 AIS cases with a range of spinal curvatures from 15° to 105° (Fig. 2a). As expected, surgically treated patients were older and had a higher median Cobb angle (Table 1). Scores of at least one on the Beighton scale occurred in 71.6% (408/570) of all patients in this cohort (Fig. 2b). GJH, defined as a Beighton score of four or higher [17], was present in 25% (141/570) of patients, although the data were skewed, with significantly more individuals having lower scores. The mean Beighton score was significantly lower in surgical compared with nonsurgical patients ($P=0.0001$) (Table 1). A weak negative correlation was noted between the Beighton score and age ($r_{sp}=-0.1641$; $P=0.0001$), reflecting loss of flexibility with age. There was also a weak negative correlation between the Beighton score and the Cobb angle ($r_{sp}=-0.1454$; $P=0.0005$) that remained significant even when controlling for age ($r_{s(partial)}=-0.103$; $P=0.014$) (Fig. 2c). Scoring no points on the Beighton scale was associated with a significantly larger spinal curve [50° (interquartile range (IQR: 26) vs. 42° (IQR: 24); $P=0.001$]. Patients with GJH (score ≥ 4) had smaller curves compared with those with lower scores, although the difference was less significant [38° (IQR: 26) vs. 46° (IQR: 28); $P=0.03$]. Patients with surgical curves (defined as a curve of $\geq 45°$) had significantly less flexibility than their counterparts with smaller curves, although the difference was less than a full point on the Beighton scale (mean Beighton:

Fig. 1



Components of the Beighton joint hypermobility score. The Beighton score assesses hyperextension of (a) the little finger (two points), (b) the thumb (two points), (c) the elbow (two points), and (d) the knees (two points), and (e) the ability to touch the palms to the floor with straight knees (one point) for a total possible score of nine points.

Fig. 2



Relationship of the Beighton score and the Cobb angle in the female adolescent idiopathic scoliosis (AIS) study cohort. (a) Number of AIS patients by Cobb angle in surgical and nonsurgical groups. Surgically treated AIS patients had a higher mean Cobb angle compared with the nonsurgically treated group (62 vs. 33°) ($P<0.0001$). (b) Number of AIS patients by the Beighton score in surgical and nonsurgical groups. The median Beighton score was significantly lower in surgical compared with nonsurgical patients (2.2 vs. 2.4) ($P=0.0001$). (c) Relationship between the Beighton score and the Cobb angle. The Beighton score and the Cobb angle were negatively correlated ($r_{sp}=-0.1454$; $P=0.0005$) even when controlling for age ($r_{s(partial)}=-0.103$; $P=0.014$).

2.4 ±2.0 vs. 2.0±2.0) ($P=0.002$). To control for the effects of age on both hypermobility and maximal spinal curve, multivariate analysis including age as a variable was carried out to determine whether joint hypermobility was predictive of an increased risk of surgical intervention. As expected, age was a strong predictor of surgical intervention ($P<0.0001$) (Table 2). In multivariate analysis, the presence of GJH was not predictive of surgical intervention ($P=0.90$), although scoring greater than or equal to 1 point on Beighton was associated with a 1.89-fold decreased risk of surgery ($P=0.003$).

To determine whether individual components of the Beighton score were predictors of surgery, odds ratios (ORs) were calculated for each (Table 3). Patients who could not touch their palms to the floor with their knees straight were 2.1 times more likely to have surgery, when controlling for age (OR: 2.1; 95%CI: 1.34, 3.22; $P=0.001$). This was supported by a logistic regression utilizing backward variable selection, in which the only predictors remaining in the model were the ability to palm the floor ($P=0.0005$) and age ($P<0.0001$), which together explained 71% of the variance. None of the other individual components of the Beighton score were predictors of surgical intervention.

Because of the concern that surgery could affect the ability of a patient to touch their palms on the floor, we repeated the analysis after excluding 133 patients for whom the measurement was obtained postoperatively. Measurements had been taken at least 6 months after surgery when activity was no longer restricted. Multivariate analysis using this cohort of 437 AIS patients showed that scoring 0 on the Beighton test resulted in a 1.9-fold increase in the risk for surgery (OR: 1.95; 95%CI: 1.15, 3.30; $P=0.01$) compared with individuals who scored greater than or equal to 1. More specifically, being unable to touch palms to the floor resulted in a 2.5-fold increase in the risk of surgery, when controlled for age (OR: 2.5; 95%CI: 1.37, 4.6; $P=0.003$). These data are consistent with the data obtained on the entire cohort and suggest that spinal surgery did not significantly alter the joint hypermobility measurements.

Discussion

Although joint hypermobility is more frequent in patients with AIS [5,18], the current study suggests, paradoxically, that having at least some hypermobility is protective against scoliosis progression. Overall, we found that the lack of any joint hypermobility, which occurred in 28% of patients who could not complete any of the tasks and scored 0 on the Beighton measurements, predicted a nearly two-fold increased risk of progression to surgery that was associated with, on average, an 8° greater Cobb angle. Although Czaprowski found no association of GJH with scoliosis severity, we reported significantly smaller curves in AIS patients with GJH perhaps because of our much larger sample size [5]. Interestingly, we noted that patients at the extreme end of the hypermobility spectrum (Beighton scores > 7) who make up an even smaller subgroup appeared to have greater Cobb angles and higher rates of surgery, suggesting that the degree of hypermobility and the specific underlying mechanism responsible for scoliosis/hypermobility may also influence scoliosis progression independently.

Table 2 Effect of generalized joint hypermobility or some joint hypermobility on the risk of surgical intervention for adolescent idiopathic scoliosis

		Univariate analysis		Multivariate analysis	
Characteristics	*N*	*P* value	OR (95%CI)	*P* value	OR (95%CI)
Beighton score of 0	162	**0.0001**	2.07 (1.43, 3.00)	**0.0031**	1.89 (1.24, 2.87)
Lack of GJH (<4 points)	429	0.0510	1.41 (0.83, 2.42)	0.9019	0.97 (0.62, 1.54)
Age	570	**<0.0001**	1.32 (1.23, 1.41)	**<0.0001**	1.31 (1.22, 1.40)

CI, confidence interval; GJH, generalized joint hypermobility; OR, odds ratio.
Bold values means statistically significant ($P > 0.05$).

Table 3 Effect of individual measures of joint hypermobility on the risk of surgical intervention for adolescent idiopathic scoliosis

		Univariate analysis		Multivariate analysis	
Characteristics	*N*	*P* value	OR (95%CI)	*P* value	OR (95%CI)
Inability to:					
Palm the floor	424	**0.0003**	2.15 (1.43, 3.25)	**0.0011**	2.08 (1.34, 3.22)
Hyperextend knees	502	0.1539	1.48 (0.86, 2.53)	0.7226	1.11 (0.62, 2.02)
Hyperextend elbows	425	**0.0401**	1.51 (1.02, 2.25)	0.1013	1.44 (0.93, 2.22)
Thumbs touch wrist	387	0.0724	1.40 (0.97, 2.01)	0.2866	1.25 (0.83, 1.89)
Little finger past 90°	457	0.4415	1.18 (0.77, 1.81)	0.3516	0.80 (0.50, 1.28)
Age	570	**<0.0001**	1.32 (1.23, 1.41)	**<0.0001**	1.32 (1.23, 1.42)

CI, confidence interval; OR, odds ratio.
Bold values means statistically significant ($P > 0.05$).

The mechanism by which having some joint hypermobility protects against scoliosis progression may be spinal flexibility because the ability to palm the floor was the only individual task of the Beighton score that predicted reduced progression to surgery. The other components of the Beighton score measure only joint hypermobility of the extremities. The ability to palm the floor reflects flexibility of multiple joints, including hips, lumbar spine, and shoulders as well as the trunk and extremity length [19,20]. As a measure of spinal flexibility, it suggests that patients with this ability may have intrinsic protection from scoliosis progression or have spinal curves that respond better to bracing. To support the latter, previous studies have shown that curve flexibility, as measured by the degree of correction while in brace, correlates negatively with progression to surgery [21–23]. Future studies to determine whether the ability to palm the floor corresponds with the degree of correction in brace are needed to support the hypothesis that the protective effect of joint hypermobility/spinal flexibility is because of the positive response to bracing that it confers.

Our study has some limitations. We did not have the ability to recruit every patient who fulfilled the inclusion criteria over the 10-year period, which raises concerns of selection bias for patients with severe curves in our cohort. To exclude the possibility that our results were confounded by the impact of spinal fusion surgery on the ability to palm the floor, we found nearly identical results by restricting our analysis to patients in whom the measurements were made preoperatively. However, the major limitation of the study is that we cannot account for the possibility that spinal curves themselves could reduce the overall length of spine or mechanically impair spinal flexibility, which may affect the ability to palm the floor. Although previous studies have shown that the spine is more flexible in mild scoliosis [24], spines with a larger curve angle and an apical vertebral rotation show less flexibility, at least on supine bending films [25]. It remains unknown whether the reduced flexibility of severe curves is itself present before curve progression is a secondary outcome of mechanical changes because of the scoliosis. An ideal prospective study design would assess Beighton scores at the beginning of treatment, when curves are small, or before curve progression to eliminate this potential confounder. As Beighton scores are measured on all patients recruited for our genetic studies, we will eventually have data and long-term follow-up from a sufficiently large cohort of patients for whom measurements were made early in their course to be able to answer this question.

As a screening tool, Beighton joint hypermobility scores take less than 60 s to administer, have no direct cost, are noninvasive and quantitative, and highly reliable. Because inability to touch the palms flat to the floor was the only component predictive of progression to surgery, our data suggest that it may be sufficient to test for this task alone. In addition to their utility in predicting scoliosis progression, higher Beighton scores indicate patients at risk for Ehlers–Danlos syndrome [7], GJH [16], and many other related disorders [8]. Thus, implementation of this screening tool may improve identification of patients with hereditary disorders of

connective tissue who would benefit from genetics referral for a definitive diagnosis.

Clinical measures of joint hypermobility will eventually be supported by genetic tests that provide diagnostic specificity. Although pathogenic variants in genes responsible for hereditary disorders of connective tissue will occasionally be identified in patients believed to have idiopathic scoliosis, our genetic data suggest that AIS patients with variants in these genes only rarely have the full syndrome [26], although these do contribute toward isolated skeletal abnormalities. Furthermore, we have previously shown that patients with AIS harbor more rare variants in connective tissue genes compared with controls, particularly in collagen and fibrillin genes that are responsible for Ehlers–Danlos syndrome and Marfan syndrome [11,12]. Accumulation of rare variants in more than one extracellular matrix gene is also associated with higher Beighton joint hypermobility scores [11]; therefore, our previous genetic data support a common etiology for both joint hypermobility and AIS.

Overall, this observational study suggests that lack of joint hypermobility is a risk factor for idiopathic scoliosis progression to surgery. GJH with increased flexibility at multiple joints is not required as most protection was conferred by the ability to touch the palms to the floor, which decreases the risk of surgery by two-fold. This simple measure of flexibility is a useful and easy-to-implement clinical predictor of curve progression for female AIS patients. Longitudinal data are needed to determine whether the ability to touch the palms to the floor changes during treatment is protective in males or predicts response to bracing. Our findings are an important step toward the development of personalized treatment strategies for AIS patients on the basis of better assessment of the individual risk of curve progression.

Acknowledgements

The authors would like to acknowledge the patients who participated in this study as well as Dr Munish Gupta, Dr Keith Bridwell, Dr Mike Kelly, Dr Scott Luhmann, Dr Brian Kelly, Dr Luke Zebala, and Christi Abeln, APRN. This research was supported by the Marfan Foundation Faculty Grant (81831) and the University of Missouri Spinal Cord Injuries Research Program (14-03). Research reported in this publication was also supported by the National Institute of Arthritis and Musculoskeletal and Skin Disease award number R01AR067715-01 and the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health under award number U54 HD087011 to the Intellectual and Developmental Disabilities Research Center at Washington University and the Washington University Institute of Clinical and Translational Sciences grant UL1 TR000448 from the National Center for Advancing Translational Sciences (NCATS) of the National Institutes of Health (NIH). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

M.B.D. and C.A.G. have received funding for the study from the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institute of Health under award number (R01 AR067715-01), the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health under award number U54 HD087011 to the Intellectual and Developmental Disabilities Research Center at Washington University (CAG), the Marfan Foundation (CAG), and the University of Missouri Spinal Cord Injuries Program (CAG). M.B.D. is a consultant for D-Bar Enterprises.

Conflicts of interest

There are no conflicts of interest.

References

1 Lonstein JE. Adolescent idiopathic scoliosis. *Lancet* 1994; **344**:1407–1412.
2 Lonstein JE, Carlson JM. The prediction of curve progression in untreated idiopathic scoliosis during growth. *J Bone Joint Surg Am* 1984; **66**:1061–1071.
3 Sanders JO, Browne RH, McConnell SJ, Margraf SA, Cooney TE, Finegold DN. Maturity assessment and curve progression in girls with idiopathic scoliosis. *J Bone Joint Surg Am* 2007; **89**:64–73.
4 Peterson LE, Nachemson AL. Prediction of progression of the curve in girls who have adolescent idiopathic scoliosis of moderate severity. Logistic regression analysis based on data from The Brace Study of the Scoliosis Research Society. *J Bone Joint Surg Am* 1995; **77**:823–827.
5 Czaprowski D. Generalised joint hypermobility in caucasian girls with idiopathic scoliosis: relation with age, curve size, and curve pattern. *Scientific World J* 2014; **2014**:370134.
6 Loeys BL, Dietz HC, Braverman AC, Callewaert BL, De Backer J, Devereux RB, *et al.* The revised Ghent nosology for the Marfan syndrome. *J Med Genet* 2010; **47**:476–485.
7 Beighton P, De Paepe A, Steinmann B, Tsipouras P, Wenstrup RJ. Ehlers-Danlos syndromes: revised nosology, Villefranche, 1997. Ehlers-Danlos National Foundation (USA) and Ehlers-Danlos Support Group (UK). *Am J Med Genet* 1998; **77**:31–37.
8 Tofts LJ, Elliott EJ, Munns C, Pacey V, Sillence DO. The differential diagnosis of children with joint hypermobility: a review of the literature. *Pediatr Rheumatol Online J* 2009; **7**:1.
9 Sponseller PD, Hobbs W, Riley LH 3rd, Pyeritz RE. The thoracolumbar spine in Marfan syndrome. *J Bone Joint Surg Am* 1995; **77**:867–876.
10 Beighton P, Horan F. Orthopaedic aspects of the Ehlers-Danlos syndrome. *J Bone Joint Surg Br* 1969; **51**:444–453.
11 Haller G, Alvarado D, McCall K, Yang P, Cruchaga C, Harms M, *et al.* A polygenic burden of rare variants across extracellular matrix genes among individuals with adolescent idiopathic scoliosis. *Hum Mol Genet* 2016; **25**:202–209.
12 Buchan JG, Alvarado DM, Haller GE, Cruchaga C, Harms MB, Zhang TX, *et al.* Rare variants in FBN1 and FBN2 are associated with severe adolescent idiopathic scoliosis. *Hum Mol Genet* 2014; **23**:5271–5282.
13 Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. *Ann Rheum Dis* 1973; **32**:413–418.
14 Clinch J, Deere K, Sayers A, Palmer S, Riddoch C, Tobias JH, *et al.* Epidemiology of generalized joint laxity (hypermobility) in fourteen-year-old children from the UK: a population-based evaluation. *Arthritis Rheum* 2011; **63**:2819–2827.
15 Cobb JR. The problem of the primary curve. *J Bone Joint Surg Am* 1960; **42-A**:1413–1425.
16 Grahame R, Bird HA, Child A. The revised (Brighton 1998) criteria for the diagnosis of benign joint hypermobility syndrome (BJHS). *J Rheumatol* 2000; **27**:1777–1779.

17 Hakim A, Grahame R. Joint hypermobility. *Best Pract Res Clin Rheumatol* 2003; **17**:989–1004.
18 Czaprowski D, Kotwicki T, Pawlowska P, Stolinski L. Joint hypermobility in children with idiopathic scoliosis: SOSORT award 2011 winner. *Scoliosis* 2011; **6**:22.
19 Perret C, Poiraudeau S, Fermanian J, Colau MM, Benhamou MA, Revel M. Validity, reliability, and responsiveness of the fingertip-to-floor test. *Arch Phys Med Rehabil* 2001; **82**:1566–1570.
20 Corben T, Lewis JS, Petty NJ. Contribution of lumbar spine and hip movement during the palms to floor test in individuals with diagnosed hypermobility syndrome. *Physiother Theory Pract* 2008; **24**:1–12.
21 Katz DE, Durrani AA. Factors that influence outcome in bracing large curves in patients with adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2001; **26**:2354–2361.
22 Upadhyay SS, Nelson IW, Ho EK, Hsu LC, Leong JC. New prognostic factors to predict the final outcome of brace treatment in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 1995; **20**:537–545.
23 Castro FP Jr. Adolescent idiopathic scoliosis, bracing, and the Hueter-Volkmann principle. *Spine J* 2003; **3**:180–185.
24 Galvis S, Burton D, Barnds B, Anderson J, Schwend R, Price N, *et al*. The effect of scoliotic deformity on spine kinematics in adolescents. *Scoliosis Spinal Disord* 2016; **11**:42.
25 Ameri E, Behtash H, Mobini B, Daraie A. Predictors of curve flexibility in adolescent idiopathic scoliosis: a retrospective study of 100 patients. *Acta Med Iran* 2015; **53**:182–185.
26 Haller GE, Alvarado DM, Willing MC, Bridwell KH, Kelly M, Luhmann SJ, *et al*. Genetic risk for aortic aneurysm in adolescent idiopathic scoliosis. *J Bone Joint Surg Am* 2015; **97**:1411–1417.