

Received: 2019.07.17

Accepted: 2019.09.09

Published: 2019.12.17

# Correction of Scoliosis with Large Thoracic Curves in Marfan Syndrome: Does the High-Density Pedicle Screw Construct Contribute to Better Surgical Outcomes

Authors' Contribution:

Study Design A  
Data Collection B  
Statistical Analysis C  
Data Interpretation D  
Manuscript Preparation E  
Literature Search F  
Funds Collection G

ABCDEF **Dengxu Jiang**  
ADF **Zhen Liu**  
ADFG **Huang Yan**  
ADF **Jie Li**  
ADF **Changchun Tseng**  
ADF **Yiwen Yuan**  
ADF **Yong Qiu**  
ACDFG **Ze Zhang Zhu**

Department of Spine Surgery, The Affiliated Drum Tower Hospital of Nanjing University Medical School, Nanjing, Jiangsu, P.R. China

**Corresponding Author:** Ze Zhang Zhu, e-mail: zhuzhang@126.com

**Source of support:** This work was supported by the Fundamental Research Funds for the Central Universities (Grant No. 021414380313) and the Youth Fund of the National Natural Science Foundation (Grant No. 81702234), and was supported by the Nanjing Clinical Medical Center and Jiangsu Provincial Key Medical Center

**Background:** The aim of this study was to determine whether higher density screw constructs resulted in better surgical outcomes in patients with scoliosis secondary to Marfan syndrome (MF-S) with large thoracic curves ( $\geq 70^\circ$ ).


**Material/Methods:** There were 34 MF-S patients who met the inclusion criteria and were evaluated radiographically before surgery, 2 weeks after operation, and at the final follow-up. The mean screw density was taken as the boundary, and patients were categorized as either in the high density (HD) group or the low density (LD) group. Parameters measured included coronal Cobb angle, T5–T12 kyphosis (TK), and T12–S1 lordosis (LL). Additionally, the operation duration, estimated blood loss, screw accuracy, complication rate, and clinical outcomes were compared between the 2 groups.

**Results:** The mean screw density of all patients was  $1.40 \pm 0.15$  (range 1.13 to 1.67). Correction rate of the thoracic curve was closely related to the screw density at the concave side ( $r=0.783$ ,  $P=0.007$ ). Intergroup comparison showed a significantly higher correction rate of the thoracic coronal curve in HD group ( $56.59 \pm 4.80\%$  versus  $44.54 \pm 9.61\%$ ,  $P=0.036$ ). At last follow-up, coronal correction loss of  $>5^\circ$  occurred in 8 cases (47.1%) in the LD group and 3 cases (17.6%) in the HD group. Both groups demonstrated improvement in each domain of the SRS-22 questionnaire after surgery and no significant intergroup difference was found.

**Conclusions:** The high-density pedicle screw construct contributed to the significantly improved correction rate of thoracic curves in MF-S patients with large thoracic curves ( $\geq 70^\circ$ ). Additionally, increasing of pedicle screw number could help to enhance the structural stability and reduce the correction loss during the follow-up period.

**MeSH Keywords:** Marfan Syndrome • Orthopedic Procedures • Scoliosis • Surgical Instruments

**Full-text PDF:** <https://www.medscimonit.com/abstract/index/idArt/918829>

 3213

 4

 2

 27



## Background

Marfan syndrome (MF-S) is a disorder caused by a mutation in the fibrillin-1 gene that affects the connective tissue [1]. About 52% to 63% of patients with MF-S are reported to be diagnosed with scoliosis [2]. Unlike idiopathic scoliosis, patients with MF-S have a reduced laminar thickness, thinner pedicles, and decreased bone mineral density [3,4]. Although pedicle screw constructs have been proven to be superior for surgical treatment of scoliosis [5], it has been suggested that insertion of pedicle screws in patients with scoliosis secondary to MF-S is more likely to result in neurological, vascular, or visceral damage due to the dystrophic pedicles [34], leading to lower screw density. Additionally, osteopenia may also weaken fixation stability. These factors are thought to account for the significantly higher number of reoperations and instrumentation-related complications in MF-S compared to adolescent idiopathic scoliosis [6,7].

In the last several years, a number of different intraoperative imaging platforms such as O-arm based navigation systems have been developed to permit safer and more accurate pedicle screw insertion [8–10]. With the assistances of navigation systems, higher-density pedicle screw constructs tended to be used and have been assessed as being capable of improving outcomes for the surgical treatment of idiopathic scoliosis [11–15]. Moreover, in dystrophic scoliosis secondary to neurofibromatosis type 1 (NF1-S), Li et al. found a superior mean coronal correction rate and less postoperative correction loss in patients with higher implant density [16]. Currently, however, there is still uncertainty about whether higher screw density results in improved surgical outcomes in MF-S.

Theoretically, the addition of fixation screws can provide a stronger pullout force during the rod rotation procedure [17]. This effect may be more pronounced with an increase in the screw number at the concave side of the curve, as most maneuvers are performed on the concave rod [18]. On the other hand, higher screw density can alleviate the load borne by every single instrumentation-bone contact, which is likely to limit the occurrence of instrumentation-related complications, such as rod fracture, in MF-S. Additionally, in a biomechanical study conducted by Wang et al., the bone-screw forces in curves of higher Cobb angles was found to be more sensitive to screw density [19]. Hence, we speculated that, in MF-S with large thoracic curves, in which the spine was more rigid and the vertebral axial rotation was larger than that of mild to moderate curves [20,21], a higher screw density construct might contribute to better surgical outcomes.

To date, no studies have assessed how screw density affects surgical outcomes in MF-S patients with large thoracic curves ( $\geq 70^\circ$ ). Therefore, in this study, we attempt to explore the

effect of high-density pedicle screw constructs on the deformity correction and clinical outcomes in MF-S patients with large thoracic curves.

## Material and Methods

### Patient population

Under the approval of local Institutional Review Board, the patient cases with MF-S undergoing one-stage posterior correction surgery from June 2008 to December 2015 at our center were reviewed. The diagnoses were made according to the Ghent nosology [22]. Patients were enrolled if they had thoracic curves  $\geq 70^\circ$  [21], underwent posterior deformity correction surgery with all pedicle screw constructs, had no history of spine surgery, and had more than 2 years of postoperative follow-up. Patients receiving halo traction or 3-column osteotomies treatment were excluded from the study.

### Clinical and radiographic evaluation

Using long-cassette standing posteroanterior and lateral radiographs, patients enrolled in the study were evaluated radiographically before surgery, 2 weeks after operation, and at the most recent follow-up. Radiographical parameters included coronal Cobb angle, T5–T12 kyphosis (TK) and T12–S1 lordosis (LL). In order to avoid the possibility of bias caused by the preference of spine surgeons on high-density or low-density spinal constructs, all measurements were performed in a blinded fashion by 2 independent radiologists to minimize bias. Preoperative flexibility was calculated based on left and right side-bending radiographs. Change of sagittal parameters (TK and LL) was calculated by subtracting the magnitude of preoperative TK and LL from the magnitude of early postoperative (2 weeks after surgery) TK and LL. Coronal and sagittal correction loss were calculated by subtracting the magnitude of the early postoperative Cobb angle from the magnitude of that at latest follow-up. The screw density was expressed as the number of screws instrumented per level [11].

Postoperative computed tomography (CT) scanning was ordered for all MF-S patients. An assessment of screw accuracy was conducted by 2 independent attending surgeons using the Gertzbein classification [23]: grade 0 (screws were completely within the pedicle), grade 1 (penetration  $< 2$  mm), grade 2 (penetration between 2 and 4 mm) and grade 3 (penetration  $> 4$  mm). Grades 0 and 1 were considered to be satisfactory (screws in), whereas grades 2 and 3 ( $> 2$  mm) were considered to be perforations (screws out). When there was a disagreement between these 2 attending surgeons, a third senior spinal surgeon was consulted to determine the final result.

In this study, the assessment of clinical outcomes was based on the Scoliosis Research Society (SRS)-22 questionnaire completed by patients preoperatively and at the latest follow-up. Any complications occurring either perioperatively or during the follow-up period were recorded.

### Surgical procedures

After successful general anesthesia, a standard posterior mid-line incision was made, and anatomical exposure of the spine was performed. Pedicle screws were placed using an O-arm navigation or free-hand technique. The screw density used was mainly depend on the degree of difficulties with screw placement. Only when the path for the pedicle screw was evaluated to be safe, the insertion would be performed. In all patients, a pre-contoured concave rod was first placed, followed by a rod on the convex side. Curve correction was performed via rod rotation or *in situ* translational correction. Posterior fusion was achieved using autogenous local bone grafts in combination with cortical and cancellous allograft. All surgeries were performed by 2 senior spine surgeons (YQ and ZZ). The somatosensory and motor evoked potentials (SSEP and MEP) were monitored continuously intraoperatively. If any deterioration of SSEP or MEP occurred, the correction procedure would be stopped. Before closure, a wake-up test was routinely performed.

### Statistical analysis

Data analysis was performed using SPSS statistical software (SPSS Inc., Chicago, IL, USA). The correlation analysis was conducted by using Pearson correlation test and bivariate analysis. Differences between pre- and post-operative and follow-up measures were evaluated by means of the paired *t*-test. Using the mean number of screws per level of all patients ( $1.40 \pm 0.15$ ) as the boundary [14], patients were separated into 2 groups as follows: the high density (HD) group was composed of those with a screw density  $\geq 1.40 \pm 0.15$ , and the low density (LD) group included those in whom the screw density was  $< 1.40 \pm 0.15$ . Independent sample *t*-test was applied for comparing patient demographics and radiographic parameters between the 2 groups. Significance was set at  $P=0.05$ .

## Results

There were 34 patients (14 males and 20 females) with an average age of 13.9 years (range 10 to 19 years) who met the inclusion criteria and were reviewed in our study. The mean number of fused levels was  $13.50 \pm 0.85$  (range 12 to 15), with a mean screw density of  $1.40 \pm 0.15$  (range 1.13 to 1.67). The proximal fusion level was T2 in 2 case, T3 in 9 cases, T4 in 18 cases, and T5 in 5 cases. The distal fusion level was L2 in 1 case, L3 in

5 cases, L4 in 25 cases, and L5 in 3 cases. The O-arm surgical imaging system was recorded to be used in a total of 14 patients with a higher mean screw density of  $1.50 \pm 0.10$  compared to those operated with free-hand ( $1.29 \pm 0.12$ ,  $P=0.019$ ). The mean length of follow-up was 37.1 months (range 24 to 84 months). Baseline data of all the patients are summarized in Table 1. Mean flexibility of the thoracic coronal curve was  $18.17 \pm 9.80\%$  (range 6.10% to 33.00%). Average thoracic coronal Cobb angle decreased from  $85.03 \pm 9.56^\circ$  (range  $73^\circ$  to  $100^\circ$ ) preoperatively to  $40.47 \pm 9.52^\circ$  (range  $27^\circ$  to  $57^\circ$ ,  $P<0.001$ ) post-operatively, the mean correction rate was 50.67%. On the sagittal plane, thoracic hypokyphosis ( $T5-T12 < 15^\circ$ ) and hyperkyphosis ( $T5-T12 > 50^\circ$ ) was present in 10 patients ( $7.89 \pm 4.58^\circ$ , range  $3^\circ$  to  $15^\circ$ ) and 7 patients ( $65.96 \pm 5.45^\circ$ , range  $59^\circ$  to  $72^\circ$ ), respectively, before surgery. After surgery, the magnitude of TK increased to  $17.70 \pm 3.65^\circ$  (range  $12^\circ$  to  $21^\circ$ ,  $P=0.006$ ) in hypokyphotic patients and decreased to  $43.17 \pm 7.96^\circ$  (range  $32^\circ$  to  $50^\circ$ ,  $P=0.006$ ) in the 7 patients with hyperkyphosis. At last follow-up, a total of 11 patients had a coronal thoracic correction loss of  $>5^\circ$  (range  $5^\circ$  to  $7^\circ$ ). A slight increase of TK was found in the 10 patients with hypokyphosis ( $19.17 \pm 5.78^\circ$  at latest follow-up). For the remaining patients, the coronal and sagittal deformity correction were maintained in the follow-up period.

Then, using the mean screw density as the boundary [14], patients were separated into the HD group (screw density  $> 1.40$ ) and the LD group (screw density  $< 1.40$ ) with a mean screw density of  $1.51 \pm 0.09$  and  $1.28 \pm 0.11$  respectively. A total of 14 surgeries used the O-arm surgical imaging system, including 3 patients in the LD group and 11 patients in the HD group. The baseline characteristics were similar in both groups with respect to age, sex, Risser, coronal Cobb angle, flexibility, and preoperative TK and LL (Table 2). The comparison of radiographic outcomes between the HD and LD groups are presented in Table 3. A significantly better correction rate of the thoracic coronal curve was found in the HD group ( $56.59 \pm 4.80\%$  versus  $44.54 \pm 9.61\%$ ,  $P=0.036$ ). Bivariate analysis noted a significant correlation between screw density and correction rate of the thoracic curve ( $r=0.735$ ,  $P=0.016$ ). Furthermore, a strong association was found between screw density at the concave side and the correction rate of the thoracic coronal curve ( $r=0.783$ ,  $P=0.007$ ) (Table 4). At latest follow-up, loss of coronal correction of  $>5^\circ$  occurred in 8 cases (47.1%) in the LD group and 3 cases (17.6%) in the HD group. Although no significant intergroup difference noted in coronal thoracic correction loss, loss of correction was more likely to happen in the LD group ( $LD 2.62 \pm 5.48^\circ$  versus  $HD -4.34 \pm 4.23^\circ$ ,  $P=0.055$ ). With respect to the sagittal deformity, there were 7 hypokyphotic patients and 3 hyperkyphotic patients in the HD group, and 3 hypokyphotic patients and 4 hyperkyphotic patients in the LD group. After surgery, among those patients with hypokyphosis, an increase of TK  $> 10^\circ$  was found in 3 patients in the HD group but

**Table 1.** Demographic characteristics and clinical features of the patients.

Variables	Mean	Rang	SD
Age at surgery (years)	13.90	10 to 19	2.18
Duration of follow-up (months)	37.10	24 to 84	14.03
Risser sign (grade)	3.50	0 to 5	1.35
Levels instrumented	13.50	12 to 15	0.85
Total screw density, screws/level	1.40	1.13 to 1.67	0.15
Screw density of the concave side, screws/level	0.76	0.60 to 0.92	0.09
Screw density of the convex side, screws/level	0.64	0.53 to 0.75	0.08
Main Thoracic curve			
Cobb angle (deg)	85.03	73 to 100	9.56
Flexibility (%)	18.17	6.10 to 33.00	9.80
Lumbar curve			
Cobb angle (deg)	81.20	61 to 94	10.30
Flexibility (%)	45.96	18.30 to 66.80	14.51
Thoracic kyphosis (T5–T12) (deg)	24.76	3 to 72	20.74
Lumbar lordosis (T12–S1) (deg)	44.73	6 to 88	24.74

SD – standard deviation; deg – degree.

**Table 2.** The baseline characteristics of patients in the LD and HD groups.

Variables	LD group	HD group	P value
No. of patients	17	17	–
Age at surgery (years)	14.00±3.24	13.80±0.45	0.895
Sex (M/F)	6/11	8/9	0.486
Risser sign (grade)	3.20±1.93	3.80±0.45	0.516
Main thoracic curve			
Cobb angle (deg)	86.20±8.18	83.86±11.63	0.723
Flexibility (%)	15.46±10.04	20.89±9.85	0.414
Lumbar curve			
Cobb angle (deg)	83.31±10.56	79.09±10.77	0.549
Flexibility (%)	39.38±16.07	52.54±10.33	0.162
Thoracic kyphosis (T5–T12) (deg)	23.44±21.40	26.10±28.10	0.872
Lumbar lordosis (T12–S1) (deg)	41.52±23.94	47.94±27.90	0.706

\* Statistically significant if  $P < 0.05$ . LD group (1.28 screw density); HD group (1.51 screw density); M – Male; F – Female; deg – degree.

none in the LD group. For the patients presenting with thoracic hyperkyphosis, all 7 achieved normalization of TK post-operatively and this was maintained at the latest follow-up.

During the operation, the HD group had a longer surgery time (317.70±51.38 minutes versus 282.00±34.58 minutes,  $P=0.085$ ), greater estimated blood loss (2420.00±702.06 mL versus 1740.00±1469.09 mL,  $P=0.203$ ) and greater volume of total transfusion (2224.50±631.45 mL versus 1574.80±1502.41 mL,

$P=0.224$ ) than the LD group, but these did not reach the significance level ( $P > 0.05$ ).

A total of 639 screws were inserted, and 520 screws (81.4%) were identified as accurate (grade 0) screws. There were 20 out of 343 screws (5.8%) in the HD group and 31 out of 296 screws (10.5%) in the LD group considered to be perforations. The perforation rate was lower in the HD group, but this difference was found to be insignificant ( $P=0.116$ ). A total of 10

**Table 3.** Postoperative radiographic outcomes of patients in the LD and HD groups.

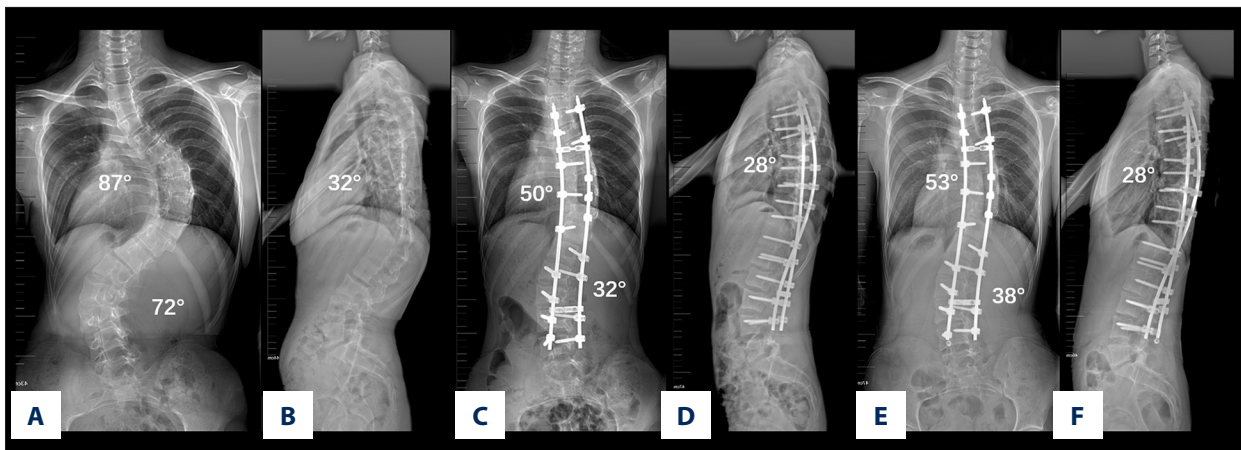
Variables	LD group	HD group	P value
Levels instrumented	14.00±0.71	13.00±0.71	0.056
Total screw density, screws/level	1.28±0.11	1.51±0.09	<b>0.008*</b>
Screw density of the concave side, screws/level	0.69±0.08	0.83±0.06	<b>0.013*</b>
Screw density of the convex side, screws/level	0.59±0.04	0.68±0.04	<b>0.012*</b>
Operation duration (minutes)	282.00±34.58	317.70±51.38	0.085
Estimated blood loss (mL)	1740.00±1469.09	2420.00±702.06	0.203
EBL per vertebra (mL)	124.19±104.79	185.01±51.26	0.117
Total transfusion (mL)	1574.80±1502.41	2224.50±631.45	0.224
<b>Early postoperative (2 weeks after operation)</b>			
Main Thoracic curve (deg)	47.73±8.90	36.29±5.50	<b>0.040*</b>
Correction rate of the main thoracic curve (%)	44.54±9.61	56.59±4.80	<b>0.036*</b>
Lumbar curve (deg)	39.47±7.81	34.26±10.26	0.393
Correction rate of the lumbar curve (%)	52.90±3.75	55.99±9.36	0.513
Thoracic kyphosis (T5–T12) (deg)	22.82±8.68	24.31±11.78	0.826
Change of thoracic kyphosis (deg)	-0.62±15.18	-1.77±20.09	0.921
Lumbar lordosis (T12–S1) (deg)	51.42±17.03	43.46±22.40	0.545
Change of lumbar lordosis (deg)	9.90±31.14	-4.48±22.35	0.426
<b>Latest follow-up</b>			
Duration of follow-up (months)	41.71±22.50	32.52±7.85	0.168
Coronal thoracic correction loss	-4.34±4.23	2.62±5.48	0.055
Coronal lumbar correction loss	-0.05±3.93	-0.03±2.12	0.991
Thoracic kyphosis (T5–T12) (deg)	21.28±9.36	24.21±6.81	0.586
Lumbar lordosis (T12–S1) (deg)	53.38±15.08	39.10±27.60	0.340

\* Statistically significant if P<0.05. LD group (1.28 screw density); HD group (1.51 screw density), deg – degree.

**Table 4.** Correlation analysis of screw density and correction outcomes.

Variable	Total screw density		Screw density of the concave side		Screw density of the convex side	
	Correlation Coefficient (r)	P value	Correlation Coefficient (r)	P value	Correlation Coefficient (r)	P value
Correction rate of the main thoracic coronal curve	0.735	<b>0.016*</b>	0.783	<b>0.007*</b>	0.568	0.087
Correction rate of the lumbar coronal curve	0.508	0.134	0.448	0.194	0.553	0.097
Coronal thoracic correction loss	0.499	0.142	0.369	0.294	0.465	0.175
Coronal lumbar correction loss	0.353	0.318	0.402	0.250	0.228	0.526
Change of thoracic kyphosis	-0.101	0.780	-0.111	0.759	-0.073	0.842
Change of lumbar lordosis	-0.130	0.721	-0.050	0.890	-0.252	0.482

\* Statistically significant if P<0.05.



**Figure 1.** A 12-year-old female with scoliosis secondary to Marfan syndrome was surgically treated with a 1.38 screw density (LD group). The magnitude of preoperative thoracic curve was 87° (A), with a 32° kyphotic curve (B). Postoperative radiographs (C, D) showed a 42.5% primary coronal curve correction rate (from 87° preoperatively to 50° postoperatively). A thoracic correction loss of 3° and a lumbar correction loss of 6° was observed at 2 years follow-up (E, F).

screws had grade 3 breaches and all occurred in the LD group. As no neurologic or vascular sequelae resulted, these screws were neither removed nor repositioned at a revision surgery.

Complications occurred in 5 cases (29.4%) in the LD group and 3 cases (17.6%) in the HD group, respectively. Seven cases of cerebro-spinal fluid leak occurred (4 in the LD group and 3 in the HD group) and resolved with pressure dressing. Revision surgery was performed in 1 case in the LD group due to a rod breakage at 1.5-year follow-up. For all other patients, no implant-related neurological, vascular, visceral complications, or failure of instrumentation were observed during the follow-up.

No significant difference in any of the SRS-22 domains was detected between the HD and LD groups based on preoperative questionnaire. At the recent follow-up, patients in the HD and LD groups scored similarly in the pain (4.4 versus 4.4), self-image (4.0 versus 3.9), function (4.0 versus 4.0), mental health (4.3 versus 4.2), and satisfaction domains (4.1 versus 4.0), with both groups demonstrating improvement in each domain.

## Discussion

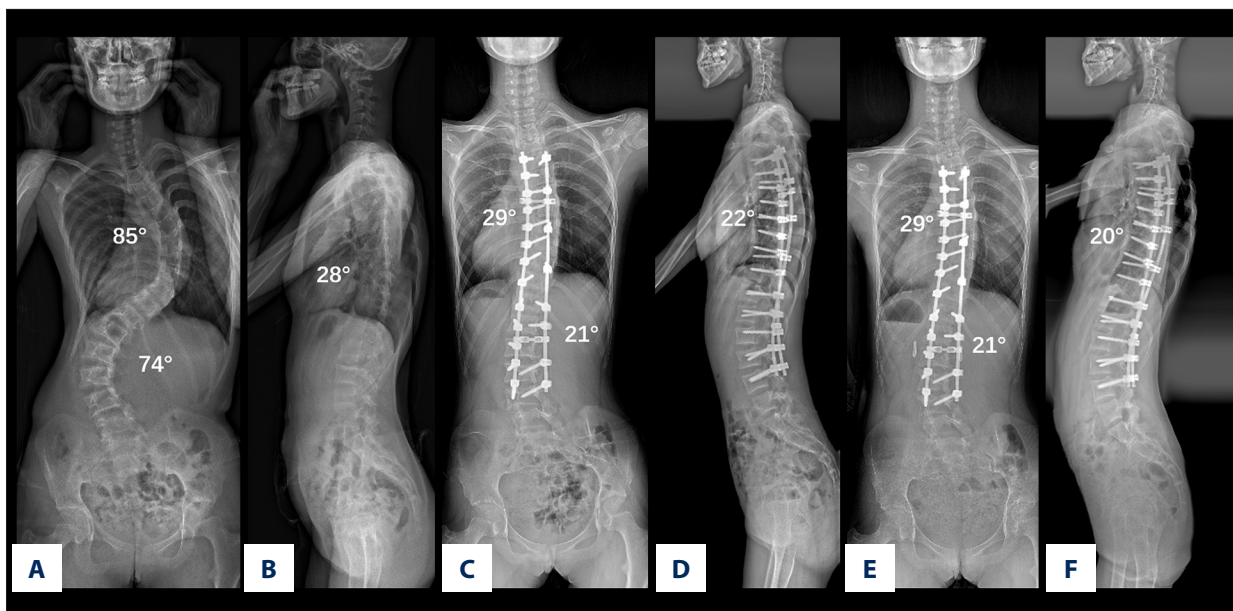
The skeletal system of patients with Marfan syndrome (MF-S) is characterized by excessive linear growth of the long bones and joint laxity, leading to progressive scoliosis [24]. Only 17% of MF-S patients had a successful result if electing to wear a brace [25]. Hence, surgical correction of the spinal deformity is required for most Marfan scoliosis.

In recent years, the use of pedicle screws has been proven to be superior in terms of mean absolute degrees and percentage of deformity correction when compared to posterior

hook and wire or hybrid constructs [26]. However, the insertion of pedicle screws is quite challenging in MF-S patients because of the poor anchorage points for internal fixation due to dystrophic pedicles and dural ectasia [3,4], leading to lower screw density (Figure 1). For patients with moderate-sized curves, even using lower-density implant constructs could achieve satisfactory correction outcomes because of the flexible spine, as previously reported in idiopathic scoliosis [14]. Nevertheless, there is concern that lower screw density may lead to compromise of clinical and radiographic outcomes in patients with large MF-S scoliosis curves, as the spine is more fixed and the vertebral axial rotation is larger than that of mild to moderate curves [20,21].

With the development of O-arm based navigation systems, marked improvement was achieved in the accuracy and safety of pedicle screw insertion [8-10]. In this way, surgeons have the chance to eliminate the limitation of the free-hand technique and increase the number of screws inserted in those patients with dystrophic pedicles, such as patients with MF-S (Figure 2) or dystrophic NF1-S. Recently, in a series of 41 patients with dystrophic NF1-S, Li et al. noted a greater coronal curve correction and a less postoperative correction loss in patients of a high-implant-density group (implant density >1.35) [16]. In patients with MF-S, especially in those with large thoracic curves, we speculated that higher screw density could also independently predict better correction outcomes. For all we know, this is the first study to explore the effect of screw density on deformity correction in a group of pediatric patients with MF-S with large thoracic curves.

In the current study, there was a positive correlation between the correction rate of thoracic coronal curve and the screw density ( $r=0.735$ ,  $P=0.016$ ). In addition, this correlation was more



**Figure 2.** A 13-year-old female with scoliosis secondary to Marfan syndrome was surgically treated with a 1.62 screw density (HD group). The preoperative Cobb angle was 85° (A), with a 28° kyphotic curve (B). Postoperative radiographs (C, D) showed a 65.9% primary coronal curve correction rate (from 85° preoperatively to 29° postoperatively). No coronal correction loss was observed after 2 years of follow-up (E, F).

pronounced with screw density at the concave side ( $r=0.783$ ,  $P=0.007$ ). Subgroup analysis further demonstrated that patients in the HD group, together with significantly higher screw density at the concave side, had a significantly higher amount of thoracic coronal correction than those in the LD group (Table 3). From a mechanical point of view, the rod rotation maneuver was mainly performed using the concave rod. On the other hand, the translational and rotational displacement required for correction at the concave side was always greater than at the convex side [18]. Consequently, an increase in the screw density at the concave side could sustain more internal stress and achieve superior thoracic coronal correction than a low-density screw construct. Concerning the difference in correction loss between subgroups, loss of coronal correction of  $>5^\circ$  occurred in 8 cases (47.1%) in the LD group and 3 cases (17.6%) in the HD group at latest follow-up. Although no significant intergroup difference noted in coronal thoracic correction loss, loss of correction was more likely to happen in the LD group ( $LD\ 2.62\pm 5.48^\circ$  versus  $HD\ -4.34\pm 4.23^\circ$ ,  $P=0.055$ ). In accordance with the present results, Li et al. [16] also demonstrated that increase of implant density could contribute to the maintenance of the deformity correction at follow-up. Possible explanation could be that more pedicle screws were capable of distributing the resistant force generating from those connecting elements of the deformed spine and thus resulted in less long-term correction loss [27].

During surgery, the average amount of blood loss in our cohort was 2080 mL. Compared to the mean estimated blood

loss per level of 80–90 mL reported in adolescent idiopathic scoliosis [14,15], a mean blood loss per level of 124 mL in the LD group and 185 mL in the HD group were noted in our study, increased by 37% to 130%. These results indicate that patients with MF-S are probably more prone to bleed during surgery than those with adolescent idiopathic scoliosis. Additionally, there was a tendency for greater estimated blood loss as well as longer duration of operation with higher screw density in our cohort. Hence, surgeons planning and performing surgery for patients with large MF-S curves should consider these characteristics of MF-S. Although an increased number of pedicle screws could contribute to superior deformity correction in large MF-S curves, this could also lead to greater additional blood loss than in idiopathic scoliosis.

In terms of clinical outcomes assessments, no intergroup significant difference was identified in any of the SRS-22 domains at the most recent follow-up. Our finding was in keeping with that of Li et al. [16] and Larson et al. [13], which implied that patients in both the HD and LD groups were satisfied with the curve correction. With respect to the complications which occurred in our cohort, we noted a case of rod breakage in the LD group, which may have been due to the decreased bone mineral density along with the excessive load borne by single screw-bone contact that weakened fixation stability [7]. Theoretically, increasing the pedicle screw number can help to enhance structural stability [17]. Nevertheless, given the dysplastic pedicles and dysplastic lamina in MF-S patients, there is concern that, even with the help of navigation systems, adding

more screws to the construct still increases the potential risk of vascular and neurological complications [3,4]. Recently, in a series of 75 patients, Qiao et al. conducted an analysis of accuracy of pedicle screw insertion in MF-S [10]. They found a dramatically decreased perforation rate using O-arm navigation technique (30.8% free-hand versus 11.4% O-arm assisted), with no impingement of visceral organs or severe neurological complications. Similarly, in our study, we attributed the lower rate of screw perforation in the HD group to the using of O-arm navigation system in most patients (11 out of 17 patients). The absence of high grade (penetration >4 mm) screw perforation or implant-related complications noted in the HD group further proved the stability and feasibility of a high-density pedicle screw construct in patients with large MF-S curves.

A limitation of this research was the retrospective nature of the review. Prospective studies with larger sample sizes are needed, in which distribution of screws, selection of the fusion levels, and preoperative health status should be fully limited.

## References:

1. Tsiouras P, Del Mastro R, Sarfarazi M et al: Genetic linkage of the Marfan syndrome, ectopia lentis, and congenital contractural arachnodactyly to the fibrillin genes on chromosomes 15 and 5. The International Marfan Syndrome Collaborative Study. *N Engl J Med*, 1992; 326(14): 905–9
2. Sponseller PD, Hobbs W, Riley LH 3<sup>rd</sup>, Peyeritz RE: The thoracolumbar spine in Marfan syndrome. *J Bone Joint Surg Am*, 1995; 77(6): 867–76
3. Sponseller PD, Ahn NU, Ahn UM et al: Osseous anatomy of the lumbosacral spine in Marfan syndrome. *Spine (Phila Pa 1976)*, 2000; 25(21): 2797–802
4. Peyeritz RE, Fishman EK, Bernhardt BA, Siegelman SS: Dural ectasia is a common feature of the Marfan syndrome. *Am J Hum Genet*, 1988; 43(5): 726–32
5. Qiao J, Xu L, Liu Z et al: Surgical treatment of scoliosis in Marfan syndrome: Outcomes and complications. *Eur Spine J*, 2016; 25(10): 3288–93
6. Di Silvestre M, Greggi T, Giacomini S et al: Surgical treatment for scoliosis in Marfan syndrome. *Spine (Phila Pa 1976)*, 2005; 30(20): E597–604
7. Gjolaj JP, Sponseller PD, Shah SA et al: Spinal deformity correction in Marfan syndrome versus adolescent idiopathic scoliosis: Learning from the differences. *Spine (Phila Pa 1976)*, 2012; 37(18): 1558–65
8. Jin M, Liu Z, Liu X et al: Does intraoperative navigation improve the accuracy of pedicle screw placement in the apical region of dystrophic scoliosis secondary to neurofibromatosis type I: comparison between O-arm navigation and free-hand technique. *Eur Spine J*, 2016; 25(6): 1729–37
9. Liu Z, Jin M, Qiu Y et al: The superiority of intraoperative o-arm navigation-assisted surgery in instrumenting extremely small thoracic pedicles of adolescent idiopathic scoliosis: A case-control study. *Medicine (Baltimore)*, 2016; 95(18): e3581
10. Qiao J, Zhu F, Xu L et al: Accuracy of pedicle screw placement in patients with Marfan syndrome. *BMC Musculoskelet Disord*, 2017; 18(1): 123
11. Quan GM, Gibson MJ: Correction of main thoracic adolescent idiopathic scoliosis using pedicle screw instrumentation: Does higher implant density improve correction? *Spine (Phila Pa 1976)*, 2010; 35(5): 562–67
12. Sudo H, Abe Y, Kokabu T et al: Correlation analysis between change in thoracic kyphosis and multilevel facetectomy and screw density in main thoracic adolescent idiopathic scoliosis surgery. *Spine J*, 2016; 16(9): 1049–54
13. Larson AN, Polly DW Jr., Diamond B et al: Does higher anchor density result in increased curve correction and improved clinical outcomes in adolescent idiopathic scoliosis? *Spine (Phila Pa 1976)*, 2014; 39(7): 571–78
14. Bharucha NJ, Lonner BS, Auerbach JD et al: Low-density versus high-density thoracic pedicle screw constructs in adolescent idiopathic scoliosis: Do more screws lead to a better outcome? *Spine J*, 2013; 13(4): 375–81
15. Shen M, Jiang H, Luo M et al: Comparison of low density and high density pedicle screw instrumentation in Lenke 1 adolescent idiopathic scoliosis. *BMC Musculoskelet Disord*, 2017; 18(1): 336
16. Li Y, Yuan X, Sha S et al: Effect of higher implant density on curve correction in dystrophic thoracic scoliosis secondary to neurofibromatosis Type 1. *J Neurosurg Pediatr*, 2017; 20(4): 371–77
17. Shea TM, Laun J, Gonzalez-Blohm SA et al: Designs and techniques that improve the pullout strength of pedicle screws in osteoporotic vertebrae: Current status. *Biomed Res Int*, 2014; 2014: 748393
18. Salmingo RA, Tadano S, Abe Y, Ito M: Influence of implant rod curvature on sagittal correction of scoliosis deformity. *Spine J*, 2014; 14(8): 1432–39
19. Wang X, Larson AN, Crandall DG et al: Biomechanical effect of pedicle screw distribution in AIS instrumentation using a segmental translation technique: computer modeling and simulation. *Scoliosis Spinal Disord*, 2017; 12: 13
20. Robins PR, Moe JH, Winter RB: Scoliosis in Marfan's syndrome. Its characteristics and results of treatment in thirty-five patients. *J Bone Joint Surg Am*, 1975; 57(3): 358–68
21. Luhmann SJ, Lenke LG, Kim YJ et al: Thoracic adolescent idiopathic scoliosis curves between 70 degrees and 100 degrees: is anterior release necessary? *Spine (Phila Pa 1976)*, 2005; 30(18): 2061–67
22. Loeys BL, Dietz HC, Braverman AC et al: The revised Ghent nosology for the Marfan syndrome. *J Med Genet*, 2010; 47(7): 476–85
23. Gertzbein SD, Robbins SE: Accuracy of pedicular screw placement *in vivo*. *Spine (Phila Pa 1976)*, 1990; 15(1): 11–14
24. Judge DP, Dietz HC: Marfan's syndrome. *Lancet* 2005; 366(9501): 1965–76
25. Sponseller PD, Bhimani M, Solacoff D, Dormans JP: Results of brace treatment of scoliosis in Marfan syndrome. *Spine (Phila Pa 1976)*, 2000; 25(18): 2350–54
26. Liljenqvist U, Lepsien U, Hackenberg L et al: Comparative analysis of pedicle screw and hook instrumentation in posterior correction and fusion of idiopathic thoracic scoliosis. *Eur Spine J*, 2002; 11(4): 336–43
27. Liu H, Li Z, Li S et al: Main thoracic curve adolescent idiopathic scoliosis: association of higher rod stiffness and concave-side pedicle screw density with improvement in sagittal thoracic kyphosis restoration. *J Neurosurg Spine*, 2015; 22(3): 259–66

In addition, it must be cautioned that these findings are interim, further research conducted over longer follow-up periods is required.

## Conclusions

High-density pedicle screw constructs contributed to the significantly improved correction of major curves in MF-S patients with large main thoracic curves ( $\geq 70^\circ$ ). Although no significant difference in healthy-related quality of life was identified between the HD and LD groups, increasing pedicle screw number could help to enhance the structural stability and reduce the correction loss during the follow-up period.

## Conflict of interest

None.