How do we follow-up patients with adolescent idiopathic scoliosis? Recommendations based on a multi-center study on the distal radius and ulna classification

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Compliance with Ethical Standards

Conflict of interest

Yusuke Yamamoto, Hideki Shigematsu, Prudence Wing Hang CHEUNG, Akinori Okuda, Sachiko Kawasaki, Yasuhito Tanaka, and Jason Pui Yin CHEUNG declare that they have no conflict of interest.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Author contributions

Yusuke Yamamoto: Collected the data, performed the statistical analysis, and wrote the manuscript.

Hideki Shigematsu: Designed the study, collected the data, performed the statistical analysis, and wrote and edited the manuscript.

Prudence Wing Hang Cheung: Collected patients' data and reviewed and approved the manuscript.

Akinori Okuda: Collected patients' data and reviewed and approved the manuscript.

Sachiko Kawasaki: Collected patients' data and reviewed and approved the manuscript.

Yasuhito Tanaka: Collected patients' data, provided critical feedback on the study, and reviewed and approved the manuscript.

Jason Pui Yin Cheung: Designed the study, collected the data, performed the statistical analysis, and wrote and edited the manuscript.

All authors read and approved the final manuscript.

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Abstract

Purpose

To determine the capability of the distal radius and ulna (DRU) classification for predicting the scoliosis progression risk within 1 year in patients with adolescent idiopathic scoliosis (AIS) and to develop simple recommendations for follow-up durations.

Methods

Medical records of patients with AIS at two tertiary scoliosis referral centers were retrospectively reviewed for their DRU classification and major curve Cobb angles. Baseline DRU grades and Cobb angles with subsequent 1-year follow-up curve magnitudes were studied for scoliosis progression, which was defined as exacerbation of the Cobb angle by ≥6°. The relationship between DRU classification and scoliosis progression risk within 1 year was investigated. Patients were divided into three groups according to the Cobb angle (10–19°, 20–29°, ≥30°).

Results

Of the 205 patients with 283 follow-up visits, scoliosis progression occurred in 86 patients (90 follow-up visits). Radius and ulna grades were significantly related to scoliosis progression ($p<0.001$). R6, R7, and

U5 grades were significantly related to scoliosis progression risk. The curve progression probability increased as the Cobb angle increased. Cobb angles ≥30°, with these grades, led to progression in >80% of patients within 1 year. Curve progression was less likely for grades R9 and U7. Most patients with more mature DRU grades did not experience progression, even with Cobb angles ≥30°.

Conclusion

With R6, R7, and U5, scoliosis may progress within a short period; therefore, careful follow-up with short intervals within 6 months is necessary. R9 and U7 may allow longer 1-year follow-up intervals due to the lower progression risk.

Keywords

Adolescent idiopathic scoliosis; Distal radius and ulna classification; Bone age; Cobb angle; Curve progression; Follow-up duration

Introduction

It is crucial to assess bone age and determine the remaining growth potential of children when managing adolescent idiopathic scoliosis (AIS) [1] as scoliosis progression is correlated with skeletal growth, which peaks during the adolescent growth spurt and usually stabilizes or slows at increased skeletal maturity [1, 2]. The remaining skeletal growth of a child is an effective indicator for determining the timing of interventions, such as initiation and weaning of brace treatment, growth-sparing surgery, and final fusion [2-5].

Luk et al. [6] described the distal radius and ulna (DRU) classification, which incorporates all growth phases, with 11 radius grades (R1–R11) and 9 ulna grades (U1–U9). Because it is solely based on the morphology of two physeal plates, it is more user-friendly than measurements of the entire hand. Cheung et al. [7, 8] reported that the DRU classification is more evenly distributed throughout the pubertal phase; this classification is easily reproducible and has excellent reliability compared to other bone maturity assessments. Furthermore, it is useful for forecasting the likely outcomes of patients with AIS at skeletal maturity [9, 10].

It is crucial to intuitively decide the observation interval and the timing of treatment modification considering the likelihood of curve progression in busy outpatient clinics. Patients who are near peak height velocity must be closely observed, whereas those nearer to skeletal maturity can have longer follow-up intervals. However, despite years of research, this is not quantified and is usually decided by consensus between patients and clinicians [11]. To solve this problem, it is important to predict how scoliosis will change in the short-term using accurate indicators of skeletal maturity. Although prediction of curve progression has been studied [3, 12], the studied follow-up periods and endpoints were inconsistent, and did not account for the effect of bracing interventions. Hence, this study aimed to investigate whether the DRU classification can predict scoliosis progression within a 1-year natural observation period and to develop recommendations for follow-up duration.

Material and methods

Study design

This study was approved by the institutional review boards of the participating institutions, and informed consent was obtained from all patients included in this study. We retrospectively reviewed the medical records of patients with AIS who visited scoliosis outpatient units at two tertiary scoliosis referral centers between January 2009 and December 2017. At these centers, the DRU classification was evaluated for bone maturity in initial visits and during long-term follow-up visits of patients with AIS. Therefore, some patients with long follow-up have several DRU grade evaluations for bone maturity assessment. In total, 326 patients with AIS and 678 DRU classifications fulfilled the study inclusion criteria (Fig. 1) of having 1-year follow-up visits from a baseline consultation visit with DRU grade evaluation. Follow-up visits that scoliosis progressed within 1 year from baseline and brace treatment was initiated at the time were counted as progression cases, but those with bracing or surgery was performed at baseline were excluded. This was done because bracing would have altered the natural history of scoliosis progression and we could not assess the pure risk of scoliosis progression associated with growth. Other exclusion criteria were the following: follow-up visits with less than one year of observation; follow-up visits with skeletal maturity, as signified by a combination of radius grade 11 and ulna grade 9, because no further growth was expected at this stage; and follow-up visits with inadequate radiographic quality or poor positioning. Up to 121 patients and 395 follow-up visits were excluded from the analysis. In total, 205 patients and 283 follow-up visits, in which the pure natural course of AIS was represented, were included in the analysis.

Study parameters

Data were collected by a spine surgeon at each facility. The Cobb angles of the main curves were recorded at each patient visit. Patients were followed up for 1 year from a baseline DRU grade, and scoliosis progression was defined as exacerbation of the Cobb angle by ≥6° within this period. If the curve pattern changed, levels with a larger change in the Cobb angle were selected. Curve pattern was recorded as proximal thoracic, main thoracic, and thoracolumbar/ lumbar curve. Additionally, other parameters associated with the risk of curve progression such as chronological age, months from the onset of menarche, Risser stage, and status of the triradiate cartilage (open or closing) were recorded. The DRU classification was measured using radiographs with left wrist at the intermediate position. All Cobb angles were measured on a standing posteroanterior whole spine radiograph, and the same radiograph was used for Risser staging and assessment of the triradiate cartilage. Risser stage was evaluated using the United States system and the French system [13]. Both systems comprised of 6 stages; they have an identical Risser stage 0, but the other stages are different. The US Risser divided the iliac crest into 4 segments, and US Risser stage 5 includes the initial contact of the apophyseal line with the crest posteriorly and complete fusion. Alternatively, the French system divided the iliac crest into three segments and fusion into two stages. The French Risser stage 5 indicates complete fusion of the apophysis to the ilium.

Statistical analyses

Data are presented as mean±standard deviation (SD). The chi-square test was used to investigate the relationship between the DRU classification and scoliosis progression risk within 1 year. If a significant relationship was identified, then Harberman's residual analysis was performed. A residual analysis identified those specific factors that made the greatest contribution to the chi-square test results [14]. The adjusted residual is a measure of the strength of the difference between observed and expected values. A significant association was confirmed with an adjusted residual of 1.96 or more. The DRU classification was categorized as high, low, or moderate risk according to the adjusted residual. To perform a subgroup analysis of the influence of the Cobb angle severity, patients were divided into three groups according to the initial Cobb angle (10–19°, 20–29°, ≥30°). Multivariate logistic regression was used to determine the scoliosis progression probability within 1 year and its 95% confidence interval based on the DRU classification and initial Cobb angle. We assumed that the probability of progression during 1 month was constant, and the probability of detecting scoliosis progression within each month during the year was calculated using the Bernoulli trial as a method of mathematical probability [15]. All statistical analyses were performed using SPSS version 25.0 for Windows (IBM, Armonk, NY, USA); $p<0.05$ was considered statistically significant.

Results

Patient and follow-up visit characteristics

The final study comprised of 205 patients and 283 follow-up visits (Table 1). Girls and boys comprised of 77.1% and 22.9%, respectively, of the study group. Follow-up visits were performed for 74.9% of girls and 25.1% of boys. The DRU classification for 1-year follow-up visits approximated a normal distribution. No cases were more immature than R5 and U4.

DRU classification and other parameters of bone maturity

Chronological age (according to sex), months from the onset of menarche, and status of the triradiate cartilage according to the DRU classification are shown in Table 2. Most intervals for the DRU grades were <1 year. The mean age tended to be lower in girls than in boys with the same DRU grade. The grades before menarche ranged from approximately R5 to R7 and from U4 to U6. Before R6 and U5, most of the patients had an open triradiate cartilage. In R8 and U6 and greater, nearly all patients had closed triradiate cartilage. In addition, the distribution of the US and French Risser stage corresponding to each DRU grades is described in Tables 3 and 4. Advances in both Risser stage systems coincided with an increase in DRU grade. The US Risser stage was assigned a higher grade for each DRU grade than the French Risser stage.

Scoliosis progression within 1 year from the DRU classification

The number of curves that progressed and scoliosis progression rates for each DRU classification are listed in Table 5. Scoliosis progression was observed in 86 patients with 90 follow-up visits (31.8%). There were no significant differences between the curve progression rates of boys and girls ($p=0.865$). No association was observed between curve pattern and scoliosis progression rate ($p=0.184$). The chi-square test indicated that the DRU classification was significantly associated with scoliosis progression within 1 year (radius grade: $p<0.001$; ulna grade: $p<0.001$). R6, R7, and U5 (adjusted residual >1.96) were associated with scoliosis progression risk. The earliest grades that were associated with no progression risk were R9 and U7 (adjusted residual <-1.96). The results of the scoliosis progression rates within 1 year for various Cobb angles are presented in Table 6. Larger Cobb angles at the time of diagnosis resulted in higher rates of scoliosis progression at 1-year follow-up. The DRU classification was categorized according to the adjusted residual as follows: R6, R7, and U5, high-risk group; R8 and U6, moderate-risk group; and R9 and U7, low-risk group (Fig. 2). R10, R11, U8 and U9 were excluded from these subgroups because of almost no scoliosis progression within 1 year. Table 7 summarizes the characteristics of patients classified into DRU classification subgroups. The age difference between DRU classification subgroups was approximately 1 year. Up to 62.6% of patients in the high-risk group had a Risser stage 0. While 61.6% of patients with Risser 0 had open triradiate cartilage, 38.4% had closed triradiate cartilage. Patients in the moderate-risk group were approximately equally divided among US Risser stages 0–4. Patients in the low-risk group had more mature Risser stages, but only 58.1% had US Risser stage 4 or 5. In addition, there were no fewer than 41.1% patients with French Risser stage 2 and below. The scoliosis progression probability within 1 year and its 95% confidence interval for the DRU classification groups and initial Cobb angle are listed in Table 8.

Recommended follow-up duration for AIS based on the DRU classification

Based on the results of this study and the Bernoulli trial, we developed simple indicators of scoliosis progression risk during the year based on the magnitude of the initial Cobb angle and the DRU classification (Table 9). According to the probability of scoliosis progression, we recommend a follow-up duration so that no more than 20% of patients have scoliosis progression. (Table 10).

Discussion

We utilized the 1-year observation period as the pure natural course of AIS to provide simple recommendations based on the DRU classification. Therefore, clinicians could determine individualized planning and procedures necessary for an upcoming 1-year follow-up.

Early dentification of AIS patients with high risk of curve progression and effective intervention with braces for them can slow or stop curvature progression before skeletal maturity [16]. However it is also important to identify patients with low risk of curve progression and no need for braces because extensive and indiscriminate use of bracing for children may lead to spinal stiffness and poor self-esteem and self-perceived body image [17, 18]. Our ability to correctly determine skeletal maturity is crucial for accomplishing this. Many radiological methods are available to predict a patient's growth potential including the Risser staging, Greulich and Pyle method, Tanner and Whitehouse (TW3), and simplified models using the olecranon apophysis [19]. Among these methods, the Risser staging is a popular and simple bone age assessment for everyday clinical use. The Risser staging includes the US and French systems which are quite different. These systems may lead to different choices of how and when to treat patients [13]. The distribution of the US and French Risser staging corresponding to each DRU grade in this study is similar to previous reports in that the French system uniformly undervalued the ossification excursion compared with the US system [13, 20]. Nevertheless, both systems have several significant limitations to its utility for prediction due to its inaccuracy and high variability [20-22]. Indeed, the present study showed inconsistency of Risser staging in predicting curve progression (Table 7). In addition, even though Risser 0 was separated into two stages using the status of the triradiate cartilage [23], it still has been shown to be suboptimal for predicting peak growth [24]. Our study results support this by showing 38.4% of patients with Risser 0 had closed triradiate cartilage despite being in the high risk group. Although TW3 is a reliable predictor of skeletal maturity, it may be too complex and time consuming for routine clinical use [7, 21, 24]. For this reason, Sanders et al. [25] described a simplified TW3 system (Sanders staging) for the classification of skeletal maturity. Recently, prognostic model in untreated AIS patients using the Sanders staging was developed [26]. Nevertheless, Sanders staging still requires physeal assessment of all digits, which is complex and cumbersome to utilize in a busy clinic setting. In addition, prior training may be required to obtain high reliability of this system [27, 28]. Hung et al. [29] proposed the thumb ossification composite index (TOCI) which has high interchangeability and correlation with the Sanders staging, simple to use and to have excellent reliability and accuracy even among novice users. However both Sanders staging and TOCI are still limited by their reliance on the distal radial and ulnar epiphysis to determine the end of remaining growth. Cheung et al. [30] reported that it is difficult to appropriate brace weaning timing using Sanders stage because the staging is not precise at the final stages (i.e. Sanders stage 8). The DRU classification has an advantage in these areas. The DRU classification (especially R grade) is reliable for evaluating skeletal maturity despite limited prior training or experience [28]. Furthermore, the DRU is more versatile with a larger range of assessment even at the end of skeletal growth [30].

The purpose of this study was to investigate the risk of curve progression with untreated and pure natural course of AIS patients using the DRU classification. There was curve progression in 90 follow-up visits. Although there were no cases with grading more immature than R5 and U4 in the present study, Cheung et al. [7] reported that this is not clinically significant for patients with AIS as the adolescent growth spurts occurs beyond these early grades. Therefore, the results of this study are applicable to most patients with AIS. Curve progression was observed in 31.0% of boys and 32.1% of girls, with no significant difference between them. Bunnell [31] reported similar sex differences in curve progression. Furthermore, Lonstein et al. [3] reported no significant sex differences in scoliosis curve progression. Therefore, our study results were similar to these results. Although there was no significant difference in curve progression risk for each curve type, it was more common in the main thoracic curve (36.8% vs. 26.6-26.7%). While thoracic curves have been reported to be associated with increased scoliosis progression [26, 32], Sitoula et al. [12] noted no difference in curve progression risk for various modified Lenke curve types. We considered that the present results are likely more generalizable for each curve pattern. We observed that the R6, R7, and U5 grades were significantly related to scoliosis progression risk within 1 year. Similar to our results, Cheung et al. [10] noted that the most specific grades for peak curve progression using the DRU classification were R7 (0.80°±0.89°/month) and U5 (0.84°±0.78°/month). Conversely, although all collected data regarding curves indicated some potential for progression, the DRU grades that were more mature than R9 and U7 were associated with a significantly lower scoliosis progression risk. We observed that the probability of curve progression increased as the Cobb angle increased (Table 6), which was similar to other studies [3, 10, 26]. Based on the scoliosis progression rate within 1 year for each DRU classification and Cobb angle (Table 8), patients in the high-risk group had a high probability of scoliosis progression within 1 year even if they had small initial Cobb angles, and almost all patients with initial Cobb angles ≥30° experienced progression. Patients in the moderate-risk group had a progression rate of 30–40% within 1 year. Conversely, the majority of patients in the low-risk group did not experience progression within 1 year, irrespective of the initial Cobb angle subgroup.

Lonstein et al. [3] reported the incidence of progression as it related to the magnitude of the curve and Risser staging. They suggested that if there is a high chance of progression, then close observation with radiographs at 3- or 4-month intervals is indicated. It makes sense to recommend a follow-up duration based on the progression risk. In the 2016 SOSORT Guidelines [11], timing of follow-up for patients with AIS can range from 6 to 12 months based on consensus according to the specific clinical situation and

Risser staging. The limitations of the Risser staging [21, 22, 24] make the DRU classification more practical; therefore, making it appropriate for determining follow-up recommendations.

In this study, there was a high scoliosis progression risk within 1 year with R6, R7, and U5 grades. With these grades, even if the Cobb angle was small, patients were highly likely to experience early scoliosis progression. Hence, we believe that careful follow-up observation for 3 to 6 months is necessary if patients have R6, R7, or U5 grades. Furthermore, patients with Cobb angles ≥30°, with these grades, may experience progression before 3 months. Thus, close observation within 3 months is required, and immediate referral to a specialist with early intervention should be considered. Although the R8 and U6 grades were not statistically correlated with scoliosis progression risk, patients had a progression rate of approximately 30–40% within 1 year. The observation period intervals may be extended to 6 months for these patients. In some cases, especially when patients have Cobb angles ≥30°, follow-up within 6 months may be necessary. However, DRU grades more mature than R9 and U7 are not associated with scoliosis progression within 1 year; therefore, less frequent observations can be safely implemented for low-risk subjects. The observation interval can be 12 months for these patients regardless of Cobb angle. We believe that the use of this simple indicator of scoliosis progression risk makes it easier to detect progressive AIS, to determine appropriate observation intervals, and to refer patients to scoliosis specialists.

This study has some limitations. Firstly, this study excluded patients who have bracing at baseline as interventions may alter natural history. However, this may make the results of this study only representative of a population of less aggressive scoliosis because more aggressive scoliosis requires bracing at the onset. Nevertheless, the aim of this study is to provide recommendations for follow-up duration and it may be more appropriate to identify the group of patients who normally do not require bracing at the outset as this is the group where we need to decide on the next follow-up date. Secondly, the results of this study may differ by race. It has been reported that bone age in children by the Greulich and Pyle method using hand and wrist radiographs has significant discrepancy depending on the subject's ethnicity [33]. Thus, the results of this study may not be readily generalizable, and we believe that conducting similar studies is necessary for validation in other ethnic groups. Thirdly, because this study had a retrospective design and observation intervals differed for each patient, we could not determine the exact time when progression occurred or when precise follow-up should have been performed. However, our recommendations are within 3 months and thus are easily applicable to most clinics. Nevertheless, our results should be verified by future prospective studies.

Conclusions

We developed simple indicators of scoliosis progression risk within 1 year and provided recommended observation intervals based on the DRU grades. Scoliosis may progress during a short period, especially in those with R6, R7, and U5 grades; therefore, it is necessary to perform careful follow-up and early treatment interventions, particularly for patients with initial Cobb angles ≥30°. However, scoliosis progression within 1 year is lower for those with R9 and U7 grades. Therefore, it is possible to perform less frequent observations for these patients.

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Table 1. Demographic data

Parameter	Number	Frequency
No. of patients	205	
Girls	158	77.1%
Boys	47	22.9%
No. of follow-up visits with DRU classification	283	
Girls	212	74.9%
Boys	71	25.1%
Radius grade		
R5	6	2.1%
R6	68	24.0%
R7	49	17.3%
R8	79	27.9%
R9	52	18.4%
R10	26	9.2%
R11	3	1.1%
Ulna grade		
U4	20	7.1%
U5	62	21.9%
U6	96	33.9%
U7	60	21.2%
U8	42	14.8%
U9	3	1.1%

DRU: distal radius and ulna

Table 2. Chronological age (according to sex), months from the onset of menarche, and status of the triradiate cartilage according to each distal radius and ulna grades

DRU grades	Mean age of boys (±SD), years	Mean age of girls (±SD), years	Mean months from the onset of menarche (±SD)	Triradiate-open n (%)
Radius				
R5	12.1 (±0.5)	10.8 (±0.4)	-46.3 (±2.5)	4 (66.7%)
R6	12.8 (±1.1)	11.7 (±0.9)	-7.8 (±10.6)	37 (54.4%)
R7	13.6 (±1.3)	12.1 (±0.8)	-0.1 (±8.1)	6 (12.2%)
R8	14.2 (±1.2)	12.9 (±1.0)	2.3 (±15.1)	1 (1.3%)
R9	15.4 (±1.0)	14.2 (±1.0)	18.4 (±15.1)	0
R10	16.2 (±0.5)	14.5 (±0.9)	25.6 (±9.7)	0
R11	None	15.8 (±0.8)	36.0 (±8.3)	0
Ulna				
U4	12.3 (±1.0)	11.1 (±0.8)	-17.1 (±17.1)	17 (85.0%)
U5	13.1 (±1.3)	11.9 (±1.0)	-6.9 (±13.4)	26 (42.0%)
U6	14.0 (±1.2)	12.6 (±1.0)	-0.5 (±11.6)	5 (5.2%)
U7	14.6 (±1.1)	13.6 (±1.2)	13.1 (±15.3)	0
U8	15.6 (±1.1)	14.4 (±1.0)	26.8 (±10.3)	0
U9	None	15.5 (±0.2)	20.0 (±8.2)	0

DRU: distal radius and ulna; SD: standard deviation

There were no simultaneous combinations of R11 and U9 grades. The combinations of R10 and U9 grades and R11 and U8 grades are included.

Table 3. US Risser stage corresponding to each distal radius and ulna grades

DRU grades	US Risser stage					
	0	1	2	3	4	5
Radius						
R5	100%	0	0	0	0	0
R6	77.9%	8.8%	7.4%	5.9%	0	0
R7	32.7%	30.6%	20.4%	14.3%	2.0%	0
R8	15.2%	10.1%	24.1%	27.8%	22.8%	0
R9	0	1.9%	9.6%	19.2%	61.5%	7.7%
R10	0	0	7.7%	11.5%	61.5%	19.2%
R11	0	0	0	0	66.7%	33.3%
Ulna						
U4	100%	0	0	0	0	0
U5	69.4%	12.9%	9.7%	4.8%	3.2%	0
U6	24.0%	18.8%	19.8%	26.0%	11.5%	0
U7	1.7%	5.0%	20.0%	25.0%	43.3%	5.0%
U8	0	2.4%	9.5%	7.1%	66.7%	14.3%
U9	0	0	0	0	66.7%	33.3%

DRU: distal radius and ulna.

There were no simultaneous combinations of R11 and U9 grades. The combinations of R10 and U9 grades and R11 and U8 grades are included.

Table 4. French Risser stage corresponding to each distal radius and ulna grades

DRU grades	French Risser stage					
	0	1	2	3	4	5
Radius						
R5	100%	0	0	0	0	0
R6	77.9%	11.8%	10.3%	0	0	0
R7	32.7%	42.9%	18.4%	6.1%	0	0
R8	15.2%	22.8%	43.0%	17.7%	1.3%	0
R9	0	5.8%	23.1%	46.2%	25.0%	0
R10	0	3.8%	11.5%	38.5%	42.3%	3.8%
R11	0	0	0	33.3%	66.7%	0
Ulna						
U4	100%	0	0	0	0	0
U5	69.4%	17.7%	8.1%	4.8%	0	0
U6	24.0%	27.1%	38.5%	10.4%	0	0
U7	1.7%	18.3%	31.7%	31.7%	16.7%	0
U8	0	7.1%	9.5%	42.9%	38.1%	2.4%
U9	0	0	0	66.7%	33.3%	0

DRU: distal radius and ulna.

There were no simultaneous combinations of R11 and U9 grades. The combinations of R10 and U9 grades and R11 and U8 grades are included.

Table 5. Scoliosis progression rate within 1 year from the DRU classification

Parameter	Progression cases	Progression rate	p value	Adjusted residual
No. of patients	86	42.0%		
No. of follow-up visits	90	31.8%		
Girls	68	32.1%	0.865	
Boys	22	31.0%		
Curve type			0.184	
Proximal Th	8	26.7%		
Main Th	53	36.8%		
TL/L	29	26.6%		
Radius grade			<0.001	
R5	3	50.0%		1.0
R6	37	54.4%		4.6
R7	22	44.9%		2.2
R8	22	27.8%		-0.9
R9	6	11.5%		-3.5
R10	0	0%		-3.7
R11	0	0%		-1.2
Ulna grade			<0.001	
U4	9	45.0%		1.3
U5	36	58.1%		5.0
U6	34	35.4%		0.9
U7	9	15%		-3.1
U8	2	4.8%		-4.1
U9	0	0%		-1.2

DRU: distal radius and ulna; Th: thoracic; TL/L: thoracolumbar/lumbar.

Table 6. Scoliosis progression rate within 1 year for each Cobb angle

		Radius grade						
		5	6	7	8	9	10	11
Cobb angle	10–19°	1/3 (33.3%)	16/32 (50.0%)	6/17 (35.3%)	5/18 (27.8%)	0/8 (0%)	0/3 (0%)	None
	20–29°	2/3 (66.7%)	19/34 (55.9%)	12/28 (42.9%)	12/46 (26.1%)	3/26 (11.5%)	0/11 (0%)	0/2 (0%)
	≥30°	None	2/2 (100%)	4/4 (100%)	5/15 (33.3%)	3/18 (16.7%)	0/12 (0%)	0/1 (0%)

		Ulna grade					
		4	5	6	7	8	9
Cobb angle	10–19°	2/9 (22.2%)	12/26 (46.2%)	12/30 (40.0%)	2/12 (16.7%)	0/3 (0%)	0/1 (0%)
	20–29°	6/10 (60.0%)	20/30 (66.7%)	16/55 (29.1%)	4/34 (11.8%)	2/21 (9.5%)	None
	≥30°	1/1 (100%)	4/6 (66.7%)	6/11 (54.5%)	3/14 (21.4%)	0/18 (0%)	0/2 (0%)

Table 7. Relationship between DRU classification subgroup and commonly used parameters of maturity

	High risk	Moderate risk	Low risk
	R6, R7, and U5	R8 and U6	R9 and U7
Mean age (±SD), years	12.2 (±1.2)	13.1 (±1.2)	14.1 (±1.2)
Mean months from the onset of menarche (±SD)	-5.3 (±11.6)	0.8 (±13.4)	15.5 (±15.4)
US Risser stage			
0	62.6%	20.0%	0.9%
Composition ratio			
with Triradiate-open	61.6%	17.1%	0%
with Triradiate-close	38.4%	82.9%	100%
1	16.2%	14.9%	3.6%
2	11.7%	21.7%	15.2%
3	7.8%	26.9%	22.3%
4	1.7%	16.6%	51.8%
5	0%	0%	6.3%
French Risser stage			
0	62.6%	20.0%	0.9%
Composition ratio			
with Triradiate-open	61.6%	17.1%	0%
with Triradiate-close	38.4%	82.9%	100%
1	22.3%	25.1%	12.5%
2	11.7%	40.6%	27.7%
3	3.4%	13.7%	38.4%
4	0%	0.6%	20.5%
5	0%	0%	0%

DRU: distal radius and ulna; SD: standard deviation.

Table 8. Scoliosis progression rate within 1 year for each DRU classification and initial Cobb angle

		High risk	Moderate risk	Low risk
		R6, R7, and U5	R8 and U6	R9 and U7
Cobb angle	10–19°	45.3% (30.6–60.9%)	35.4% (20.9–53.4%)	10.0% (2.4–33.8%)
	20–29°	55.4% (40.6–69.4%)	27.7% (19.9–37.2%)	11.7% (5.1–24.5%)
	≥30°	83.3% (50.8–96.0%)	42.3% (23.1–64.2%)	18.8% (7.9–38.4%)

DRU: distal radius and ulna

Table 9. Probability of detecting scoliosis progression using Bernoulli trial

DRU classification	Cobb angle	3 months	6 months	9 months	12 months
High risk R6, R7, and U5	10–19°	14.0%	26.0%	36.4%	45.3%
	20–29°	18.3%	33.2%	45.4%	55.4%
	≥30°	36.1%	59.1%	73.9%	83.3%
Moderate risk R8 and U6	10–19°	10.4%	19.6%	28.0%	35.4%
	20–29°	7.8%	15.0%	21.6%	27.7%
	≥30°	12.8%	24.0%	33.8%	42.3%
Low risk R9 and U7	10–19°	2.6%	5.1%	7.6%	10.0%
	20–29°	3.1%	6.0%	8.9%	11.7%
	≥30°	5.1%	9.9%	14.5%	18.8%

DRU: distal radius and ulna

Table 10. Recommended follow-up duration for adolescent idiopathic scoliosis based on the DRU classification and initial Cobb angle

		High risk	Moderate risk	Low risk
		R6, R7, and U5	R8 and U6	R9 and U7
Cobb angle	10–19°	Within 6 months	6 months	12 months
	20–29°	3 months	6 months	12 months
	≥30°	Within 3 months	Within 6 months	Within 12 months

DRU: distal radius and ulna

Figure 1

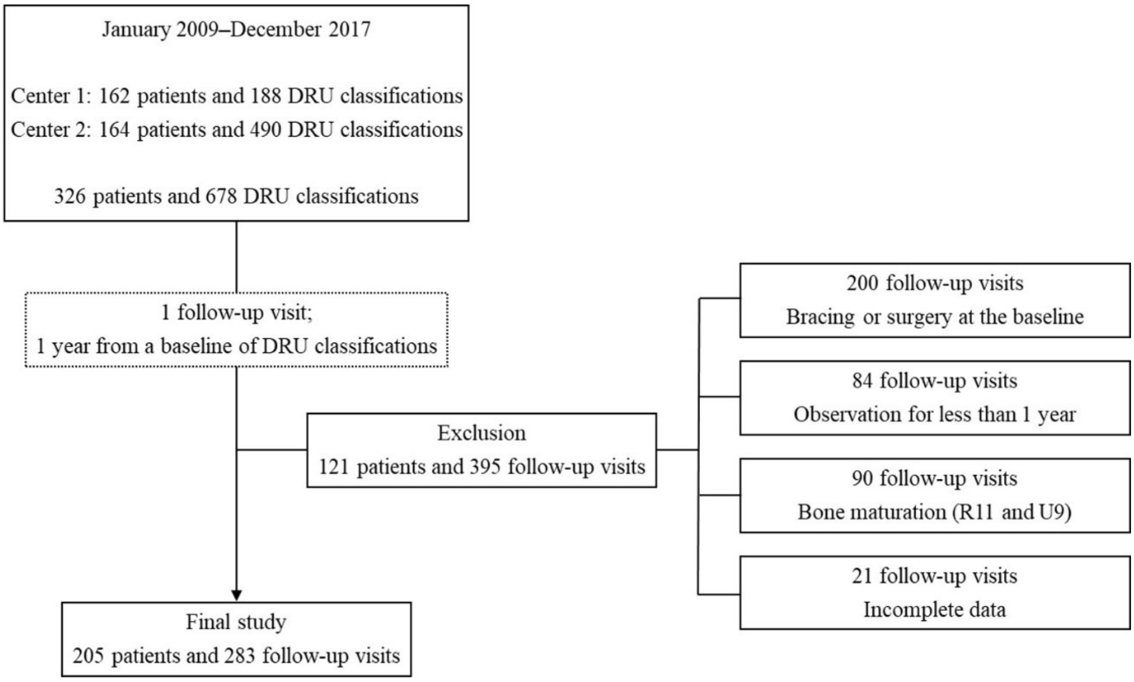

Figure 2

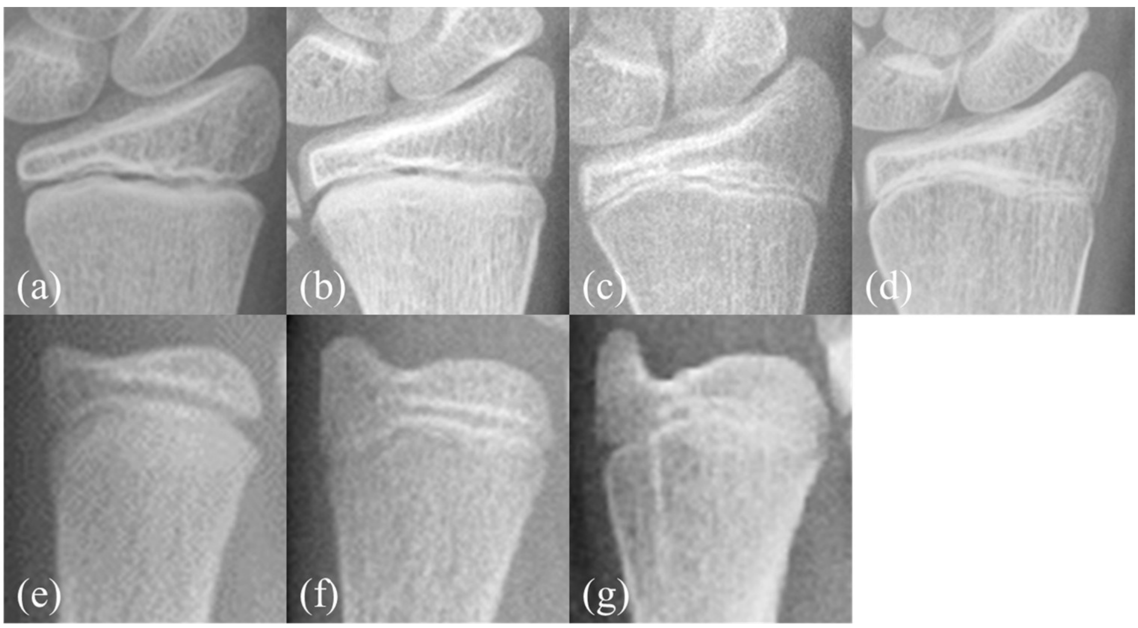

Figure legends

Fig. 1 Flow diagram of the initial study enrollment of 326 patients and 678 follow-up visits DRU classification and curves are indicated.

Fig. 2

(a) R6: Both medial and lateral parts of the epiphysis are wider than the metaphysis but without capping, (b) R7: Only the medial part of the epiphysis is capped on the same part of the metaphysis, (c) R8: Both medial and lateral parts of the epiphysis are capped over the metaphysis, and the center of the physeal line is narrower than both medial and lateral sides, (d) R9: The epiphysis is capped, and ossification of the physeal line is started, (e) U5: The head of the ulna is clearly seen and is denser than the styloid, (f) U6: The epiphysis is as wide as the metaphysis, and the physeal line is unclear at the central third because of overlapping, (g) U7: The medial physeal plate narrows, the medial border of the epiphysis and the metaphysis forms a smooth curve line, and fusion may begin on the medial side.