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Skeletal Age Assessment from the Olecranon for Idiopathic Scoliosis at Risser Grade 0

By Yann Philippe Charles, MD, Alain Diméglıo, MD, Federico Canavese, MD, and Jean-Pierre Daures, PhD, MD

Investigation performed at the Service d’Orthopédie Pédiatrique, Hôpital Lapeyronie and Institut Universitaire de Recherche Clinique, UFR Médecine, Université Montpellier, Montpellier, France

Background: The main progression of idiopathic scoliosis occurs during peak height growth velocity, which is between the ages of eleven and thirteen years in girls and thirteen and fifteen years in boys and corresponds to the accelerating phase of pubertal growth. The Risser sign remains at grade 0 during this stage of growth. Triradiate cartilage closure occurs at approximately twelve years of age in girls and fourteen years in boys, which is in the middle of this phase. In addition to regular height measurements, a more detailed evaluation of skeletal maturity would be desirable prior to the identification of Risser grade 1. From the method of Sauvegrain et al., Diméglıo derived a simplified method based on the radiographic appearance of the olecranon, which allows skeletal age to be assessed in six-month intervals. The purpose of this study was to determine the accuracy and the value of this simple method for the follow-up of patients with scoliosis.

Methods: Five radiographic images demonstrate the typical characteristics of the olecranon during pubertal growth: two ossification nuclei, a half-moon image, a rectangular shape, the beginning of fusion, and complete fusion. This classification method was evaluated by three experienced and independent observers from lateral radiographs of the elbow in 100 boys and 100 girls with idiopathic scoliosis during the time of peak height velocity. Skeletal ages were correlated with the integral Sauvegrain method. The degree of interobserver concordance was determined, and skeletal age was compared with chronological age and the time of triradiate cartilage closure.

Results: For the three observers, the average concordance between the Sauvegrain and olecranon methods was excellent ($r = 0.977$ for boys and $r = 0.938$ for girls). The interobserver agreement was also excellent ($r = 0.987$ for the olecranon method and $r = 0.958$ for the Sauvegrain method for boys, and $r = 0.992$ and $r = 0.985$, respectively, for girls). Skeletal and chronological age were considered to correspond to each other within a six-month range for 49% of the boys and 51% of the girls, while 25% of the boys and 26% of the girls had an advanced skeletal age and 23% of girls had a delayed skeletal age. Triradiate cartilage closure occurred at the same time as the appearance of the rectangular shape of the olecranon in 65% of the boys and 61% of the girls, corresponding to skeletal ages of fourteen and twelve years, respectively. In 91% of the boys and 88% of the girls, the triradiate cartilage fused within six months before to six months after the appearance of the rectangular shape of the olecranon, which occurred between the half-moon image and the beginning of fusion of the olecranon.

Conclusions: The method of assessing skeletal age from the olecranon allows skeletal maturity to be evaluated in regular six-month intervals during the phase of peak height velocity. This method is simple, precise, and reliable. It complements the Risser grade-0 and the triradiate cartilage evaluation.

Level of Evidence: Prognostic Level II. See Instructions to Authors for a complete description of levels of evidence.

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Skeleton maturity and remaining growth represent essential parameters that must be considered in the evaluation of the risk of curve progression in idiopathic scoliosis. Duval-Beaupère et al. as well as Lonstein and Carlson demonstrated that the main progression of idiopathic scoliosis occurs at the time of the most rapid adolescent skeletal growth, which occurs around eleven to thirteen years of skeletal age in girls and thirteen to fifteen years in boys. This growth phase...
corresponds to the accelerating phase of the pubertal growth diagram and is characterized by a gradual increase in the spinal growth rate. Peak height velocity is a reliable clinical marker for the prediction of remaining growth and the risk of curve progression in idiopathic scoliosis. Yet, during this growth phase, the Risser sign remains at grade 0. The Risser grade-1 sign appears only around a skeletal age of 13.5 years in girls and 15.5 years in boys.

Most current clinical and radiographic markers do not help pediatric orthopaedic surgeons to readily distinguish maturity levels prior to Risser grade 1. Triradiate cartilage closure is closely related to peak height velocity, with this period of accelerated spinal growth split into approximately two halves by the closure of the triradiate cartilage, which occurs around a skeletal age of twelve years in girls and fourteen years in boys. Triradiate cartilage closure is mainly used in the preoperative evaluation of the risk for the development of a crankshaft phenomenon after posterior spinal fusion in patients with an immature spine and an open triradiate cartilage.

A more detailed evaluation of skeletal maturity would be suitable during Risser grade 0, which corresponds to the phase of highest spinal growth velocity, in addition to a height measurement every six months and an assessment of the status of the triradiate cartilage. Precise information about maturity levels and remaining growth could help to better evaluate the efficacy of brace treatment, the curve progression risk, or the potential for the development of a crankshaft phenomenon. The method of Sauvégrain et al. for the assessment of skeletal age with use of radiographs of the elbow has been used in France over the last forty years, and a detailed analysis of this method has demonstrated its reliability during the time of peak growth velocity. A method used during the accelerating phase of the pubertal growth diagram, from a skeletal age of eleven to thirteen years in girls and thirteen to fifteen years in boys, at which time the development of elbow ossification centers is clearly identified. Complete elbow ossification correlates with the end of accelerated growth velocity and marks the beginning of the decelerating growth phase. Derived from the Sauvégrain method, a simplified method described by Diméglìo et al. is characterized by clear and regular morphological development of the olecranon during the accelerating growth phase. This method determines skeletal age to be evaluated very easily and accurately at intervals of six months.

The purpose of this study was to determine the accuracy of this simplified method of olecranon staging, to compare it with the time of triradiate cartilage closure, and to investigate its capacity to increase information on skeletal maturation during Risser grade 0 in patients with idiopathic scoliosis.

Materials and Methods

The medical records and radiographs of patients with juvenile or adolescent idiopathic scoliosis who were followed at our pediatric orthopaedic department between 1988 and 2006 were reviewed. From 561 complete and analyzable records, the charts of 100 boys and 100 girls were randomly selected for this retrospective study. The patients had to have been followed regularly every six months for a minimum of two years during the phase of peak height velocity with a Risser grade 0 (between eleven and thirteen years of skeletal age in girls and between thirteen and fifteen years in boys). The clinical and radiographic evolution of the scoliosis had to be well documented. Anteroposterior and lateral radiographs of the left elbow made to assess the skeletal age during this growth period had to be available. When more than one skeletal age assessment had been performed, only the first elbow radiograph was retained for the review in this study. Clinical growth parameters, such as standing height, sitting height, weight, and menarche, were documented on the checklist and the growth curve that is regularly used in our clinic. Patients with congenital scoliosis as well as scoliosis with an underlying neurological disorder, a syndrome, or an endocrinopathy were excluded from the study protocol. In juvenile idiopathic scoliosis, magnetic resonance imaging was carried out in addition to clinical and neurological examinations to detect any neural axis abnormality.

In the group of 100 boys, fifty-eight patients had juvenile scoliosis, with an onset of between four and ten years, and forty-two had adolescent scoliosis, with an onset after ten years. In the group of 100 girls, forty-nine patients had a juvenile scoliosis and fifty-one had an adolescent scoliosis.

Standing and sitting height were measured in centimeters every six months, including five consecutive measurements during two years, which allowed the calculation of average annual growth velocity for standing and sitting height, respectively, as follows: (last height measurement – first height measurement) / 2 (years). Age at menarche was also documented.

The Sauvégrain method is used shortly before the onset of puberty and during the first two years of the pubertal growth spurt, from a skeletal age of ten to thirteen years in girls and twelve to fifteen years in boys. This method determines skeletal age from anteroposterior and lateral radiographs of the left elbow and is based on a 27-point scoring system, which assesses four ossification centers. The lateral condyle (1 to 9 points), the trochlea (1 to 5 points), the olecranon apophysis (1 to 7 points), and the proximal radial epiphysis (1 to 6 points) are rated according to their developmental stage. The scores are added together, and the total score allows skeletal age in years to be assessed on a graph for girls and a graph for boys. These graphs contain typical scores of skeletal ages at intervals of six months, which allow a clear and regular differentiation of skeletal age during the phase of peak height velocity.

Derived from the Sauvégrain method, the simplified olecranon method developed by Diméglìo allows skeletal age in intervals of six months to be assessed easily and quickly. Five images of the olecranon are identified, with two ossification nuclei indicating eleven years of age in girls and thirteen years in boys; a half-moon image, 11.5 years in girls and 13.5 years in boys; a rectangular aspect, twelve years in girls and fourteen years in boys; the beginning of fusion, 12.5 years in girls and 14.5 years in boys; and a complete fusion, thirteen years in girls and fifteen years in boys (Fig. 1).
In order to compare this simplified method of skeletal age assessment from the olecranon with the entire Sauvegrain method, the elbow radiographs of the 100 girls and 100 boys with idiopathic scoliosis were reviewed once by three independent and experienced pediatric orthopaedic surgeons who had all routinely used both methods for a minimum of two years in their practice. No time limit was imposed for skeletal age determination with use of the Sauvegrain method or the olecranon method, which were used respectively in two separate review sessions. Prior to the review, the name and age of the patient were omitted from all radiographs, which were marked with consecutive numbers from one to 200 by an individual who did not participate in the study. Apart from gender, information about the patients was not accessible to any of the observers during the analysis of the radiographs. The skeletal age as well as the respective chronological age of the patient were then stored in a data file.

After the review of the elbow radiographs was completed, the three observers analyzed a series of five consecutive posteroanterior radiographs of the spine made when the patient was at Risser grade 0 during the growing period of peak height velocity. The time of triradiate cartilage closure was compared with the chronological age and the skeletal age from the olecranon. Triradiate cartilage closure was considered to correspond to stage 2 of the Oxford method for assessing skeletal age from the pelvis. The radiographic status of the triradiate cartilage was discussed by the three observers in order to minimize intraobserver and interobserver errors.

**Statistical Analysis**

The concordance correlation coefficient of Lin was used to analyze the concordance between skeletal age data assessed with the olecranon method and skeletal age data assessed with the Sauvegrain method for each observer separately. Furthermore, the concordance between the three observers was analyzed for each method of skeletal age assessment. According to the Landis and Koch scale for intraclass correlation coefficients, the concordance was considered to be excellent if
r > 0.80, good if r = 0.61 to 0.80, fair if r = 0.41 to 0.60, and poor if r ≤ 0.40.

**Results**

**Standing Height Velocity, Sitting Height Velocity, and Menarche**

Growth velocities of standing and sitting height were analyzed during the first two years of the pubertal growth spurt. Clinically, the beginning of this phase was detected by a sharp increase in growth velocity when the skeletal age was approximately eleven years in girls and thirteen years in boys.

In the boys, the average chronological age was 13.89 ± 1.01 years (range, 12.2 to 15.5 years), while the average skeletal age was 12.11 ± 0.40 years (range, 11.0 to 14.3 years). Menarche occurred at an average chronological age of 13.11 ± 1.03 years (range, 11.0 to 16.0 years).

**Concordance Between the Olecranon and Sauvegrain Methods**

An excellent concordance was noted between skeletal ages assessed by means of the olecranon method and skeletal ages assessed with use of the Sauvegrain method (average concordance, r = 0.977 for boys and r = 0.938 for girls). Correlation coefficients and respective confidence intervals in Table I demonstrate that this finding applies for each of the three observers equally. There was no difference when boys were compared with girls.

**Interobserver Concordance of the Olecranon and Sauvegrain Methods**

The correlation coefficients in Table II show that the concordance among the three observers was equally excellent for skeletal ages assessed by means of the olecranon method or by the Sauvegrain method. A comparison of the genders demonstrated no discrepancy between the skeletal ages of boys and girls.

**Comparison of Chronological and Skeletal Age Data**

In the boys, the average chronological age was 13.89 ± 1.01 years (range, 12.2 to 15.5 years), while the average skeletal age determined with the olecranon method was 13.82 ± 0.69 years (range, 13.0 to 15.0 years).

In the girls, the average chronological age was 12.01 ± 1.16 years (range, 10.0 to 14.3 years), while the average skeletal age was 12.17 ± 0.68 years (range, 11.0 to 13.0 years).

Chronological age and skeletal age assessed with the olecranon method were considered to be the same if the difference was less than six months. Skeletal age was defined as **advanced** if it exceeded chronological age by more than six months and as **delayed** if it was less than the chronological age by at least six months. Table III shows that chronological age and skeletal age corresponded to one another within a six-month range in 49% of the boys and 51% of the girls.

**Triradiate Cartilage Closure**

The time of triradiate cartilage closure was compared with the chronological age and with the skeletal age assessed with the olecranon method. The determination of triradiate cartilage closure and skeletal age was based on the consensus of the three observers who worked together in this part of the study. However, this review of the spine radiographs and all available elbow radiographs for each patient was completed only after the initial review of independent skeletal age-grading had been completed.

In the boys, the average chronological age at the time of triradiate cartilage closure was 14.55 ± 1.01 years (range, 12.4 to 16.2 years), and the average skeletal age was 14.02 ± 0.44 years (range, 13.5 to 15.0 years).

In the girls, the average chronological age at the time of triradiate cartilage closure was 12.08 ± 0.87 years (range, 10.3 to 13.8 years), while the average skeletal age was 12.11 ± 0.40 years (range, 11.5 to 13.0 years).

Triradiate cartilage closure occurred at the time of the appearance of the rectangular shape of the olecranon apophysis in 65% of the boys and 61% of the girls and corresponded to a skeletal age of fourteen years in the boys and twelve years in the girls (Fig. 1). In 91% of the boys and in 88% of the girls, triradiate cartilage closure occurred within six months before to six months after the appearance of the rectangular shape of the olecranon.

**Discussion**

The progression of scoliosis is closely related to the beginning of the pubertal growth spurt, which is character-
ized by a gradual but major increase in spinal growth velocity with an increase in the risk of scoliosis progression\textsuperscript{5,22,23}. This phase of accelerating growth velocity lasts approximately two years, from eleven to thirteen years of skeletal age in girls and from thirteen to fifteen years in boys, with an average increase in sitting height of 7.5 cm in girls and 8.5 cm in boys\textsuperscript{3,4}. Little et al.\textsuperscript{6} and Song and Little\textsuperscript{7} demonstrated that peak height velocity, determined with use of clinical standing height measurements, is a valuable marker to predict remaining growth. Growth curves in these studies showed that a standing height velocity of >6 cm per year in girls and >8 cm per year in boys implies that the patient is within his or her greatest growth spurt. Analogue values reported by Dimélio\textsuperscript{3,4} show that the average gain in sitting height during the two years of peak height velocity is 14.5 cm in girls and 16.5 cm in boys. Retrospective height measurements in our study are comparable with those results and confirm that these patients were in the period of their most rapid adolescent growth\textsuperscript{3,4}. Even if standing height velocity is used, it is important to consider sitting height velocity, which reflects trunk growth. These dual height measurements allow the determination of the increase in the length of the lower limb segment and the increase in the spine length, events which occur nearly six months apart\textsuperscript{5,10}.

Menarche is used for the follow-up and treatment of girls with idiopathic scoliosis. Menarche most often occurs when

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
 & Boys & Girls \\
\hline
Advanced >6 months & 25\% & 26\% \\
Corresponding 6 months & 49\% & 51\% \\
Delayed >6 months & 26\% & 23\% \\
\hline
\end{tabular}
\caption{Skeletal Age Assessed from the Olecranon Compared with the Chronological Age in 100 Boys and 100 Girls}
\end{table}

Fig. 2
Application of the olecranon method in the evaluation of curve progression risk during the accelerating pubertal growth phase of peak height velocity at Risser grade 0. Y cartilage closure = triradiate cartilage closure.
the rate of growth is slowing, at the beginning of the decelerating growth phase, usually between the skeletal age of thirteen and 13.5 years, and it corresponds to Risser grade 1 at the iliac apophysis. Little et al. showed that menarche occurred at a median of seven months after peak height velocity. For instance, at this stage of puberty, the average remaining growth approximates 4 cm on sitting height during the phase of decelerating growth velocity. Although chronological age was the only analyzable data point to determine menarchal age in the present study, our results confirm that menarche often occurs after peak height velocity. Furthermore, the large range of menarchal age from eleven to sixteen years in this study makes this indicator less precise when predicting remaining growth. However, menarche should be considered as an approximate landmark of the pubertal growth spurt, which indicates that spinal growth will probably cease two years after menarche if it occurs around Risser grade 1. The spinal growth velocity progressively decreases from this point, which makes maximal curve progression unlikely following menarche.

The Risser sign is used widely to assess spinal maturity, although the main risk for progression of idiopathic scoliosis occurs prior to the appearance of Risser grade 1. Risser grade 0 lasts for approximately two-thirds of the pubertal growth period, and it needs to be segmented into clearer stages to allow for the evaluation of skeletal maturity in a more precise manner. Our study indicates that chronological age is an insufficient marker for the evaluation of skeletal maturity as chronological age corresponded to skeletal age within a six-month range in only 49% of the boys and 51% of the girls. Skeletal age data from the hand and wrist according to the method of the Greulich and Pyle atlas are difficult to assess precisely from the age of eleven to thirteen years in girls and from thirteen to fifteen years in boys because radiographic morphological changes are difficult to interpret and because this atlas is not regularly divided into six-month intervals during this period. Sanders et al. confirmed that morphological changes in the wrist, radius, and ulna were not correlated to curve progression during peak height velocity, but they presented a new method of assessment of digital skeletal age derived from the Tanner-Whitehouse-3 method, which is based on a radiographic analysis of the metacarpals and fingers. This method provides several markers prior to Risser grade 1 and could eventually add helpful information to Risser grade 0 in the future. The time of triradiate cartilage closure in the pelvis represents a valuable radiographic marker during Risser grade 0. Song and Little demonstrated that triradiate cartilage closure is closely related to peak height velocity and precedes the appearance of Risser grade 1. Triradiate cartilage closure occurs approximately halfway through the phase of accelerated growth velocity, between the ages of eleven and thirteen years in girls and between thirteen and fifteen years in boys. Our study confirms the finding that triradiate cartilage closure occurs around the age of twelve years in girls and around fourteen years in boys. When this radiographic marker in the pelvis was related to skeletal age data, the time frame when triradiate cartilage closure occurred became quite narrow, with full closure noted between 11.5 and 12.5 years in 88% of the girls and between 13.5 and 14.5 years in 91% of the boys. This indicates that the triradiate cartilage status is a relatively precise marker for the evaluation of skeletal maturity during Risser grade 0 even though it represents only one point during a period of peak height velocity of two years.

The Sauvegrain method uses the elbow to assess skeletal age during this phase of the pubertal growth spurt. The introduction of additional scores on the four ossification centers of the elbow and the development of simplified graphs for skeletal age assessment allowed improved reliability of this method and simplified its use. Derived from this method, the olecranon is characterized by a clear and regular morphological development during this period. As described by Diméglio et al., grading of the olecranon apophysis allows one to evaluate skeletal age very easily in six-month intervals from the ages of eleven to thirteen years in girls and from thirteen to fifteen years in boys. The morphological sequence of five distinct images of the olecranon develops over this relatively short period of two years, making this method simple to use every six months. Furthermore, the learning curve of this simplified method is short. In the present study, all three observers were familiar with this method. Therefore, further studies that include less experienced observers would be necessary to demonstrate that a novice to the method is as accurate as one with experience. The results in the present study demonstrate that, although only one ossification center is considered, the olecranon method is as precise and reliable as the Sauvegrain method for the evaluation of skeletal age from the age of eleven years in girls and thirteen years in boys, which is the stage of puberty when the growth velocity is increasing and is typically characterized by the occurrence of a second ossification center on the olecranon apophysis. The skeletal age of twelve years in girls and fourteen years in boys corresponds to the appearance of a typical rectangular shape of the olecranon ossification center. A concordance between this stage and the time of triradiate closure was noted in 65% of the boys and in 61% of the girls. Complete fusion of the olecranon and all other elbow physis occurs at the skeletal age of thirteen years in girls and fifteen years in boys, which indicates that pubertal growth velocity decreases rapidly from this point of skeletal maturity. Complete olecranon physeal fusion divides the two main phases of accelerating and decelerating height velocity from each other.

Accurate measures of maturity are required when evaluating the efficacy of brace treatment of scoliosis. Duval-Beaupère et al. demonstrated the importance of annual growth velocity and secondary sexual characteristics to identify the beginning of the pubertal growth spurt, a decisive period for curve progression. Lonstein and Carlson noted that three strong fractures for the progression of idiopathic scoliosis were the curve magnitude along with the chronological age and the Risser sign. Nevertheless, patients with idiopathic juvenile scoliosis have a spinal deformity prior to the onset of the pubertal growth spurt and go through the entire period of peak height velocity at Risser grade 0. The curve progression risk
with juvenile scoliosis is higher, with approximately half of these patients needing surgical treatment. Therefore, growth in these younger patients needs systematic follow-up. In addition to height measurements at six-month intervals, skeletal age assessment from the olecranon appears to be helpful in the evaluation of skeletal maturity. It complements the lack of information of Risser grade 0, which is the phase where 90% of surgically treated curves primarily increase, and it aids in the identification of patients with juvenile scoliosis who are at higher risk of progression (Fig. 2).

In Risser grade 0, the olecranon helps to identify immature patients with scoliosis (i.e., patients with two ossification nuclei or a half-moon-shaped nucleus of the olecranon) who are at risk of developing a crankshaft phenomenon at the posterior spinal fusion. The need for an anterior anular release and discectomy to avoid remaining vertebral body growth can be more accurately determined and may be of use for patients treated with vertebral body stapling.

The morphological development of the olecranon represents a simple but reliable method of skeletal age assessment during the phase of peak height velocity. It allows skeletal age to be determined in regular six-month intervals from the ages of eleven to thirteen years in girls and from thirteen to fifteen years in boys. This information complements Risser grade 0, corresponding to the critical phase of accelerating growth velocity, and the triradiate cartilage closure, which occurs at around twelve years in girls and fourteen years in boys. Complete olecranon physeal fusion occurs between the two main phases of accelerating and decelerating growth velocity during puberty. This method should be correlated with regular height measurements and Tanner stages. All of these parameters can help to better evaluate the efficacy of brace treatment, to identify scoliosis that is at high risk of progressing during pubertal growth, and to identify patients who are at higher risk for developing the crankshaft phenomenon following posterior spinal fusion.

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