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Commentary and Perspective, data tables, additional images, video clips and/or translated abstracts are available for this article. This information can be accessed at <http://www.ejbjs.org/cgi/content/full/87/8/1689/DC1>

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# ACCURACY OF THE SAUVEGRAIN METHOD IN DETERMINING SKELETAL AGE DURING PUBERTY

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**Background:** The method of Sauvegrain et al. for the assessment of skeletal age from radiographs of the elbow is useful during the two years of the pubertal growth spurt. The purpose of this study was to determine the accuracy of the method and its value in pediatric orthopaedics.

**Methods:** The Sauvegrain method uses four anatomical landmarks of the elbow: the lateral condyle, trochlea, olecranon apophysis, and proximal radial epiphysis. It is based on a 27-point scoring system. The scores for these structures are summed, and a total score is determined. A graph is then used to determine the skeletal age. The method was evaluated by three independent observers who used it to assess skeletal age on anteroposterior and lateral radiographs of the left elbow of sixty boys and sixty girls and compared the results with assessments made with use of the Greulich and Pyle atlas on posteroanterior radiographs of the left hand and wrist. Skeletal age determinations were performed twice by each observer at a four-week interval.

**Results:** The skeletal age determination from radiographs of the elbow was more precise because a clear semianual age determination was possible. On the basis of the rating by the observers, the Sauvegrain method presented excellent interobserver correlation ( $r = 0.93$ ) and excellent reproducibility ( $r = 0.96$ ). The correlation between the methods of Sauvegrain et al. and Greulich and Pyle was good ( $r = 0.85$ ). Nevertheless, certain elbow growth centers showed an intermediate developmental morphology, which failed to correspond to the score described by Sauvegrain et al. This led to errors in the interpretation of data. We suggest an intermediate score for these cases, and we modified the original graph to make it more accurate.

**Conclusions:** The modified method of Sauvegrain et al. is simple, reliable, and reproducible, and it complements the Greulich and Pyle atlas. In clinical practice, maturity can best be evaluated by associating skeletal age, annual growth rate, and secondary sexual characteristics. Therefore, this method is useful when major decisions such as the timing of epiphysiodesis or spinal arthrodesis are necessary during puberty.

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

The determination of skeletal age is a controversial but useful and necessary parameter in pediatric orthopaedics<sup>1,2</sup>. Decisions regarding epiphysiodesis or spinal arthrodesis as well as predictions of limb-length discrepancy and standing height are influenced by skeletal age and are usually made during puberty.

Many different methods are used to assess skeletal maturity<sup>3-10</sup>. Each method involves very different parts of the skeleton. The Oxford method of Acheson<sup>4</sup> is based on the pelvis; the method of Pyle and Hoerr<sup>5</sup>, on the knee; the method of Hoerr et al.<sup>6</sup>, on the foot; and those described by Tanner et al.<sup>7</sup>, Sempé and Pavia<sup>8</sup>, De Roo and Schröder<sup>9</sup>, and Greulich and Pyle<sup>10</sup> are based on the hand and wrist.

The Greulich and Pyle atlas<sup>10</sup> is the most widely used

method based on the hand and wrist. Individual ossification centers are used as indicators of maturity as they tend to occur and develop regularly in a definite order. The chronological age when the various indicators appear was determined in order to assign a skeletal age to a typical developmental status. In clinical practice, these morphological characteristics on posteroanterior radiographs of the left hand and wrist are compared with references in the Greulich and Pyle atlas<sup>10</sup>. Nevertheless, the atlas has some disadvantages during the time of the pubertal growth spurt. It is not regularly divided in six-month intervals. There are no standards that correspond to the skeletal ages of 11.5 and 12.5 years in girls as well as 14.5 years in boys. During the phase of increased growth velocity, between eleven and thirteen years of age in girls and between

thirteen and fifteen years in boys, the morphological changes of the hand and wrist are neither obvious nor important. The beginning of puberty is marked by the appearance of the sesamoid of the first ray. The end is characterized by advanced fusion in the epiphyses of the distal phalanx of the thumb and the first metacarpal. Other developmental signs described by Greulich and Pyle<sup>10</sup>, such as the shape of the radial and ulnar epiphyses related to the metaphysis, the outline of the hamulus of the hamate, or the wideness of the metacarpal epiphyses, present many nuances and are difficult to evaluate.

Cundy et al.<sup>11</sup> demonstrated that the Greulich and Pyle atlas<sup>10</sup> had a large interobserver error, which is problematic in the assessment of skeletal maturity during pubertal growth. Little et al.<sup>12</sup> demonstrated that the use of the Greulich and Pyle atlas could not improve accuracy in the prediction of limb-length inequality.

In order to compensate for the difficulties with the Greulich and Pyle atlas<sup>10</sup>, Sauvegrain et al.<sup>13</sup>, in 1962, developed a method to determine skeletal age from elbow radiographs. The elbow is characterized by clear developmental sequences of its ossification centers beginning at nine years of age in girls and eleven years in boys. Fusion of the elbow growth centers is complete at thirteen years in girls and fifteen years in boys. The method has been used successfully in France<sup>14</sup> and in Belgium<sup>15</sup> for the past forty years.

The purposes of this study were to describe this method, to demonstrate its reliability, and to investigate its capacity to replace or complement information provided by the Greulich and Pyle atlas<sup>10</sup>.

### Materials and Methods

The method of Sauvegrain et al.<sup>13</sup> determines skeletal age from anteroposterior and lateral radiographs of the left

elbow. It is based on a 27-point scoring system and takes into account the following four anatomical structures of the elbow: 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). As shown in Figure 1, each score corresponds to the specific developmental status of these anatomical landmarks. Once each of these structures has been rated, the scores are summed and the total score is placed on a graph (Fig. 2). The skeletal age is then determined. The graph represents a mean curve of points corresponding to characteristic scores for each age. It contains two separate curves—one for boys and one for girls. However, this method can only be used shortly before the onset and during the first two years of puberty, which are marked by an increased growth velocity and the development of secondary sexual characteristics<sup>1,2</sup>.

In order to test this method, assessments of skeletal age were performed on sixty boys and sixty girls during the pubertal period by three observers, including two experienced pediatric orthopaedists (A.D. and V.dR.) and an orthopaedic resident (Y.P.C.). Their training consisted only of the previous routine use of the method of Sauvegrain et al. in the pediatric orthopaedic clinics; no other advice or training was given. All three observers worked independently, and no time limit was imposed on the review. Skeletal age determination was performed twice by each observer. There was an interval of four weeks between both grading sessions, and all radiographs were mixed before the second analysis. The radiographs were blinded with respect to name and age by an individual who did not participate in the review and who transferred the data to a separate file in order to compare chronological and skeletal age after all observers had completed the second review. This information was not accessible to any of the observers during the analysis of the radiographs.

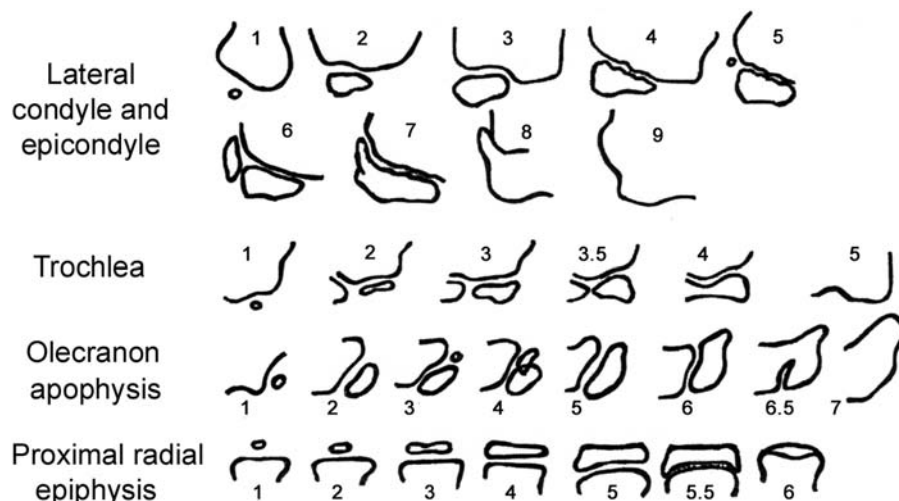


Fig. 1

The scoring system for the four ossification centers of the elbow. Characteristic scores, such as 3.5 points for the trochlea, 6.5 points for the olecranon apophysis, and 5.5 points for the proximal radial epiphysis, were added to the score developed by Sauvegrain et al., after radiographic and statistical review, to give the method greater reliability.

TABLE I Intraclass Correlation Coefficients Between Observers

	Girls		Boys	
	First Review	Second Review	First Review	Second Review
Age method of Sauvegrain et al.	0.96	0.96	0.88	0.90
Point method of Sauvegrain et al.	0.97	0.97	0.93	0.95
Points for lateral condyle	0.95	0.95	0.90	0.90
Points for olecranon apophysis	0.96	0.97	0.92	0.93
Points for proximal radial epiphysis	0.77	0.79	0.64	0.62
Points for trochlea	0.92	0.92	0.94	0.95
Age method according to atlas of Greulich and Pyle	0.89	0.93	0.79	0.89

These skeletal ages were then compared with those determined from posteroanterior radiographs of the left hand and wrist with use of the Greulich and Pyle atlas<sup>10</sup>. These radiographs were from the same sixty boys and sixty girls. They were made at the same time as the elbow radiographs. An identical review protocol was applied to the hand and wrist radiographs so as to determine the degree of correlation between the two types of skeletal age assessment.

The children were all healthy and had no history of systemic illnesses or endocrinopathies. They presented with

abnormalities such as idiopathic limb-length discrepancies, idiopathic scoliosis, or sequelae of epiphyseal trauma of the lower limb. In clinical practice, we usually determine other factors, such as measurement of sitting and standing height and the secondary sexual characteristics, to provide a better assessment of puberty. In this study, these parameters were not taken into account.

In the course of the first and second analyses, we observed the degree of correlation among the three observers with respect to the use of the methods of Sauvegrain et al.<sup>13</sup> and Greulich and Pyle<sup>10</sup> by calculating intraclass correlation coefficients.

Intraclass correlation coefficients were also calculated for each observer's grading obtained throughout the first and the second review in order to evaluate the reproducibility of the two methods of skeletal age assessment.

#### Statistical Analysis

Statistical analysis was performed the same way for both groups of subjects. The data obtained were treated with use of the intraclass correlation coefficient for quantitative or scale data. The value of the results was expressed with use of the Kohr classification: correlation 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  $r \leq 0.40$ .

#### Results

##### Method of Sauvegrain et al.

The mean correlation coefficient among the three observers was  $r = 0.93$ , which indicated an excellent correlation for the method of Sauvegrain et al.<sup>13</sup>. A detailed analysis of the 27-point scoring system used for the elbow demonstrated excellent correlation between the various observers ( $r = 0.96$ ); excellent correlation was also found with respect to the scores for the lateral condyle ( $r = 0.93$ ), the olecranon apophysis ( $r = 0.95$ ), and the trochlea ( $r = 0.93$ ). For the proximal radial epiphysis, the mean interobserver correlation coefficient was  $r = 0.71$ . As shown in Table I, no major discrepancy in the correlation coefficients was found between the first and second review or between boys and girls, when the results of the integral scoring system as well as those of the four anatomical areas were analyzed separately. Nevertheless, some intermediate images with scores of between 6 and 7 points for the olecranon

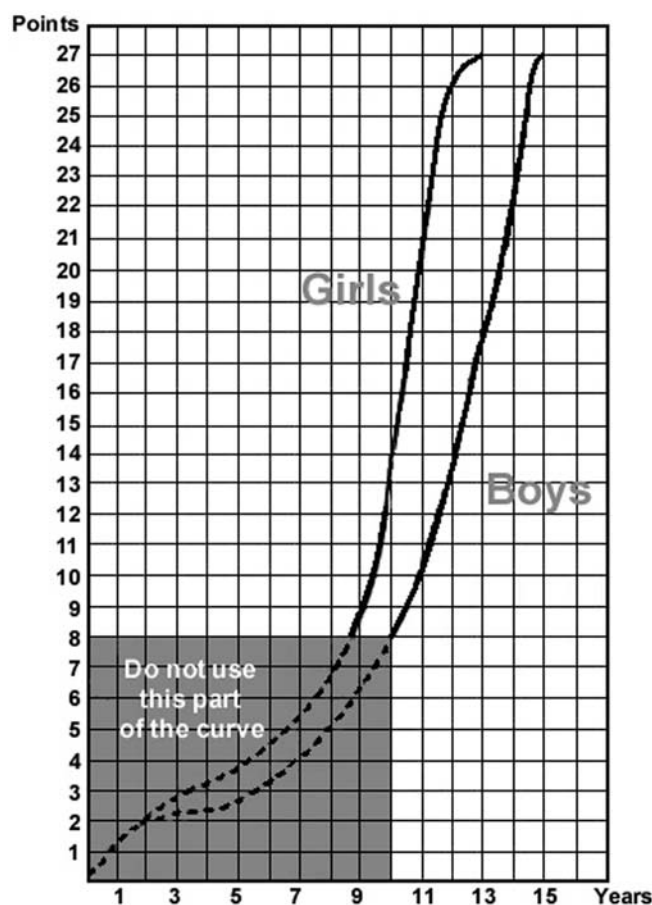


Fig. 2  
Graph of the method of Sauvegrain et al. for determining skeletal age.

**TABLE II Intraobserver Reproducibility During  
First and Second Assessment**

	Comparison of First and Second Review	
	Girls	Boys
Observer 1		
Method of Sauvegrain et al.	0.92	0.98
Method of Greulich and Pyle	0.89	0.94
Observer 2		
Method of Sauvegrain et al.	0.93	0.97
Method of Greulich and Pyle	0.96	0.92
Observer 3		
Method of Sauvegrain et al.	0.98	0.96
Method of Greulich and Pyle	0.89	0.91

apophysis were frequently observed and were a potential source of error. When these scores were extracted and analyzed separately, the mean interobserver agreement ( $r = 0.82$ ) was lower. The same was true for scores of 5 and 6 points for the proximal radial epiphysis ( $r = 0.42$ ) as well as scores of 3 and 4 points for the trochlea ( $r = 0.81$ ).

Moreover, the mean correlation coefficient of  $r = 0.96$  showed an excellent intraobserver reproducibility between the first and second analysis for the complete method of Sauvegrain et al.<sup>13</sup> Table II indicates the intraclass correlation coefficients obtained for each observer and for each group of subjects.

#### *Atlas of Greulich and Pyle*

An excellent correlation between observers of  $r = 0.88$ , on the average, was noted. An equally excellent intraobserver reproducibility ( $r = 0.92$ ) was seen between the first and second analyses (Tables I and II).

#### *Comparison of the Method of Sauvegrain et al. and the Atlas of Greulich and Pyle*

Skeletal age determination based on radiographs of the hand and wrist and based on radiographs of the elbow demonstrated a strong correlation between the two methods, with a mean coefficient of  $r = 0.85$ . In Table III, all correlation coefficients calculated by category (observer, cycle of analysis, and gender) are shown.

When the overall agreement of both methods was analyzed, the observers differed by two years or more for three (5%) of the sixty girls and for five (8%) of the sixty boys according to the atlas of Greulich and Pyle<sup>10</sup>. No disagreement of two years or more occurred when the method of Sauvegrain et al.<sup>13</sup> was used.

When the two methods were compared, the method of Sauvegrain et al.<sup>13</sup> was found to be more accurate because it allowed a clearer differentiation of skeletal age in six-month intervals. The atlas of Greulich and Pyle<sup>10</sup> is made up of single annual serial determinations for girls, and the six-month age increments for boys are incomplete. There are no references

corresponding to 14.5 years in boys and 11.5 and 12.5 years in girls. Agreement between these two methods can therefore be evaluated only in terms of complete years: thirteen, fourteen, and fifteen years of age in boys and eleven, twelve, and thirteen years of age in girls.

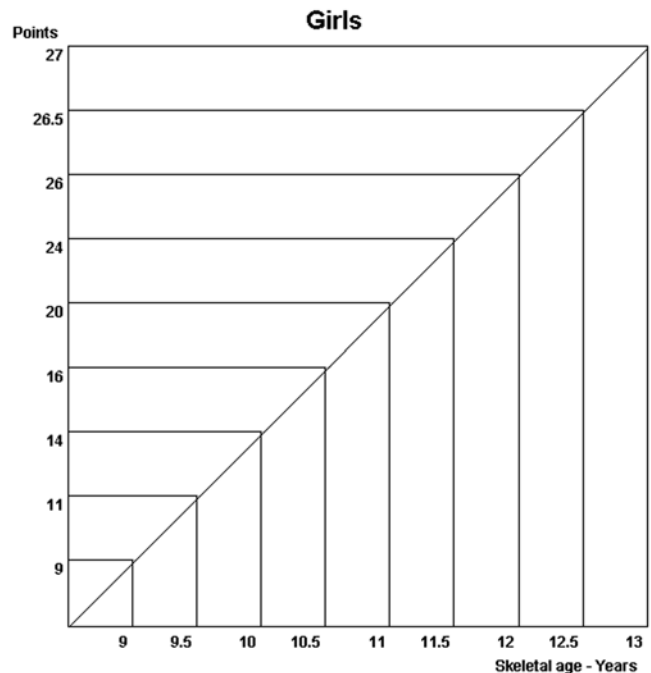


Fig. 3-A

Recalibrated graph for girls, allowing more accurate skeletal age determination.

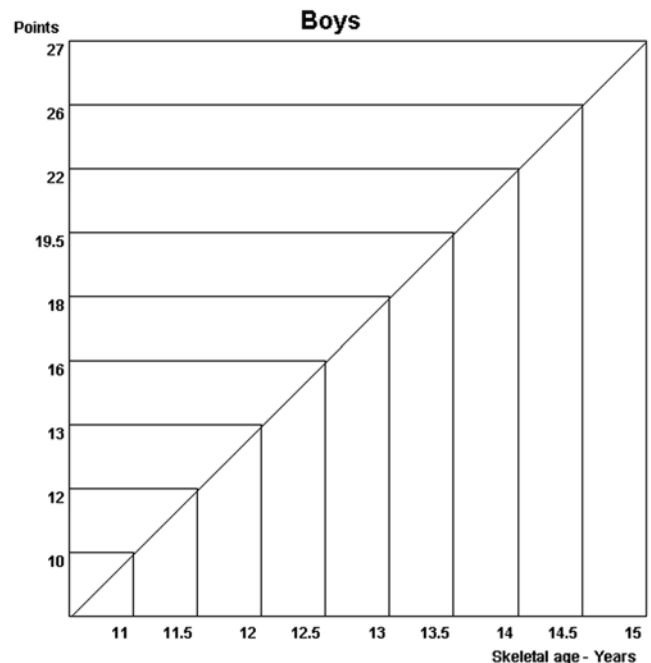


Fig. 3-B

Recalibrated graph for boys.



Fig. 4-A



Fig. 4-B

**Figs. 4-A, 4-B, and 4-C** Intermediate scores for the system of Sauvegrain et al. **Fig. 4-A** Intermediate score of 3.5 points for the trochlea. **Fig. 4-B** Intermediate score of 6.5 points for the olecranon apophysis.

#### *Comparison of Data for Chronological and Skeletal Age*

Chronological age and skeletal age were considered to be the same if the difference between them was not greater than six months. These ages were the same for twenty (33%) of the sixty boys and for twenty-one (35%) of the sixty girls, according to the method of Sauvegrain et al.<sup>13</sup> When the atlas of Greulich and Pyle<sup>10</sup> was used, the chronological and skeletal ages for eighteen (30%) of the sixty boys and seventeen (28%) of the sixty girls ranged within this margin. A statistical correlation analysis between chronological and skeletal ages was not performed because skeletal maturity may be advanced or delayed in some patients.

#### **Discussion**

The method of Sauvegrain et al.<sup>13</sup> was found, on the basis of our results, to have advantages over the atlas of Greulich and Pyle<sup>10</sup>. The method is dynamic because morphological transformations apparent on elbow radiographs are clear and easily assessed. At the onset of puberty (eleven years of age in girls and thirteen years in boys), the elbow is still largely cartilaginous. Two years later, fusion of the elbow growth centers is complete. This period is critical since it is marked by the pubertal growth spurt. It is an accurate method and was found to be more detailed than the Greulich and Pyle atlas. It allows the evaluation of skeletal age in six-month intervals. This is most valuable during puberty when events occur in quick succession. It is a practical method because, with practice, it is possi-



Fig. 4-C

Intermediate score of 5.5 points for the proximal radial epiphysis.

**TABLE III Correlation Between Methods of Sauvegrain et al. and Greulich and Pyle**

	Girls		Boys	
	First Review	Second Review	First Review	Second Review
Observer 1	0.93	0.94	0.89	0.84
Observer 2	0.83	0.88	0.84	0.73
Observer 3	0.78	0.84	0.81	0.85

ble to interpret skeletal age in less than a minute. It is also a reproducible method.

Nevertheless, the method of Sauvegrain et al.<sup>13</sup> has its limitations. It is restricted to the period of the pubertal growth spurt and to the year preceding this phase, that is, between ten and thirteen years of age in girls and between twelve and fifteen years in boys. Prior to the prepubertal period, the elbow is mainly cartilaginous and changes in the ossification centers cannot clearly be differentiated at this stage.

The method does provide, however, the possibility of dividing puberty into two phases: acceleration and deceleration. Acceleration in the velocity of growth occurs between eleven and thirteen years of skeletal age in girls, who gain an average of 12 cm in standing height, and between thirteen and fifteen years of skeletal age in boys, who gain an average of 14 cm in standing height during this time. This period is called the "ascending phase" of pubertal growth. Growth centers of the elbow are open and ossify progressively during this time. The beginning of this phase is determined by the radiographic appearance of a second growth center in the olecranon apophysis. The Risser sign<sup>16</sup> is still grade 0 within this portion of growth. Deceleration of the growth rate occurs between thirteen and sixteen years of skeletal age in girls and between fif-

teen and eighteen years of skeletal age in boys. Physeal closure at the elbow marks the beginning of the phase known as the "descending phase" of pubertal growth, and the Risser sign of 1 usually appears six months after elbow physeal closure.

Nevertheless, several weak points in the use of the method of Sauvegrain et al.<sup>13</sup> were identified as a result of our work. The curves established by Sauvegrain et al.<sup>13</sup> were difficult to read especially in the upper part (see Fig. 2). These curves were recalibrated so as to facilitate the mapping of scores on a more accessible graph (Figs. 3-A and 3-B). The morphology of certain ossification centers illustrated by Sauvegrain et al. in their original study proved to be a source of ambiguity and errors in the interpretation of data. When the available image failed to correspond precisely to the outline of the landmark, we suggested an intermediate score. A particular morphological characteristic should be inserted between the olecranon apophysis classified as 6 and 7 points and given a score of 6.5 points. Likewise for the trochlea between scores 3 and 4 and for the proximal radial epiphysis between 5 and 6 points (Figs. 1, 4-A, 4-B, and 4-C). These further precisions provide the method with greater reliability. For instance, the score of 5.5 points given to the proximal radial epiphysis will greatly improve the interobserver correlation coefficient espe-

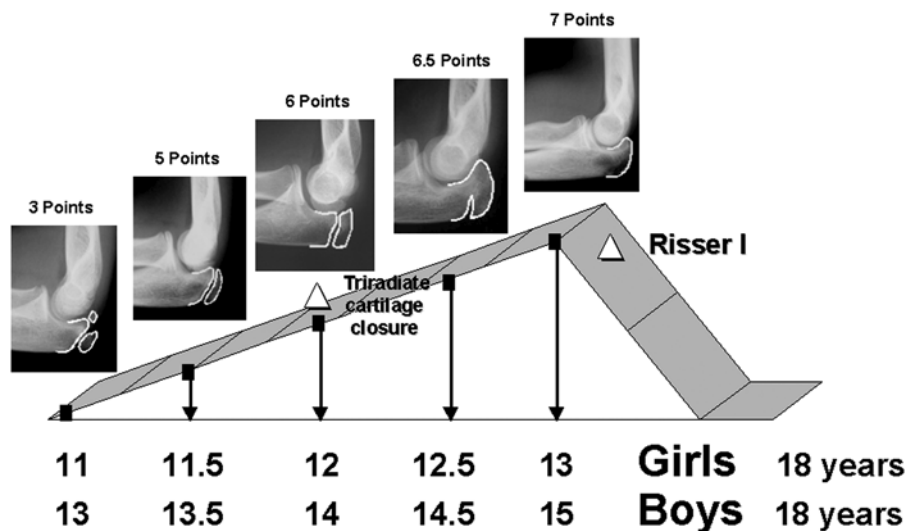


Fig. 5

Characteristic morphology of the olecranon apophysis during the pubertal growth spurt between the ages of eleven and thirteen years in girls and between the ages of thirteen and fifteen years in boys.

cially for girls between twelve and thirteen years of age.

As a result of our experience with this method, we were able to pay particular attention to osseous maturation of the olecranon apophysis. During the critical pubertal period, morphological changes of the olecranon apophysis are very characteristic. Five images were identified: two ossification nuclei were seen at the age of eleven years in girls and thirteen years in boys; a half-moon image was seen at the age of 11.5 years in girls and 13.5 years in boys; a rectangular aspect, at the age of twelve years in girls and fourteen years in boys; the beginning of fusion, at the age of 12.5 years in girls and 14.5 years in boys; and complete fusion, at the age of thirteen years in girls and fifteen years in boys (Fig. 5).

The interpretation of skeletal age performed on the olecranon apophysis alone is a simplified but very practical method in clinical practice<sup>1,2</sup>. When a more thorough and detailed assessment is required, the integral method of Sauvegrain et al.<sup>13</sup>, including the morphology of all four areas, is recommended.

Skeletal age assessment is an important exercise. Cundy et al.<sup>11</sup> showed that the interpretations of skeletal age by four radiologists who used the atlas of Greulich and Pyle<sup>10</sup> differed by more than two years for six of sixty children. This margin of error was smaller in the present study, with such a difference noted for three of sixty girls and five of sixty boys. There was no instance in which the method of Sauvegrain et al.<sup>13</sup> led to a difference of two years or more. Little et al.<sup>12</sup> stated that the skeletal age data of Greulich and Pyle<sup>10</sup> could not increase the accuracy over serial chronological age data when predicting the outcome of limb-length inequality. The comparison of chronological and skeletal age in our study showed that these two parameters only corresponded to each other for one-third of the patients. In children in whom skeletal maturity is advanced or delayed, this would substantially affect the timing of epiphysiodesis, especially if only chronological age or a single skeletal age determination were used. We agree that there is no ideal method. In complex cases, the best approach is to match the clinical landmarks of puberty and the skeletal ages with use of several methods such as Greulich and Pyle<sup>10</sup>, Sauvegrain et al.<sup>13</sup>, Tanner et al.<sup>7</sup>, and Acheson<sup>4</sup>. For assessments made during the pubertal growth spurt, the method of Sauvegrain et al.<sup>13</sup> proved to be very valuable, permitting a reduction in the margin of error.

Skeletal age determination is also useful in idiopathic scoliosis to assess the remaining growth and the risk for curve progression. Duval-Beaupère et al.<sup>17</sup> demonstrated the importance of skeletal age, annual growth velocity, and secondary

sexual characteristics in the identification of the beginning of the pubertal growth spurt, which is a decisive period. The first two years of puberty represent the period of peak growth velocity as well as the main spinal growth rate<sup>18</sup>. Little et al.<sup>19</sup> confirmed these observations, showing that peak height velocity was a useful contemporary clinical marker to predict the cessation of growth (occurring, on the average, 3.6 years after the peak height velocity). This phase of peak height velocity corresponds to the time frame of the method of Sauvegrain et al.<sup>13</sup>. It may complement the lack of information from the Greulich and Pyle atlas<sup>10</sup> and aid in the identification of patients with idiopathic scoliosis who are at high risk of progression. Fusion of the elbow physes indicates the end of peak height velocity when the adolescent is entering the decelerating phase of pubertal growth.

Our main objective was to obtain a detailed evaluation of skeletal age without confining ourselves to a rigid mathematical formula. In clinical practice, biological maturity can best be evaluated by determining skeletal age in the context of a critical analysis of the annual growth rate and secondary sexual characteristics. To choose an adequate date for epiphysiodesis or spinal arthrodesis, we now use the modified score and graphs of Sauvegrain et al.<sup>13</sup> to complement the Greulich and Pyle atlas<sup>10</sup> in order to obtain the most exact and valuable skeletal age data. ■

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