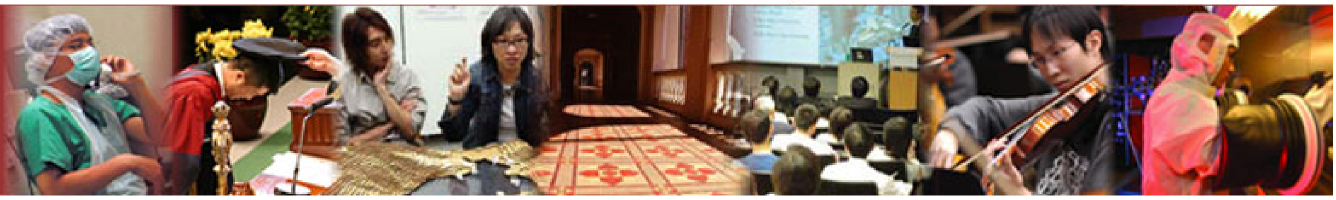

Title	**The distal radius and ulna classification in assessing skeletal maturity: a simplified scheme and reliability analysis**
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The Distal Radius and Ulna (DRU) Classification in Assessing Skeletal Maturity: A Simplified Scheme and Reliability Analysis

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ABSTRACT

Introduction: Managing adolescent idiopathic scoliosis (AIS) requires accurate prediction of a patient's remaining growth potential. Usually adopted methods include change in body height, age of menarche, Risser sign, and phalangeal epiphyseal maturity but their accuracy and utility is still questionable. The Distal Radius and Ulna (DRU) classification has been shown to accurately determine important time points in skeletal maturity including peak growth spurt and cessation of growth. The aim of study is to simplify the classification for practical use and test its reliability.

Methods: This was a prospective single center study of patients with AIS followed-up at a specialty clinic. The study was divided into two stages. In the first stage, samples of left hand radiographs were retrieved from patients seen in one clinic session. The classification was simplified by consensus between two examiners (JPYC and KDKL). For the second stage, a random selection of 50 subjects over a three-month period were recruited. Left hand radiographs were extracted for measurement using the simplified DRU grading. A third examiner (KHL) was included for the second stage assessment. Inter- and intraobserver reliability was performed using intraclass correlation (ICC).

Results: There were 34 females and 16 males in the study. The mean age was 12.7 years (±SD 1.7; range: 8–16 years). The spread of grades were from R4-R11 and U1-U9. There was strong to near perfect ICC between the three examiners. Consensus was that the original classification was descriptive and might not be completely specific about the physis appearance, definition of capping and the epiphysis width.

Discussion: The DRU classification scheme has been simplified into a simpler, user-friendly and equally reliable tool for assessment of skeletal maturity, confirming its utility in the clinical setting. Future prospective studies regarding its ability to identify patients in peak growth spurt and to predict curve progression are needed.

Introduction

Timely bracing treatment in managing adolescent idiopathic scoliosis (AIS) may prevent deterioration and the need for future surgery.[1] This is particularly suitable for the children still in their adolescent growth spurt. Thus, interventions should be initiated at an earlier stage of the clinical course. The decision for bracing however should not be made lightly. Indiscriminate use may be detrimental to these young patients as prolonged bracing may reduce spinal mobility, lead to poor body image and self-esteem, and worse quality of life. In practice, the decision for when to brace is based upon the clinician's judgment on a patient's remaining growth potential.

Although many clinical and radiological methods are available to predict a patient's growth potential including the age at menarche, difference in body height growth and arm span difference, Risser sign and Tanner and Whitehouse (TW3) digital skeletal age,[2-5] none of these measures are perfect in terms of accuracy and utility. The peak growth spurt can be easily missed using clinical measurements such as standing height and arm span because these require serial measurements to determine growth trends and can only be assessed retrospectively. The appearance of menarche is inconsistent and it marks a stage too late for meaningful bracing. TW3[3-5] or the Greulich and Pyle[6] methods for digital skeletal age assessment is accurate but are too complex for practical clinical use.

The DRU classification was created and reported by Luk *et al*.[7] as a response to the limitations of current growth potential prediction tools. This classification included 11 radius grades (R1-R11) and 9 ulna grades (U1-U9), and was found to accurately determine the peak growth spurt (R7 and U5) and cessation of growth (R10 and U9). However, the current classification scheme has been criticized for being too descriptive, making it difficult to use in a busy clinic. As such, the following study aimed to refine the classification and verify its reliability so that it could be simplified and reproducible.

Methods

A prospective radiographic study assessing adolescent idiopathic scoliosis (AIS) patients undergoing bracing during the month of June 2014 was performed. Ethics approval was obtained from our institute's review board. The study was performed at the Duchess of Kent Children's Hospital, Pokfulam, Hong Kong, a tertiary referral center for spinal disorders.

The study consisted of two stages. The first stage required a simplification of the existing DRU classification. The follow-up left hand radiographs of all subjects during one clinic (161 patients) in the study month were obtained. These radiographs were not specific to gender, age or treatment given. Radiographs were accessed by a DICOM based Radworks 5.1 (Applicare Medical Imaging BV, Zeist, The Netherlands) computer software program. Two examiners (JPYC and KDKL), one junior and one senior consultant spine surgeon, discussed each hand radiograph for discrepancies in grading. Ambiguous and inconsistent descriptions of the original classification were identified and parts of the descriptions were simplified. Consensus was reached by the two examiners regarding the clarity and appropriateness of the simplified descriptions.

In the second stage of the study, an independent investigator randomly selected 50 subjects from the total subject pool of braced individuals within the study period. This group of young adolescents was chosen because the DRU classification should be verified in a patient population that would benefit from bracing. Choosing the braced patients would also likely span a larger range of radius and ulna grades and avoid tunnel vision assessment of one age group or DRU grade. In addition to the two examiners (JPYC and KDKL) from the first stage of study, an additional junior spine surgeon (KHL) was recruited to grading using the new classification scheme **(Figure 1).** This part of the study was a re-evaluation of the reliability of the simplified classification system. Again all patient information was blinded to the observers. The third examiner was not present during the consensus meeting and hence acted as an examiner with no prior knowledge of how the simplified classification scheme was derived. A second round of reliability testing by JPYC, KHL and KDKL for intraobserver reliability was performed with the same 50 subjects but with the order in the database scrambled. All intraobserver reliability assessments were performed at least one month apart.

Statistical Analysis

All data were coded and entered on a spreadsheet kept only by PWHC until the end of reliability measurements. SPSS version 20 (Chicago, IL, USA) was utilized to perform the statistical analysis. Descriptive and frequency statistics were performed of the data. Reliability assessment was based on intraclass correlation (ICC) which had been shown to be an appropriate statistical tool for this analysis.[8] ICC could be interpreted based on the following alpha values: 0-0.29 indicated poor agreement; 0.30-0.49 indicated fair agreement; 0.50-0.69 indicated moderate agreement; 0.70-0.80 indicated strong agreement; and >0.80 indicated almost perfect agreement.[9,10] The 95% confidence interval (CI) bounds were assessed for precision.

Results

After the reading for the first stage of the study, both examiners agreed that the descriptions in both the radius and ulna were too complex and descriptive. The various descriptions in each grade leads to ambiguity and variations among different readers and thus difficult to be applied successfully in the clinical setting. These factors were re-evaluated in the second stage of the study and descriptions were inserted into the footnotes of the simplified classification **(Figure 1).**

For the 50 randomly selected subjects in the second stage of the study, there were 34 females and 16 males. The mean age was 12.7 years (±SD 1.7; range: 8–16 years). The spread of grades were from

R4-R11 and U1-U9. Using the simplified classification scheme, strong to near perfect ICC was found for both inter and intraobserver reliability **(Table 1)** between the three examiners.

Table 1: Inter- and intra-observer reliability

ICC reliability	Radius	95% CI	Ulna	95% CI
Interobserver	**0.973**	**0.956-0.984**	**0.979**	**0.967-0.987**
Intraobserver (JPYC)	**0.983**	**0.970-0.990**	**0.985**	**0.973-0.991**
Intraobserver (KDKL)	**0.971**	**0.949-0.983**	**0.958**	**0.927-0.976**
Intraobserver (KHL)	**0.883**	**0.794-0.934**	**0.926**	**0.869-0.958**

ICC: Intraclass correlation; CI: Confidence Interval

Discussion

The original publication on the DRU classification[7] possessed several limitations. The classification was based on descriptions of multiple parameters and each clinician might focus on something different, such as the appearance of the physis narrowing, definition of capping and when the epiphysis acquired the same width as the metaphysis, etc. Using an ambiguous classification scheme may be too time consuming to be practical in a busy clinic. The discussion among JPYC and KDKL after the first reliability testing was important in identifying the more consistent and reliable descriptions in each grade. This allows modification of the classification scheme into a simpler version **(Figure 1)**. We did not have patients young enough presenting with radius stages R1–R4 for testing. Nevertheless, this is of no significance to our present focus on AIS since interventions such as bracing is only applicable during the peak growth spurt. On the contrary, the R6-9 and U5-8 are important grades because they represent the period of peak growth spurt. The difficulties encountered with using the original classification mainly arose from the unclear descriptions of the overhanging of the medial epiphysis and lateral border width for R6, and the flattening of the radial epiphysis and ulna head density for U5. In addition, the lack of consensus definition of capping for the R7-8 and the width of epiphysis compared to the metaphysis for U6-7 required further modification.

For clarity in the radius grading, R6 was redefined as when the width of the epiphysis reaches a vertical tangential line drawn from the lateral margin of the metaphysis. R7 was capping on the medial side while R8 was capping on both the medial and lateral sides. Capping was defined as a horn-like structure at the ends of the epiphysis like a sharp bony outgrowth. In some cases where the horn-like structure may not be well visualized, the proximal border of the epiphysis can be traced to find any dipping of the line towards the metaphysis at the medial or lateral ends. In some difficult cases where even this method fails to identify any capping, we suggest that clinicians choose the lower grade classification. Finally R9 was blurring or fusion of the central physis.

For the ulna, the width of the epiphysis is the main determinant between U4-U6. U4 was defined with a visible styloid and when the width of the epiphysis is not as wide as the metaphysis. U5 was redefined as when the width of the epiphysis reaches a vertical tangential line drawn from the lateral margin of the metaphysis. For U6, the epiphysis is wider than the tangential line and forms a smooth curve with the medial metaphysis. Grades U7-8 were both describing the amount of fusion of the medial physeal plate. For clarity and simplicity, less than 50% fusion of the medial growth plate indicated U7 and more than 50% fusion indicated U8.

With the above modifications and simplification, the reliability analysis yielded strong to near perfect ICC reliability verifying its applicability to clinical practice. This is particularly significant in our study as a third examiner without any prior knowledge of the simplified classification scheme was recruited. This indicates that any clinician should be capable in using the classification without difficulty.

Further work is necessary to determine the DRU classification’s role in clinical practice. Current prospective studies are being developed to apply this on patients with AIS in order to determine its sensitivity and specificity in identifying the peak growth spurt, predicting curve deterioration as well as detecting skeletal maturity. All these will help in deciding the appropriate timing for initiating and stopping bracing, when to use growth guidance surgery, and when to recommend fusion. Additional studies are needed to validate this simplified DRU classification in other ethnicities and populations and to further directly compare it with other established skeletal maturity schemes.

Conclusions

The DRU classification scheme has been simplified into a simpler, user-friendly and equally reliable tool for assessment of skeletal maturity, confirming its utility in the clinical setting. Further studies are required to assess its predictability of peak growth spurt and growth cessation, and to compare it with other skeletal growth measures. Prospective trials may be required to determine which grade is most suitable for brace prescription and weaning.

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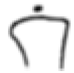
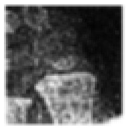
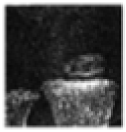
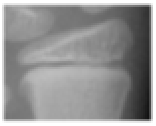
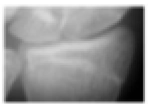
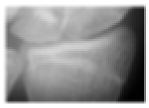
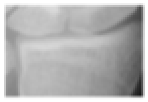
Figure Legend

Figure 1: Simplified Distal Radius and Ulna classification

Table 1: Simplified Distal Radius and Ulna (DRU) Classification Stages of Skeletal Maturity

DRU	TW3 (RUS)	**Characterization of distal radius stages**	Illustration	Radiograph
R1	B	Epiphysis appears as single or multiple spots.		
R2	C	Distinct and oval shaped epiphysis.		
R3	D	Maximal diameter of epiphysis is more than half the width of metaphysis.		
R4	E	Double line at the distal border of epiphysis, represent palmar and dorsal surface.		
R5	F	Thickened white line shaped as a triangle in epiphysis; width of epiphysis not as wide as metaphysis.		
R6	G	Epiphysis is as wide as metaphysis using a vertical tangential line. No capping or narrowing of the physis is seen.		
R7	H	Epiphysis capping on the medial side but not on the lateral side. Irregular narrowing of the physis can be seen.		
R8	H	Epiphysis capping on both medial and lateral side. The physis at the medial and lateral ends are wider than the center.		
R9	I	The central physis is blurred or beginning to fuse.		
R10	I	The physeal line is completely obliterated, forming a sclerotic line, A notch is still visible at the medial or lateral end of the growth plate.		
R11	I	Complete fusion of the physis with the metaphysis at both the lateral and medial ends A growth plate scar may still be visible.		

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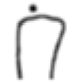
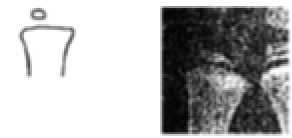
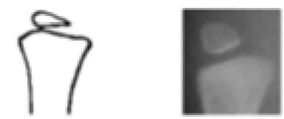
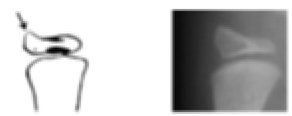
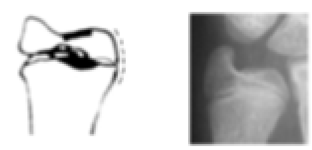
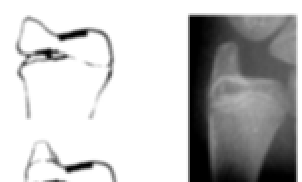
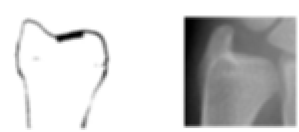
DRU	TW3 (RUS)	Characterization of distal ulna stages	Illustration	Radiograph
U1	B	The epiphysis appears at single/multiple spots.		

(Continued)

U2	C	A rounded shape epiphysis.	
U3	D	The epiphysis is at least half the width of metaphysis.	
U4	E	The styloid is visible on the medial end of the epiphysis which is not as wide as the metaphysis.	
U5	F	Epiphysis width up to the metaphysis based on a vertical tangential line.	
U6	G	Medial epiphysis beyond metaphyseal vertical tangential line with rounding of the medial epiphysis to form a smooth curve with metaphysis.	
U7	H	Narrowing or fusion of the medial physeal plate.	
U8	H	>50% fusion of the medial growth plate. The unfused part is just proximal to styloid process.	
U9	H	Complete fusion of the physeal line. A growth plate scar may still be visible.	

*** Whenever in doubt of features present, choose the lower grade classification.**

DRU, distal radius and ulna; TW3, Tanner and Whitehouse. Note: Modified from Tanner JM, Healey MJR, Goldstein H, Cameron N. Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 Method). Third ed. London: WB Saunders; 2001.

* The epiphysis is considered as wide as the metaphysis (R6 and U5) when a vertical tangential line transects both the epiphyseal and metaphyseal edges.

** Capping indicates an epiphysis that is wider than the metaphysis and has a horn-like structure at the ends of the epiphysis similar to a sharp bony outgrowth. The method for defining capping on the radius is to trace along the proximal border of the epiphysis and locate any dipping of this line towards the metaphysis at its medial or lateral end. If the epiphysis turns distally instead without dipping, no capping is present.