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A demonstration of appearance and union times of three shoulder ossification centers in adolescent and post-adolescent children

Maureen Schaefer [a,*], Gerald Aben [b], Caitlin Vogelsberg [c]

[a] Department of Radiology, Division of Anatomy, Michigan State University, United States
[b] Department of Radiology, Michigan State University, United States
[c] Department of Anthropology, Michigan State University, United States

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ABSTRACT

It is well known that appearance and union times of epiphyseal/apophyseal elements can be used as a tool to estimate age in both living and deceased children. Radiographic documentation of ossification centers within the shoulder region however remains underexplored. This study fills that niche by recording the appearance and, or, union times of the proximal humerus, acromial process and coracoid angle/apex. Shoulder radiographs from 264 males and 189 females between the ages of 10 and 21 years were examined. These images were obtained via two sources including the Michigan State University's Clinical Center as well as Query Patricia, an online juvenile radiographic database. Developmental progress of each element was divided into a unique staging system based on the extent to which that center could be visualized. Observations were recorded for each of the three elements and their age/phase distributions are provided. A number of developmental milestones (phases) were observed to always occur before the age of 16 or 18 years. These results suggest that the shoulder region may be of particular value when evaluating the likely direction of an individual's age in relation to either of these two common threshold values.

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1. Introduction

With immigration on the rise, forensic practitioners are increasingly being asked to estimate the age of living children who lack proper documentation of their birth [10,19,34–37,39,40]. Understandably, imaging modalities are crucial for this type of interpretation as there is no other viable option for visualizing the skeletal system within a living individual. While many individuals lack proper documentation of their birth, and their age never comes into question, the need to know chronological age may come to light in a number of situations. One of the more common reasons for estimating chronological age in an undocumented living individual constitutes criminal investigation [35,37]. Either the age of the perpetrator, or the age of a victim may be needed to ensure proper penalization of the offender. Specific ages have been designated as the threshold at which penalties increase in severity. While the specific threshold ages vary from country to country and state to state, two common threshold ages exist, those being 18 years, the age at which a person is considered a legal adult, and 16 years, the age of consent [29,41,35,37,39].

Radiographic age estimation during the adolescent to post-adolescent time period is generally achieved through observations of epiphyseal union. Times in which the epiphyses appear are normally reserved for aging younger children; however, a few later appearing epiphyses can also assist with estimating the age of older children through post-adolescence [31].

One of the most extensive pieces of research documenting appearance times comes from Garn et al. [11] in which they report ages representing the 5th, 50th and 95th percentiles of nearly every epiphysis of the body in their sample. While their thorough documentation of human variation is commendable, use of the data offered within this study has received criticism due to the antiquated nature of the sample which originated from radiographs obtained in the 1920s and 30s. It is unknown whether Garn's published ages continue to reflect the developmental timings of modern American children, or whether secular change has resulted in differential bone development. Fojas [9] examined this conundrum in respect to appearance times of the distal radius and found that the upper limit in which the epiphysis was observed to appear was younger in her modern male sample when compared to males in Garn's sample.

Rates of epiphyseal union have been well documented on dry bone specimens [5,7,21,30,31]. Unfortunately, ages associated with stages of epiphyseal union differ depending on the method in which the skeleton is visualized [32]. It is well known that ages derived from radiographic images tend to be younger than those derived from dry bone interpretation. For that reason, it is always

* Corresponding author.

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suggested to use data derived from the same image source as that which will be used in the age estimation.

While many clinical studies look at the radiographic times of epiphyseal union, they tend to report on the average times of occurrence rather than the range of variation that is required in a forensic case. That being said, there has been a recent surge in research dedicated to this topic, focusing mostly on the bones of the hand and wrist, foot and ankle, knee, medial clavicle and iliac crest [1,14,15,16,8,22,23,42,38,2,25].

One joint region that appears to be understudied is the shoulder. While radiographic atlases that demonstrate developmental changes and their associated ages have been published for many joint regions (including the knee, foot and ankle, hand and wrist and elbow), the shoulder remains conspicuously absent from the collection [28,17,13,4,18], looked at union times of the proximal humerus, however they did not include any information on the apophyses of the coracoid or acromion process. This piece of research aims to fill that void by providing data on union times of the coracoid angle and apex, the acromion process, and the proximal humerus via radiographic interpretation. Appearance times of the coracoid and acromial apophyses will also be included to further expand the content of knowledge on this region. The results within this study will then be compared to Jit and Singh's data on union times of the proximal humerus and Garn et al.'s appearance times of the coracoid and acromial apophyses to determine whether population differences or secular trend differences are notable.

2. Materials

The images utilized within this study were obtained via two sources, a Clinical Center located on Michigan State University's (MSU) East Lansing campus as well as from Query Patricia 3.6, a juvenile database of radiographic images developed and maintained by Mercyhurst University. The MSU sample consisted of shoulder radiographs from 346 patients between the ages of 10 and 21 years who attended the Clinical Center, and was comprised of 214 males and 132 females. IRB approval (IRB# x13-606e) was granted prior to collecting the images. Due to the limited number of individuals below the age of 14, Query Patricia was utilized to subsidize the sample. This sample consisted of shoulder radiographs from 107 individuals between the ages of 10–13 years (50 males; 57 females) that were pulled from their larger database. Sample sizes associated with each age and sex for both sources can be viewed in Table 1. In addition to age in years, age in months was also recorded for both samples.

Numerous images displaying multiple views of the shoulder were supplied for each patient within the MSU sample. The total number of radiographs available for each individual varied according to the suspected injury that was sustained; however, typical views included an AP with both internal and external rotation, a Y view as well as an axillary view. AP views included use of 6–16 MaS with 70Kvp and patient exposure averaging 0.786 mGy, while the Y views utilized 10–40 MaS with 75 Kvp and patient exposure averaging 1.437 mGy. All images were viewed on a Dell monitor.

Demographic information on the patients was not available, although one can assume that the sample is representative of the general population who visit the clinical center. In addition to the expected American individuals, there is a high percentage of international students and their families who utilize this facility. The socioeconomic levels of the patients also vary in that the pediatric population at the center is heavily weighted toward Medicaid patients, while also serving those with their own private health insurance.

The sample derived from Query Patricia was much more limited in the variety of radiographic views displayed. Typically only an AP view demonstrating either internal or external rotation was available. Occasionally a second axillary or Y view was also provided. Technical details regarding imaging techniques are unknown owing to the fact that the database is compiled of radiographs obtained from multiple medical examiner's offices and clinical centers around the country. Demographic information such as ancestry was recorded for individuals within the Query Patricia database, however that information was not available to the public at the time of writing this paper. All major ethnic groups and ancestries in the US are noted as being reasonably well represented [24].

Table 1
Frequency distribution in relation to the number of individuals present within each of the two samples according to sex and age.

Age	MSU Males	Patricia Males	Total	MSU Females	Patricia Females	Total
10	0	16	16	1	16	17
11	2	17	19	4	19	23
12	5	7	12	6	9	15
13	11	10	21	4	12	16
14	17	0	17	12	1	13
15	28	0	28	21	0	21
16	29	0	29	18	0	18
17	24	0	24	15	0	15
18	36	0	36	19	0	19
19	30	0	30	15	0	15
20	30	0	30	17	0	17
21	2	0	2	0	0	0
Total	214	50	264	132	57	189

3. Staging criteria

Data was collected on the ossification centers of the angle and apex of the coracoid process, the acromion process and the proximal humerus. Each center was assigned a similar but unique staging system representing developmental changes from appearance of the ossification center through to complete union. A single unified scoring system was not permissible due to the unique challenges of phasing each element.

3.1. Proximal humerus

The proximal humerus epiphysis was divided into four stages, including: open union (Phase 1), active union (Phase 2), union that had almost completed, other than a small notched area along the periphery of the bone (Phase 3), and complete union (Phase 4). Table 2 provides a written description of the phasing criteria, while Figs. 1 and 2 provide a visual demonstration.

The distinction between open versus active union became challenging once the epiphysis grew into its complete size and closely approximated the metaphysis. If there was slight discontinuity in the central aspect of the line of fusion, the epiphysis was recorded as displaying active union (Fig. 1). In reality, many of these specimens probably had not yet initiated the fusing process, however the distinction between open and active union can be difficult to assess radiographically due to overlying structures masking some of the finer detail. It was believed that the visual distinction utilized in this study would produce more reliable phase assignments and thus this criterion was adopted.

3.2. Acromial apophysis

Fusion of the acromial apophysis was more difficult to evaluate, and therefore was only divided into three phases, including: not present (Phase 0), present and exhibiting either open or active union (Phase 1), and complete union (Phase 4) (Table 2; Figs. 1, 3 and 4).

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