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Scapular Development from the Neonatal Period to Skeletal Maturity: A Preliminary Study

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ABSTRACT An understanding of the basic growth rates and patterns of development for each element of the human skeleton is important for a thorough understanding and interpretation of data in all areas of skeletal research. Yet surprisingly little is known about the detailed ontogenetic development of many bones, including the scapula. With the intention of describing the changes that accompany postnatal ontogeny in the scapula and algorithms to predict sub-adult age at death, this communication examines the development of the scapula through nine measurements (3 from the glenoidal area, 4 from the body and 2 related to the spinous process) by polynomial regression. Data were collected from 31 of the individuals that comprise the Scheuer Collection, which is housed at the University of Dundee (Scotland).

Four of the derived mathematical curves (scapular length, infra- and suprascapular height and spine length) displayed linear growth, whilst three (maximum length of the glenoid mass, acromial width and scapular width) were best expressed by a second-degree polynomial and two (maximum and middle diameter of the glenoidal surface) by a third-degree polynomial. All single measurements proved useful in the prediction of age at death, although derived indices proved to be of limited value. In particular, scapular width, suprascapular height and acromial width showed reliable levels of age prediction until late adolescent years. Copyright © 2007 John Wiley & Sons, Ltd.

Key words: scapular growth; immature bones; age prediction

Introduction

Growth studies are central to the accurate reconstruction of demographic profiles for past populations, and the reliable evaluation of age at death is core to the assessment and interpretation of many factors including indicators of health status and life conditions. It therefore follows that the normal pattern and progression of growth and skeletal maturation must be understood for each skeletal element to permit a realistic evaluation of the discriminatory potential for any bone that might present in an assemblage. It is also important that the methodology be based on osteological material of documented biological identity (i.e. known sex, age and ethnic origin) to avoid inappropriate circular arguments relating to the establishment of methods derived from a dependent and inherent pre-existing age profile (Bocquet-Appel & Masset, 1985; Black & Scheuer, 1996; Rissech *et al.*, 2003).

Recent literature has highlighted the lack of primary information regarding the developing human skeleton, and this has resulted in a poor understanding of growth patterns in different

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regions of the skeleton (Scheuer & Black, 2000). Current work on the innominate (Major, 2000; Rissech *et al.*, 2003; Rissech & Malgosa, 2005) and the femur (Rissech, 2003) has begun to redress this situation, but the limitation often lies with the lack of documented material upon which to base an osteological growth study of this nature.

Despite extensive literature on the scapula (Graves, 1921, 1922; Gray, 1942; Hrdlicka, 1942a,b; Vallois, 1946; Khoo & Kuo, 1948; Wolffson, 1950; Bainbridge & Tarazaga, 1956; Olivier & Pineau, 1957; McKern & Stewart, 1957; Hanihara, 1959; Iordanidis, 1961; Fazekas & Kósa, 1978; Schulter-Ellis, 1980; Shulin & Fangwu, 1983; Saunders *et al.*, 1993; Miles & Bulman, 1995), there is a paucity of information relating to its pre- and postnatal growth profile (Hrdlicka, 1942a; Vallois, 1946; Fazekas & Kósa, 1978; Saunders *et al.*, 1993; Miles & Bulman, 1995). In addition, only a small proportion of these studies have utilised documented skeletal collections (Hrdlicka, 1942a; Vallois, 1946; Fazekas & Kósa, 1978), and all have focused on the earliest growth period where skeletal material is more abundant. This leads to a limitation on the ability to establish reliable algorithms for age prediction when so little is known about the largest portion of the postnatal growth spectrum.

From this perspective, this paper examines cross-sectional information on the growth of the scapula from documented skeletal material through the full developmental spectrum from birth to the attainment of adult form. The main purpose of this study is to analyse the growth of the scapula, with the intention of describing the changes that accompany postnatal ontogeny in this bone and develop algorithms that facilitate accurate evaluation of sub-adult age at death.

Material and methods

Scapulae were selected from the Scheuer Collection of juvenile skeletal remains which is housed in Anatomy and Forensic Anthropology at the University of Dundee (UK). This collection arose from the accumulation of forensic, anatomical and archaeological sub-adult skeletons that formed the basis of two textbooks (Scheuer & Black, 2000, 2004). Most of the individuals in the Scheuer Collection have documented biological identity (age and sex known). For the remainder, which are archaeological specimens, sex and age were estimated by several methods (Crétot, 1978; Weaver, 1979; Brothwell, 1981; Krogman & Iscan, 1986; Schutkowski, 1987, 1993; Alduc-Le Bagouse, 1988; Ubelaker, 1989; Black & Scheuer, 1996; Rissech & Malgosa, 1997, 2005; Rissech *et al.*, 2003; Kahana *et al.*, 2003 among others).

Following exclusion of fragmentary specimens or those that displayed abnormal conditions, 31 individuals (8 males, 13 females and 10 of undocumented sex) were selected that ranged from neonatal to 19 years of age. Where possible, both right and left sides were measured. This resulted in a final sample size of 55 scapulae aged between birth and 19 years. Table 1 shows details of the distribution of age and sex in this sample.

Classical scapular metrics were recorded (length and width of the scapula, infra- and supra-scapular heights, spine length and maximum and middle diameter of the glenoid articular surface). Two new measurements relating to the glenoid mass and the acromion were included. All measurements were recorded to the nearest 0.1 mm using sliding callipers.

Definitions of these measurements are as follows:

(1) Maximum length of the glenoidal surface (Figures 1a and 2b): distance between the superior and inferior borders of the glenoid articular surface (Hrdlicka, 1942a; Olivier, 1960).

(2) Middle diameter of the glenoidal surface (Figures 1a and 2b): distance from the middle of the posterior border of the glenoidal rim to

Table 1. Specimens used in the study per group of age and sex

Age	Sex not known	Males	Females	*n*
0–4 years	11	2	6	19
5–8 years	5	2	2	9
9–12 years	2	2	6	10
13–16 years	—	2	3	5
17–19 years	—	6	6	12
Total	18	14	23	55

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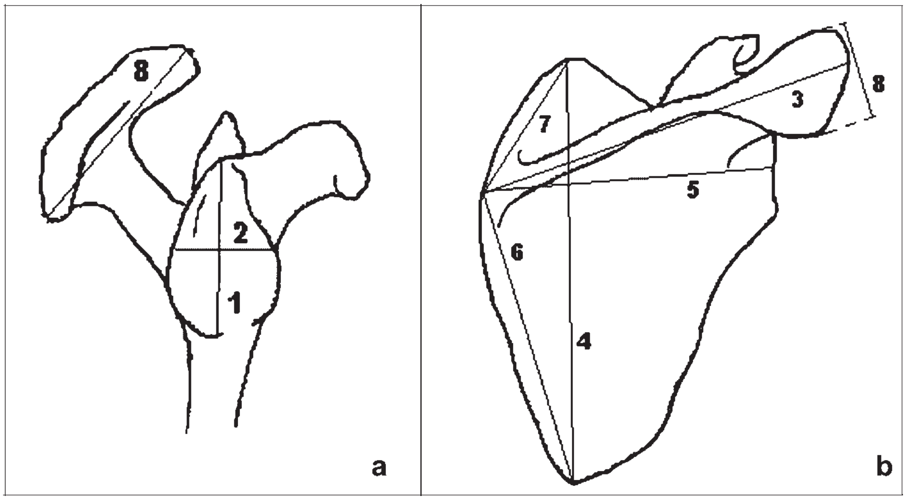

Figure 1. Lateral (a) and dorsal (b) view of adult scapula. Maximum length (1) and middle diameter (2) of the glenoidal surface; scapular spine length (3); scapular length (4); scapular width (5); infra-scapular height (6); supra-scapular height (7); and acromial width (8).

the anterior border perpendicular to the maximum length (Hrdlicka, 1942a).

(3) Maximum length of the glenoidal mass (Figures 2b, 3 and 4): distance between the superior border of the articulation site for the coracoid process and the inferior border of glenoid surface. If the coracoid is fused, the distance from the intersection point between the coracoid tubercle and the surgical neck, and the inferior border of the glenoid surface will be taken.

(4) Scapular spine length (Figures 1b and 2a): maximum distance between the medial end of the spine and the tip of the acromion process (Vallois, 1946; Fazekas & Kósa, 1978).

(5) Scapular length (Figures 1b and 2a,b): maximum distance between superior and inferior

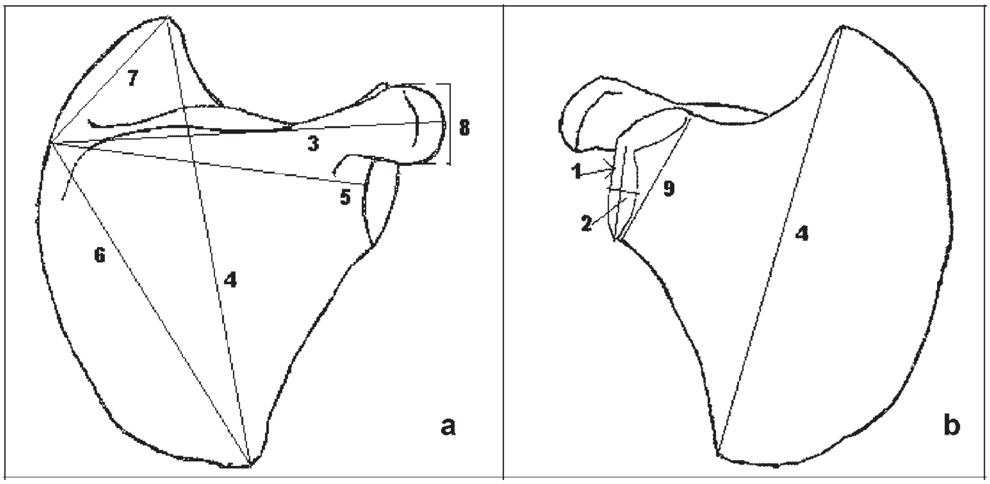

Figure 2. Dorsal (a) and ventral (b) view of sub-adult scapula. Maximum length (1) and middle diameter (2) of the glenoidal surface; scapular spine length (3); scapular length (4); scapular width (5); infra-scapular height (6); supra-scapular height (7); acromial width (8); and maximum length of the glenoidal mass (9). This last measurement includes the glenoidal surface and the coracoid process.

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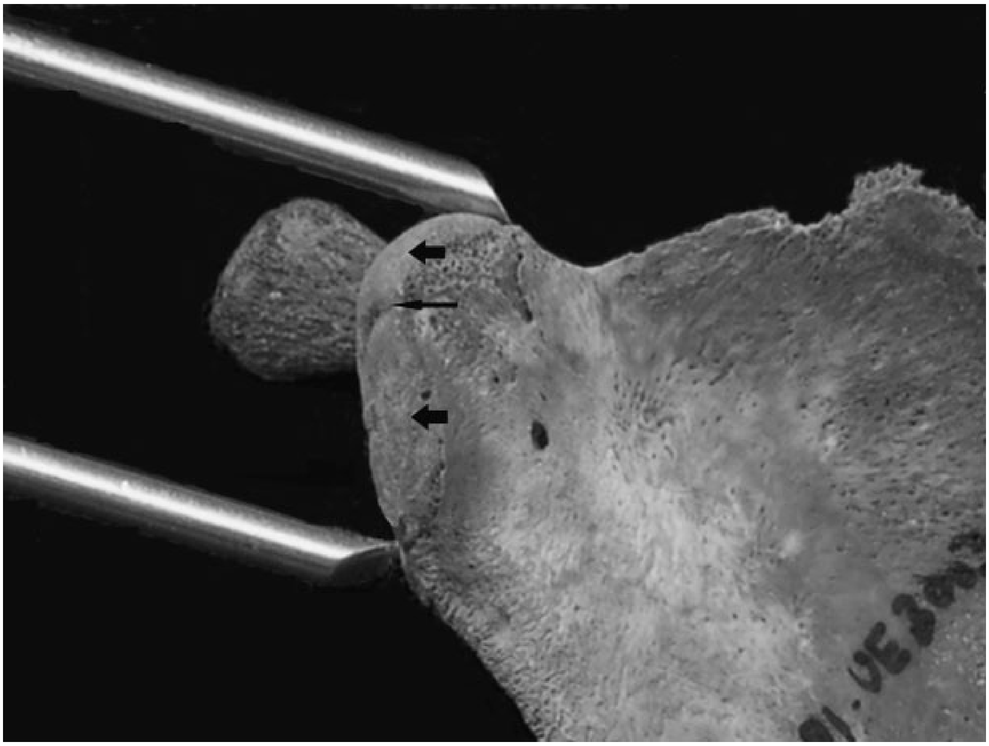

Figure 3. Ventral view of a sub-adult right scapula from a female of 41 weeks of intrauterine life. The extremes of the calliper show the maximum length of the glenoidal mass. The thin arrow shows the line of separation between coracoid site (superior wide arrow) and the glenoid fossa (inferior wide arrow).

scapular angles (Broca, 1878; Fazekas & Kósa, 1978).

(6) Scapular width (Figures 1b and 2a): distance between the posterior border of the glenoid rim and the medial end of the spine (Broca, 1878; Fazekas & Kósa, 1978).

(7) Infra-scapular height (Figures 1b and 2a): distance between the point at which the axis of the spine intersects the medial border of the scapula to the inferior angle (Hrdlicka, 1942a; Pospísil, 1965).

(8) Supra-scapular height (Figures 1b and 2a): distance between the point at which the axis of the spine intersects the medial border of the scapula to the superior angle (Broca, 1878; Pospísil, 1965).

(9) Acromial width (Figure 1a,b and Figure 2a): maximum width between the anterior and posterior borders of the acromion process, perpendicular to the axis of the scapular spine.

(10) Scapular index: percentage ratio between scapular width (6) and the scapular length (5) (Broca, 1878).

(11) Glenoidal index: percentage ratio between the middle diameter (2) and maximum diameter (1) of the glenoidal surface (total glenoid cavity index of Hrdlicka, 1942a).

(12) Supra-infra scapular index: percentage ratio between supra-scapular (8) and infra-scapular (7) heights (Broca, 1878).

Statistical analysis

Preliminary comparisons (Mann–Whitney U-test and Graphic Lowes method) showed: (a) negligible differences between right and left bones allowing for combination of them; and (b) similar patterns of growth and no significant differences in the means of the variables between

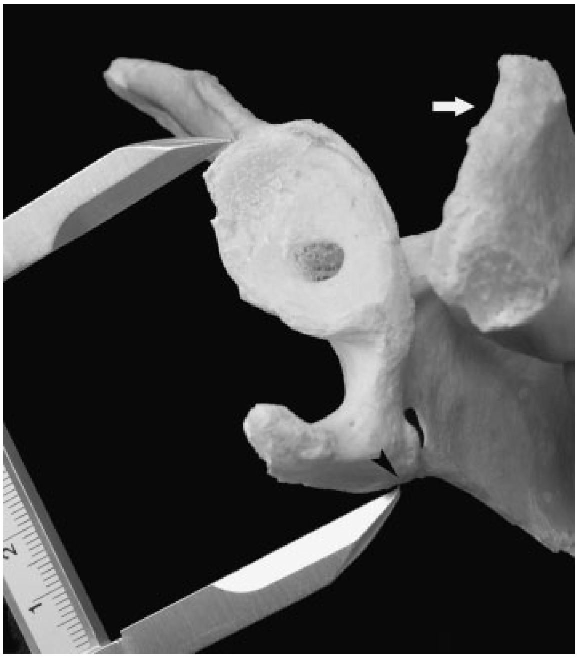

Figure 4. Lateral view of adult male scapula. The extremes of the calliper show the maximum length of the glenoidal mass when coracoid process is fused. Arrowhead indicates the intersection point between the coracoid tubercle and the surgical neck of the scapula. Arrow indicates the acromion.

the two sexes in each age group until age 16, allowing combination of the sexes in the younger age ranges.

To have a first approximation of growth before and after sexual dimorphism, the means and standard deviations for each scapular variable in each age group (4-year intervals) were calculated. However, results should be used carefully due to the small size of the sample. Moreover, it should be taken into account that the rhythm of growth is not the same within and among groups. Therefore, our reason for using this calculus is only to have an image of the growth and dimorphism at different stages of life.

To analyse the growth of the scapula before the development of sexual dimorphism, polynomial regression models were performed for each variable taking into account all the individuals under the age of the development of appreciable sexual dimorphism in that variable. In general terms, growth may be described by the lowest order polynomial (Tanner, 1962; Coleman, 1969; Strádalová, 1978). The best statistical model was selected on the basis of three factors: (1) the strength of the correlation coefficient (R^2); (2) the significance of the function expressed by the F value; and (3) the significance of the coefficients of the function obtained by the ANOVA test.

To predict age at death from the variables, their inverse relationship was calculated by using age as the dependent variable. Polynomial regressions were calculated using Windows SPSS (v. 12.0).

Results

Table 2 shows the mean and the standard deviation of the variables in the age groups. Between birth and 16 years the sexes were combined. For the sake of clarity, the variables are listed by topographical positioning.

Glenoidal region

The variables included maximum length and middle diameter of the glenoidal surface, maximum length of the glenoidal mass, and glenoidal index. All variables displayed an increase up to 19 years of age (Table 2) with the exception of glenoidal index, which decreased slightly until 16 years. After this age, the index increased, suggesting that maximum diameter grows slightly faster than middle diameter during the first 16 years of life, and after this age it is the middle diameter that predominates.

Between 17 and 19 years of age (Table 2), male values significantly exceeded female values for all variables pertaining to the glenoidal region with the exception of glenoidal index, in which sexual dimorphism did not reach statistical significance. These results agree in principle with the findings of Dorsey (1897), Dwight (1887), Corrêa (1915), Vallois (1946) and Hrdlicka (1942a). However, Vallois and Correa identified significant sexual dimorphism for glenoidal index. This disagreement may be explained by a slightly different definition for measuring the width of the glenoidal surface between the two studies.

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Table 2. Descriptive statistics of the 12 analysed variables classified according to each age category and, in the two last age categories, sexual differences by Mann–Whitney U-test

Age	Max length. glenoid	Middle diam. glenoid	Max. length mass	Scapular spinal length	Scapular length	Scapular width	Infra-scapular height	Supra-scapul height	Acromial width	Scapular index	Glenoidal index	Supra-infra-scap. Ind.
0–4												
n	19	19	19	15	15	15	15	15	16	15	19	15
Mean	13.95	9.68	19.55	43.63	51.77	36.60	41.59	18.65	7.58	72.88	68.00	45.08
SD	4.28	3.66	6.81	15.53	21.23	12.10	15.19	6.58	2.49	6.76	8.51	3.95
5–8												
n	9	9	9	8	6	8	6	8	9	6	9	6
Mean	21.73	15.08	30.64	70.91	82.90	55.58	66.37	25.70	12.91	65.75	69.46	40.14
SD	2.81	1.94	2.49	9.28	10.05	6.73	8.99	1.98	1.71	1.91	3.63	6.22
9–12												
n	10	10	10	4	5	8	5	7	5	5	10	5
Mean	26.15	17.68	38.61	92.63	109.16	71.56	84.50	33.41	18.08	66.71	67.71	40.88
SD	1.61	1.02	2.53	11.42	9.50	5.41	8.30	2.15	5.21	1.69	3.52	3.48
13–16												
n	5	5	5	5	5	5	5	5	5	5	5	5
Mean	31.56	19.66	42.00	111.64	129.92	87.32	99.14	38.94	32.26	67.17	61.62	38.88
SD	2.96	4.99	4.12	12.12	13.44	10.01	7.12	10.26	8.68	1.81	11.15	7.62
17–19												
Male												
n	6	6	6	6	4	6	6	4	6	4	6	4
Mean	36.27	25.03	50.55	126.67	149.08	94.12	114.4	43.85	38.65	64.18	69.23	38.97
SD	2.50	0.05	5.77	7.96	6.95	2.82	4.00	4.70	2.58	2.80	3.72	3.69
Female												
n	6	6	6	6	5	6	5	6	5	5	6	5
Mean	32.42	21.40	42.15	122.84	134.94	91.95	98.76	45.57	34.68	66.78	65.98	45.66
SD	2.08	1.87	4.69	16.43	5.63	8.89	4.12	6.67	7.41	4.75	3.34	6.04
P	0.015*	0.002*	0.026*	1.000*	0.032*	0.818	0.004*	0.914	0.662	0.556	0.132	0.111

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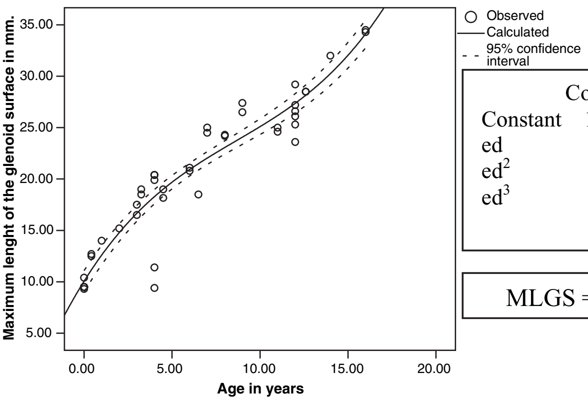


	Coefficient	t	p_1	
Constant	10.0500	11.860	0.000*	F=112.9264
ed	2.7361	5.271	0.000*	p_2 = 0.000*
ed^2	-0.2002	-2.397	0.021*	R^2=0.89687
ed^3	0.0077	2.096	0.043*	

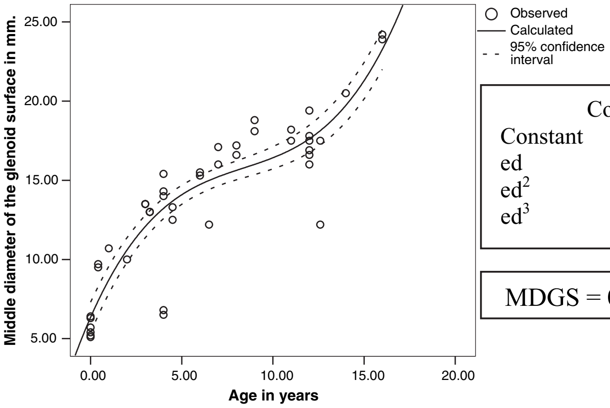
$$MLGS = 0.007ed^3 - 0.2002ed^2 + 2.7361ed + 10.050$$

Figure 5. Polynomial regression line with 95% confidence intervals and equation for maximum length of the glenoid surface (MLGS). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.

The best growth model for maximum length and middle diameter of the glenoidal surface (Figures 5 and 6) was a third-degree polynomial regression with an explained variability of 90% and 81% respectively. For maximum length of the glenoidal mass (Figure 7) the best model was a second-degree polynomial regression with an explained variability of 89%.

Glenoidal index displayed considerable variability. The best growth model for this variable was a first-degree polynomial regression with an explained variability of only 1%. Dispersion is normal in indices as they reflect a multiplicity of factors (Genoves, 1959; Rissech *et al.*, 2003; Rissech & Malgosa, 2005). Due to the variability and dispersion involved, its value as a predictor of age was not considered.

Maximum length and middle diameter of the glenoidal cavity and maximum length of the glenoidal mass were found to be useful predictors of age up to 16 years, prior to the onset of sexual dimorphism. Therefore the inverse relationships between these variables and age were calculated. The results for these analyses (Table 3) show a first-degree polynomial for each of them. The variability expressed is 88% for the maximum



	Coefficient	t	p_1	
Constant	6.3431	8.143	0.000*	F=53.0727
ed	2.6173	5.485	0.000*	p_2 = 0.000*
ed^2	-0.2667	-3.474	0.001*	R^2=0.8144
ed^3	0.0106	3.130	0.003*	

$$MDGS = 0.0106ed^3 - 0.2667ed^2 + 2.6173ed + 6.3431$$

Figure 6. Polynomial regression line with 95% confidence intervals and equation for middle diameter of the glenoid surface (MDGS). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.

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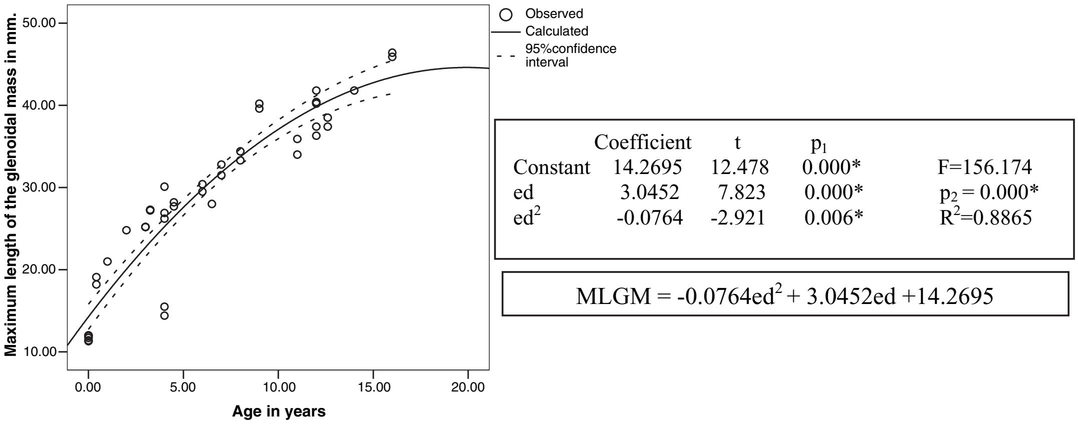

	Coefficient	t	p_1	
Constant	14.2695	12.478	0.000*	F=156.174
ed	3.0452	7.823	0.000*	p_2 = 0.000*
ed^2	-0.0764	-2.921	0.006*	R^2=0.8865

$$MLGM = -0.0764ed^2 + 3.0452ed + 14.2695$$

Figure 7. Polynomial regression line with 95% confidence intervals and equation for maximum length of the glenoidal mass (MLGM). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.

length of the glenoid surface, 78% for the middle diameter of the glenoid, and 86% for the maximum length of the glenoidal mass.

Body of the scapula

Measurements of scapular length, scapular width, infra-scapular and supra-scapular heights, along with scapular index and supra-infra-scapular index, were the variables used to examine growth in the blade or body of the scapula. All of these variables (but not the indices) increase in size until 19 years of age (Table 2). These results suggest that scapular width grows faster than scapular height, and that infra-scapular height grows faster than supra-scapular height during the earlier years. These results are in general agreement with Vallois (1946), who found that in the first years of life supra-scapular height is under-represented in relation to infra-scapular height, and the juvenile scapula is relatively wider than the adult scapula.

In the 17–19 years age group (Table 2), males had larger mean values than females for scapular length, scapular width and infra-scapular height, whereas females were larger than males for supra-scapular height, scapular index and supra-infra-scapular index. However, statistical significance for sexual dimorphism was only evident in scapular length and infra-scapular height (Table 2).

A first-degree polynomial was found to be the most appropriate way to describe growth and

Table 3. Inverse functions for age prediction – coefficient of correlation of the function R^2

	R^2
Up to 16 years of age	
Age = 0.63467 × Maximum length of the glenoidal surface – 6.545373	0.88
Age = 0.855343 × Middle diameter of the glenoidal surface – 5.38895	0.78
Age = 0.440738 × Maximum length of the glenoidal mass – 6.300855	0.86
Age = 0.140472 × Scapular length – 5.059151	0.89
Age = 0.18983 × Infra-scapular height – 5.751440	0.88
Age = 0.166100 × Spine length – 5.160903	0.91
Up to 19 years of age	
Age = 0.262093 × Scapular width – 7.489091	0.91
Age = 0.528610 × Supra-scapular height – 6.811764	0.84
Age = –0.012320 × $(\text{Acromial width})^2$ + 1.068638 × Acromial width – 5.069435	0.92

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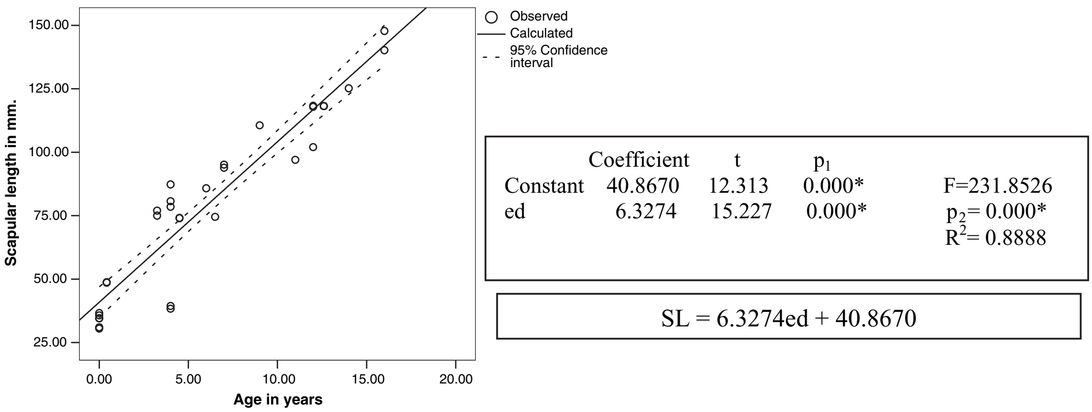


	Coefficient	t	p_1	
Constant	40.8670	12.313	0.000*	F=231.8526
ed	6.3274	15.227	0.000*	p_2= 0.000*
				R^2= 0.8888

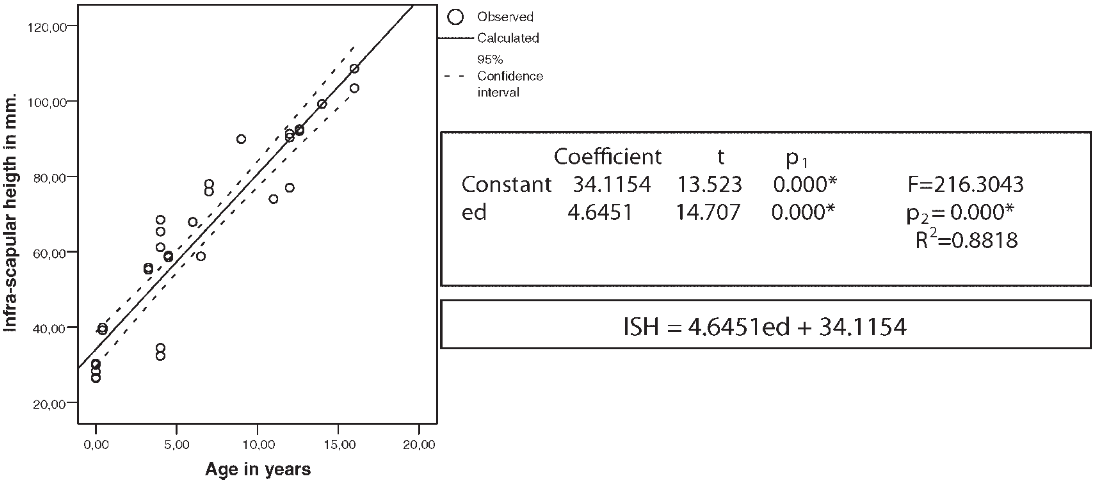
SL = 6.3274ed + 40.8670

Figure 8. Polynomial regression line with 95% confidence intervals and equation for scapular length (SL). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.

development in scapular length (Figure 8), infra-scapular height (Figure 9) and supra-scapular height (Figure 10), with 89%, 88% and 84% of the variability explained respectively. Development of scapular width (Figure 11) was best expressed by a second-degree polynomial regression, with 92% of variability explained.

Changes in scapular index and supra-infra-scapular index were best described by a second-degree polynomial, with 43% and 25% of variability explained respectively. Scapular index displayed decreasing values, indicating that relative increases in scapular width exceeded those in scapular length. Supra-infra-scapular index initially decreased but then increased, indicating that up to 12 years of age, growth in supra-scapular height exceeded that in infra-scapular height, but this reverses later. Due to the low expressed variability, its value as predictor of age was not considered.

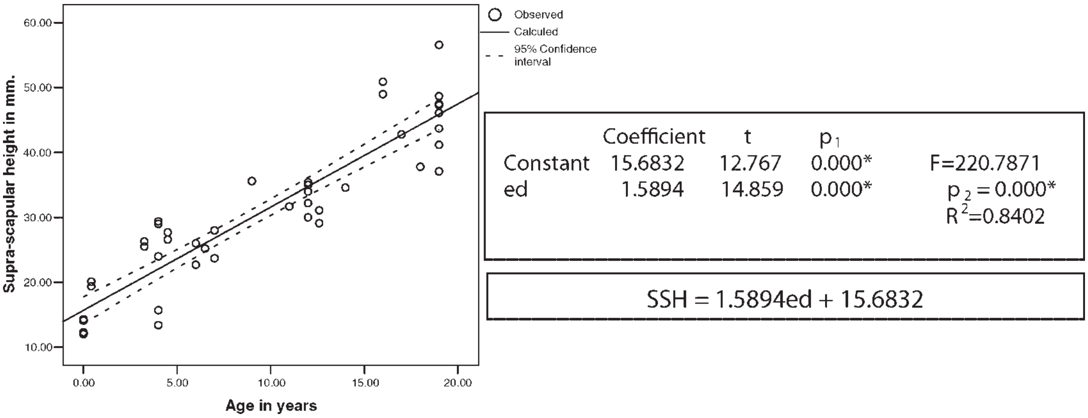
For the prediction of age at death, scapular length and infra-scapular height proved to be useful discriminators up to 16 years of age, and scapular width and supra-scapular height were of



	Coefficient	t	p_1	
Constant	34.1154	13.523	0.000*	F=216.3043
ed	4.6451	14.707	0.000*	p_2= 0.000*
				R^2=0.8818

ISH = 4.6451ed + 34.1154

Figure 9. Polynomial regression line with 95% confidence intervals and equation for infra-scapular height (ISH). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.



	Coefficient	t	p_1	
Constant	15.6832	12.767	0.000*	F=220.7871
ed	1.5894	14.859	0.000*	$p_2 = 0.000$*
				R^2=0.8402

SSH = 1.5894ed + 15.6832

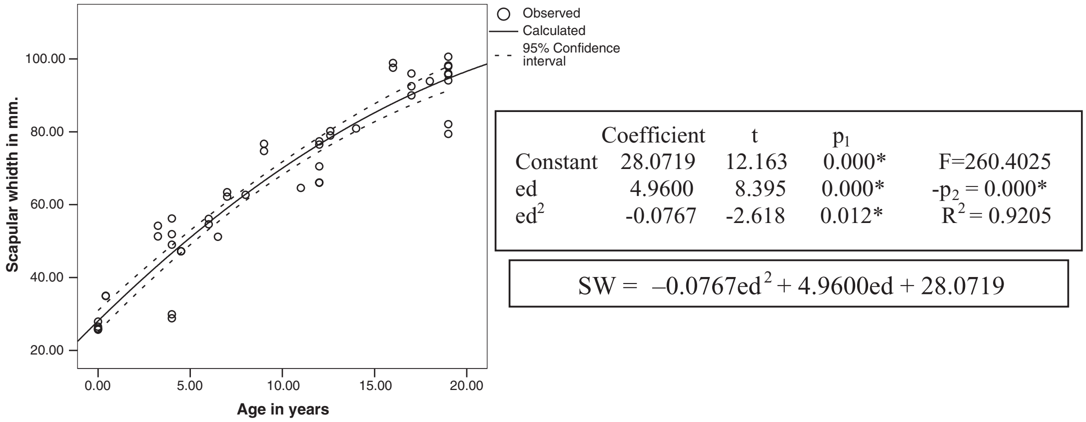
Figure 10. Polynomial regression line with 95% confidence intervals and equation for supra-scapular height (SSH). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.

value up to 19 years of age, prior to the onset of sexual dimorphism. The results of these analyses (Table 3) show a first-degree polynomial inverse relationship with age. The variability expressed is 89% for scapular length, 88% for infra-scapular height, 91% for scapular width and 84% for supra-scapular height.

Spine and acromion

Scapular spine length and acromial width increased markedly until 19 years of age (Table 2). Sexual differences were evident in scapular spine length after 16 years of age, where male values were larger than females. Acromial width did not display significant sexual dimorphism (Table 2) and this agrees with the findings of Vallois (1946).

The growth in length of the spine is best expressed by a first-degree polynomial regression (Figure 12) with an explained variability of 91%. In contrast, growth in acromial width is best expressed by a second-degree polynomial (Figure 13) with 90% explained variability. The form of this curve shows a concavity indicating accelerated growth in this region, which may be



	Coefficient	t	p_1	
Constant	28.0719	12.163	0.000*	F=260.4025
ed	4.9600	8.395	0.000*	$-p_2 = 0.000$*
ed^2	-0.0767	-2.618	0.012*	$R^2 = 0.9205$

$$SW = -0.0767ed^2 + 4.9600ed + 28.0719$$

Figure 11. Polynomial regression line with 95% confidence intervals and equation for scapular width (SW). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.

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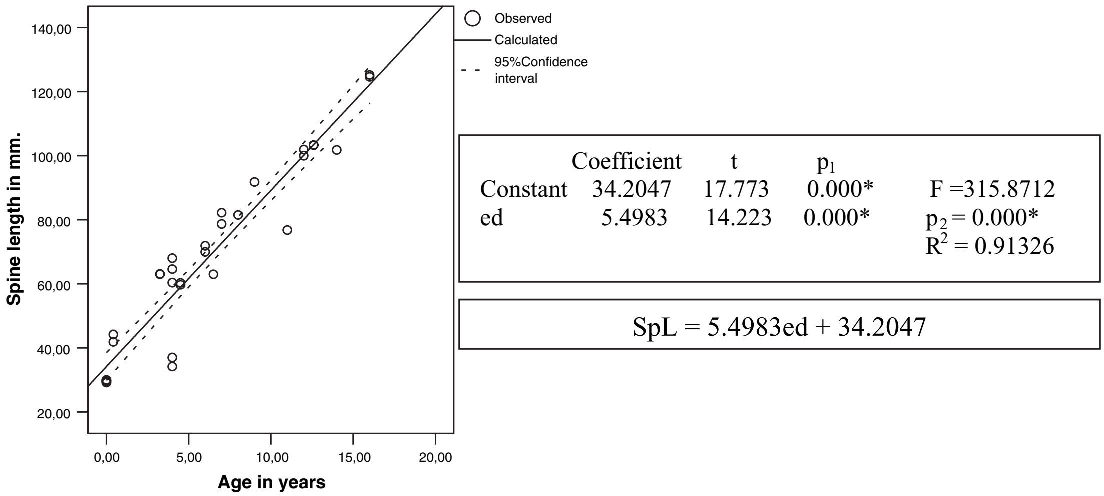


	Coefficient	t	p_1	
Constant	34.2047	17.773	0.000*	F =315.8712
ed	5.4983	14.223	0.000*	p_2 = 0.000*
				R^2 = 0.91326

$$SpL = 5.4983ed + 34.2047$$

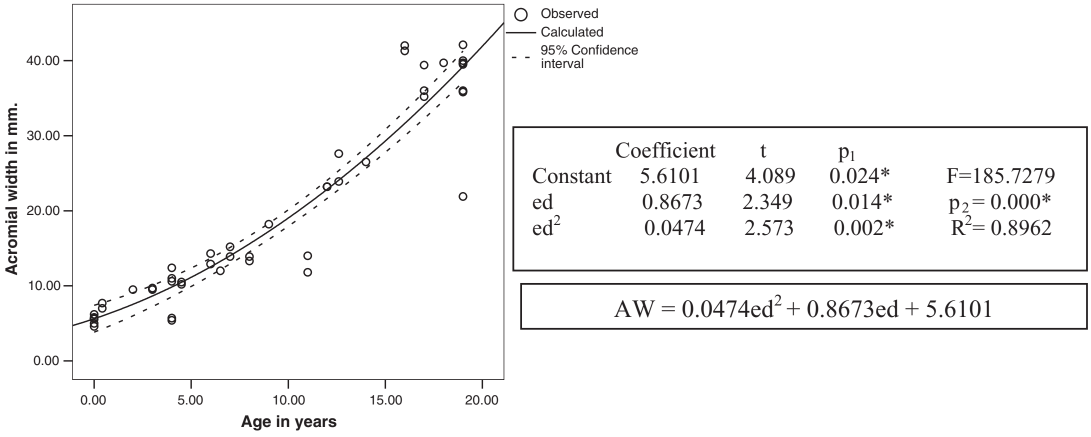
Figure 12. Polynomial regression line with 95% confidence intervals and equation for spine length (SpL). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; and R^2 the explained variability.

explained by the great growth in width of the spinous process and the posterior fusion of the acromial epiphysis, to form the shoulder articulation.

In the prediction of age at death, scapular spine length proved useful up to 16 years of age and the acromial width up to 19 years of age, prior to the development of appreciable sexual dimorphism. The results of the inverse relationship of these variables with age (Table 3) show first- and second-degree polynomials with expressed variability of 91% and 92% respectively.

Discussion

The results of this study show that as the scapula increases in size with age, it proportionally increases more in width than it does in length. However, the growth in length is not a simple



	Coefficient	t	p_1	
Constant	5.6101	4.089	0.024*	F=185.7279
ed	0.8673	2.349	0.014*	p_2= 0.000*
ed^2	0.0474	2.573	0.002*	R^2= 0.8962

$$AW = 0.0474ed^2 + 0.8673ed + 5.6101$$

Figure 13. Polynomial regression line with 95% confidence intervals and equation for acromial width (AW). Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 significance of the function; and R^2 explained variability.

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linear function but rather a differential accumulation of parts as the infra-scapular height increases faster than supra-scapular height. In addition, maximum length of the glenoidal surface grows faster than the middle diameter, resulting in the well recognised adult pear shape for this surface.

The development of the absolute variables is essentially linear in form with the exception of the variables which define the glenoidal cavity, scapular and acromial width, which follow third- and second-degree polynomials respectively. Therefore it is possible to observe a growth restraint before adolescent acceleration in maximum and middle diameters of the glenoidal surface. The beginning of the growth spurt for these scapular dimensions is at shortly over 13 years of age (14–15 years of age approximately) and it is observed as a growth acceleration in maximum and middle diameters of the glenoidal surface. It is not possible to determine exactly when this growth spurt commenced, but the approximate age of the growth spurt found for the variables of the glenoidal cavity falls into the standard range of 9.5–14.5 for females and 10.5–17.5 for males in the existing population.

None of the curves show flattening by the age of 19 years, and it is impossible to predict whether flattening would have occurred soon after, but there is perhaps some suggestion that growth can continue in some areas of the scapula after 19 years. These observations agree with the age of complete fusion of the medial epiphysis of the clavicle, and three secondary centres of the scapula: the inferior angle and medial border of the scapula, and the acromion, which fuse around 30, 23 and 20 years of age respectively (Black & Scheuer, 1996; Scheuer & Black, 2000). In fact, this later growth is not a new finding as it is observed in some parts of the body. The ages of cessation of growth established for the stature were fixed for practical reasons (Tanner, 1962; Roche & Davila, 1972) and show the end of the most notable growth. Even in the stature there is an increase of 2%, due mainly to body height growth (Tanner, 1962; Büchi, 1950 in Tanner, 1962); thus, certain segments continue to grow, specifically some areas of the vertebral column, innominate and shoulder (Tanner, 1962, 1986; Susanne, 1979; Grasser *et al.*, 1991; Tague, 1994; Rissech *et al.*, 2003; Rissech & Malgosa, 2005).

From our results, sexual dimorphism is statistically detectable following the anticipated normal adolescent growth spurt, but not before. The pattern of dimorphism exhibited by maximum length of the glenoidal surface, scapular length and supra-scapular height seems to arise due to an earlier cessation of feminine growth (see Table 2). This fact is to be expected since sexual dimorphism in longitudinal variables is caused by the cessation of female growth characteristics rather than the spurt itself (Tanner *et al.*, 1976). This growth behaviour was also observed in anterior osteological studies of the innominate (Rissech *et al.*, 2003; Rissech & Malgosa, 2005). The variables useful for sex determination after 17 years of age are the maximum length and middle diameter of the glenoidal surface, glenoidal mass length, spine length, scapular length and infra-scapular height. For each of these variables, male values significantly exceed female values.

All of the absolute scapular measurements proved valuable in the determination of age at death in the juvenile. The most useful measurements proved to be acromial width, scapular width and supra-scapular height, where sexually dimorphic change was not detectable prior to 19 years of age. Measurements of the maximum and middle diameters of the glenoidal surface, maximum length of the glenoidal mass, spine length, scapular length and infra-scapular height have a more restricted time period of application, being of value until only 16 years of age.

The formulae proposed in this study allow us to obtain expected growth or to attribute age to young human remains with good reliability. The calculated curves fit well to the analysed juvenile data studied here, and correspond with deductions from previous studies. They are the first formulae obtained from scapula to diagnose the osseous age taking into account the fact that they focus on the scapula until adult age. However, further analysis and additional series are required in order to reinforce the results obtained. Meanwhile, forensic work and anthropological studies can take advantage of these results, which enlarge the possibilities for the analysis of age and sex in juvenile remains.

Conclusion

This cross-sectional study of scapular growth, based on a documented skeletal collection from Western Europe, has yielded formulae to obtain valuable age estimates of the skeleton, and has thus provided an important tool for osteoarchaeological studies and forensic tasks. It has also provided us with information about sub-adult sexual dimorphism. The importance of the formulae is that they are the first obtained from the scapula to diagnose osseous age, taking into account the fact that they are based on a documented osteological collection from birth to adult age. Grant sponsorship: post-doctoral research grant (SFRH/BPD/6075/2001) from Fundação para a Ciência e a Tecnologia – Operational Program Science Technology and Innovation (POCTI) to Carme Rissech.

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