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Quantitative anatomy of the growing supraspinatus muscle in the human fetus

M. Biernacki, M. Badura, M. Grzonkowska, M. Szpinda, M. Dąbrowska, M. Paruszewska-Achtel, M. Wiśniewski, M. Baumgart

Department of Normal Anatomy, the Ludwik Rydygier Collegium Medicum in Bydgoszcz, the Nicolaus Copernicus University in Torun, Poland

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Background: *The supraspinatus muscle, one of the four rotator cuff muscles, initiates abduction of the arm, simultaneously stretching the articular capsule at the glenohumeral joint, and also contributes to exorotation of the arm. In the present study we aimed to evaluate the age-specific normative values for morphometric parameters of the supraspinatus muscle in human fetuses at varying ages and to elaborate their growth models.*

Materials and methods: *Using anatomical dissection, digital image analysis (NIS Elements AR 3.0) and statistics (Student's t-test, regression analysis), the length, width, circumference and projection surface area of the supraspinatus muscle were measured in 34 human fetuses of both sexes (16 males, 18 females) aged 18–30 weeks of gestation.*

Results: *Neither sex nor laterality differences were found in numerical data of the supraspinatus muscle. In the supraspinatus muscle its length and projection surface area increased logarithmically, while its width and circumference grew proportionately to gestational age. The following growth models of the supraspinatus muscle were established: $y = -71.382 + 30.972 \times \ln(Age) \pm 0.565$ for length, $y = -2.988 + 0.386 \times Age \pm 0.168$ for greatest width (perpendicular to superior angle of scapula), $y = -1.899 + 0.240 \times Age \pm 0.078$ for width perpendicular to the scapular notch, $y = -19.7016 + 3.381 \times Age \pm 2.036$ for circumference, and $y = -721.769 + 266.141 \times \ln(Age) \pm 6.170$ for projection surface area.*

Conclusions: *The supraspinatus muscle reveals neither sex nor laterality differences in its size. The supraspinatus muscle grows logarithmically with reference to its length and projection surface area, and proportionately with respect to its width and circumference.* (Folia Morphol 2023; 82, 4: 862–868)

Key words: supraspinatus muscle, growth dynamics, fetal development

INTRODUCTION

Morphometric data referring to skeletal muscles in man may provide a great amount of conducive information for a precise assessment of the musculoskeletal systems and may be of relevance in surgery [16]. Developmental disturbances at the embryonic period may result in congenital defects of skeletal muscles, thus being responsible for their dysfunction, reduced joint mobility, joint stiffness and consecutive muscle atrophy.

Address for correspondence: Dr. M. Biernacki, Department of Normal Anatomy, the Ludwik Rydygier Collegium Medicum in Bydgoszcz, ul. Łukasiewicza 1, 85–821 Bydgoszcz, Poland, tel: +48 52 585 37 05, e-mail: kizanat@cm.umk.pl

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The supraspinatus muscle is triangular in shape, tapers laterally and occupies the osteofibrous supraspinous compartment on the posterior surface of the scapula, bounded inferiorly by the supraspinous fossa, which is sealed superiorly by the supraspinatus fascia. The supraspinatus muscle fibres end in a strong short tendon, which inserts onto both the superior posterior one-third surface of the greater tubercle of humerus and the shoulder joint capsule. Along with the three other tendons of the infraspinatus, teres minor and subscapularis muscles, the supraspinatus tendon contributes to the formation of the so called musculotendinous cuff or rotator cuff. The function of the supraspinatus muscle is to abduct the arm with stretching the articular capsule at the glenohumeral joint, as well as to rotate the arm laterally (exorotation) with minimum flexion, working in conjunction with the deltoid muscle [9]. The supraspinatus muscle alone initiates abduction at the glenohumeral joint until first 30 degrees, and then continues this action with the deltoid muscle [17].

Compression of the supraspinatus tendon may first lead to its haemorrhage and oedema, occurring in its critical section. This is followed by degeneration and ultimately by mechanical partial damage to the rotator cuff, resulting in both a weakening and a pain of the shoulder joint. The partial or complete damage to the rotator cuff muscles, especially to the supraspinatus muscle, may necessitate surgery [11].

Despite the use of different modern imaging methods, including ultrasound, magnetic resonance imaging, computed tomography and autopsy studies in adults, we still failed to find any numerical data about the supraspinatus muscle in human fetuses. Therefore, according to our best knowledge, the present study constitutes the first report in the professional literature to morphometrically analyse the size of the growing supraspinatus muscle in the human fetus.

The three aims of the present study were:
- to perform morphometric analysis of the fetal supraspinatus muscle (linear and planar parameters), so as to determine their age-specific normative values;
- to examine possible sex and laterality differences for all analysed morphometric parameters; and finally
- to compute growth dynamics for all the analysed morphometric parameters, expressed by best-matched mathematical models.

MATERIALS AND METHODS

The study material comprised 34 human fetuses (16 males and 18 females) aged 18–30 weeks of gestational age, which originated from spontaneous abortions and preterm deliveries. The fetuses were acquired before the year 2000 and constitute part of the specimen collection of the Department of Normal Anatomy in the Ludwik Rydygier Collegium Medicum in Bydgoszcz of the Nicolaus Copernicus University in Torun. This experiment was approved by the Bioethics Committee of our University (KB 275/2011). The gestational ages were based on the crown-rump length. Table 1 lists the characteristics of the study group, including the ages, number and sex of the fetuses studied.

With the use of anatomical dissection, the supraspinatus muscle was bilaterally visualised and excised, then imaged due to a Canon EOS 70D(W) digital camera and finally subjected to morphometric analysis with a digital image system (NIS Elements AR 3.0). For every supraspinatus muscle examined, the following five parameters on the dorsal projection of the scapula were precisely defined and measured (Fig. 1):
- its length based on the determined distance between its origin and insertion;
- its greatest width based on the determined distance between its superior and inferior borderlines, just perpendicular to the superior angle of scapula;
- its width based on the determined distance between the superior and inferior borderlines, just perpendicular to the scapular notch;
- its circumference, based on the contour of the entire supraspinatus muscle;
- its projection surface area bounded by the contour of the supraspinatus muscle.

The obtained numerical data was statistically analysed in such a manner that distribution of variables was checked using the Shapiro-Wilk (W) test, while homogeneity of variance was checked using Fisher's test. The results were expressed as arithmetic means with standard deviations. To compare the means, Student's t-test for independent variables and one-way analysis of variance were used. Tukey's test was used for post-hoc analysis. If no similarity of variance occurred, the non-parametric Kruskal-Wallis test was used. The description of growth dynamics of the analysed parameters was based on linear and nonlinear regression analysis. The match between the numerical data and computed regression curves was evaluated based on the coefficient of determination (R^2).

Table 1. Age, number and sex of the fetuses studied

Gestational age	Crown-rump length [mm]				Number of fetuses	Sex	
	Mean	Standard deviation	Minimum	Maximum		Male	Female
18	135.17	130.00	142.00	4.22	6	3	3
19	151.00	148.00	154.00	4.24	2	1	1
20	166.00	165.00	167.00	1.41	2	1	1
21	172.67	169.00	176.00	3.51	3	2	1
22	182.00	182.00	182.00	–	1	1	0
23	198.00	194.00	202.00	5.66	2	1	1
24	208.00	205.00	212.00	3.61	3	1	2
25	217.00	214.00	221.00	3.16	4	1	3
26	229.33	225.00	232.00	3.79	3	1	2
27	237.00	235.00	240.00	2.16	4	1	3
28	246.00	245.00	247.00	1.41	2	1	1
29	257.00	255.00	260.00	2.65	3	2	1
30	265.00	265.00	265.00		1	1	1
Total					36	16	18

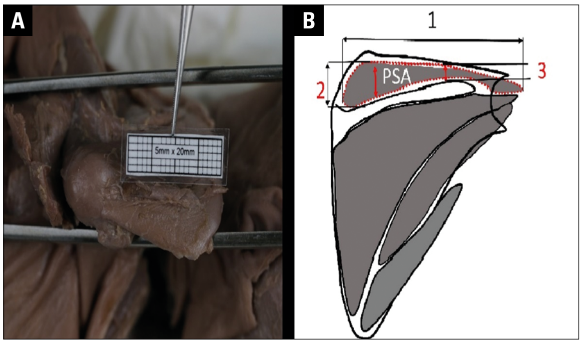

Figure 1. The supraspinatus muscle (**A**) in a male fetus at 27 weeks showing the measured parameters (**B**); 1 — length; 2, 3 — widths; PSA — projection surface area.

RESULTS

No anatomical variability of the supraspinatus muscle was found. Of note, the statistical analysis revealed neither sex nor laterality differences for all the analysed parameters ($p > 0.05$). The mean numerical data, including the length, widths, circumference and projection surface area of the supraspinatus muscle have been presented in Tables 2 and 3. Thus, we evaluated the growth dynamics of all parameters without taking the sex or age into account. The growth dynamics of the widths and circumference of the supraspinatus muscle followed linear functions, while those of the length and projection surface area of the supraspinatus muscle revealed natural logarithmic models (Fig. 2).

The mean length of the supraspinatus muscle in the gestational age range of 18–30 weeks increased from 17.79 ± 0.68 to 33.17 mm on the right side, and from 17.76 ± 0.70 to 33.21 mm on the left side, following the natural logarithmic function: $y = -71.382 + 30.972 \times \ln(\text{Age}) \pm 0.565$ ($R^2 = 0.98$) (Fig. 2A).

The mean greatest width of the supraspinatus muscle ranged from 3.93 ± 0.34 mm at 18 weeks of gestation to 8.40 mm at 30 weeks of gestation on the right side, and from 3.91 ± 0.32 to 8.41 mm on the left side, in accordance with the linear function: $y = -2.988 + 0.386 \times \text{Age} \pm 0.168$ ($R^2 = 0.99$) (Fig. 2B). The mean width of the supraspinatus muscle at the gestational ages of 18–30 weeks grew from 2.38 ± 0.12 to 5.26 mm on the right side, and from 2.38 ± 0.13 to 5.28 mm on the left side, following the linear function: $y = -1.899 + 0.240 \times \text{Age} \pm 0.078$ ($R^2 = 0.98$) (Fig. 2C).

In the analysed gestational age range the supraspinatus muscle revealed an increase in mean circumference from 39.10 ± 1.91 to 81.32 mm on the right side, and from 38.99 ± 1.96 to 81.54 mm on the left side, following the linear function: $y = -19.7016 + 3.381 \times \text{Age} \pm 2.036$ ($R^2 = 0.97$) (Fig. 2D).

At the age of 18–30 weeks the mean projection surface area of the supraspinatus muscle oscillated from 46.89 ± 7.23 to 179.29 mm^2 on the right side, and from 48.44 ± 5.06 to 179.41 mm^2 on the left side, following the natural logarithmic function: $y = -721.769 + 266.141 \times \ln(\text{Age}) \pm 6.170$ ($R^2 = 0.98$) (Fig. 2E).

Table 2. Statistical analysis of numerical data (mean ± standard deviation [SD]) of the right supraspinatus muscle

Gestational age [weeks]	N	Right supraspinatus muscle									
		Width 1 [mm]		Width 2 [mm]		Length [mm]		Circumference [mm]		Projection surface area [mm^2]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
18	6	3.93	0.34	2.38	0.12	17.79	0.68	39.10	1.91	46.89	7.23
19	2	4.46	0.06	2.65	0.02	19.09	0.03	45.64	0.49	62.53	2.14
20	2	4.89	0.04	2.95	0.01	22.15	0.05	49.95	0.04	75.85	1.41
21	3	5.08	0.18	3.11	0.11	22.51	0.40	53.59	5.46	79.65	2.60
22	1	5.31		3.32		23.64		53.67		89.82	
23	2	5.71	0.14	3.62	0.21	26.20	1.56	57.63	2.96	10.77	9.72
24	3	5.94	0.19	3.80	0.02	27.77	0.59	61.98	2.44	127.06	14.28
25	4	6.59	0.29	4.20	0.15	28.64	0.15	66.35	1.92	144.67	1.63
26	3	7.13	0.18	4.42	0.05	29.69	0.45	69.45	0.90	147.70	1.04
27	4	7.55	0.13	4.56	0.06	30.67	0.41	70.74	0.28	150.58	0.95
28	2	7.74	0.06	4.71	0.00	31.16	0.01	71.87	0.21	157.08	0.48
29	3	8.12	0.08	4.93	0.10	31.83	0.44	76.61	2.89	172.11	2.09
30	1	8.40		5.26		33.17		81.32		179.29	

Table 3. Statistical analysis of numerical data (mean ± standard deviation [SD]) of the left supraspinatus muscle

Gestational age [weeks]	N	Left supraspinatus muscle									
		Width 1 [mm]		Width 2 [mm]		Length [mm]		Circumference [mm]		Projection surface area [mm^2]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
18	6	3.91	0.32	2.38	0.13	17.76	0.70	38.99	1.96	48.44	5.06
19	2	4.53	0.05	2.67	0.04	19.29	0.08	45.95	0.54	62.81	2.10
20	2	4.89	0.03	2.97	0.02	22.08	0.09	49.85	0.10	75.76	1.38
21	3	5.09	0.15	3.10	0.10	22.52	0.40	50.36	0.32	79.95	2.93
22	1	5.34		3.33		23.62		53.59		89.71	
23	2	5.70	0.18	3.62	0.19	26.21	1.52	57.73	3.00	105.83	9.45
24	3	5.92	0.09	3.82	0.07	27.81	0.51	61.75	1.97	127.08	13.69
25	4	6.55	0.26	4.18	0.16	28.62	0.12	66.33	1.72	144.55	1.23
26	3	7.15	0.18	4.43	0.04	29.69	0.49	69.43	0.93	147.63	1.12
27	4	7.54	0.16	4.56	0.08	30.66	0.46	70.57	0.33	150.82	1.12
28	2	7.72	0.01	4.70	0.01	31.13	0.03	71.77	0.18	156.79	0.61
29	3	8.13	0.11	4.93	0.12	31.86	0.43	75.65	1.23	172.21	2.11
30	1	8.41		5.28		33.21		81.54		179.41	

DISCUSSION

The supraspinatus tendon is the most frequently injured structure within the musculotendinous (rotator) cuff. The incidence of supraspinatus tendinopathy is approximately 61.9% in men and 38.1% in women [12]. According to some authors [6, 10], supraspinatus tendinopathy is associated with an extremely complex structure of the supraspinatus tendon, which is not typical of fusiform muscles. In fact, in the supraspinatus tendon two disparately anterior and posterior subregions are distinguished. It is noteworthy that the anterior subregion of supraspinatus tendon is thicker and more cylindrical, when compared to the posterior subregion of supraspinatus tendon, which is thinner and belt-like. Furthermore, unlike the posterior subregion, the anterior subregion of supraspinatus tendon extends further medially from its insertion on the greater tubercle of humerus and form a ramified fibrous structure [1]. Therefore, it is important to understand the development and

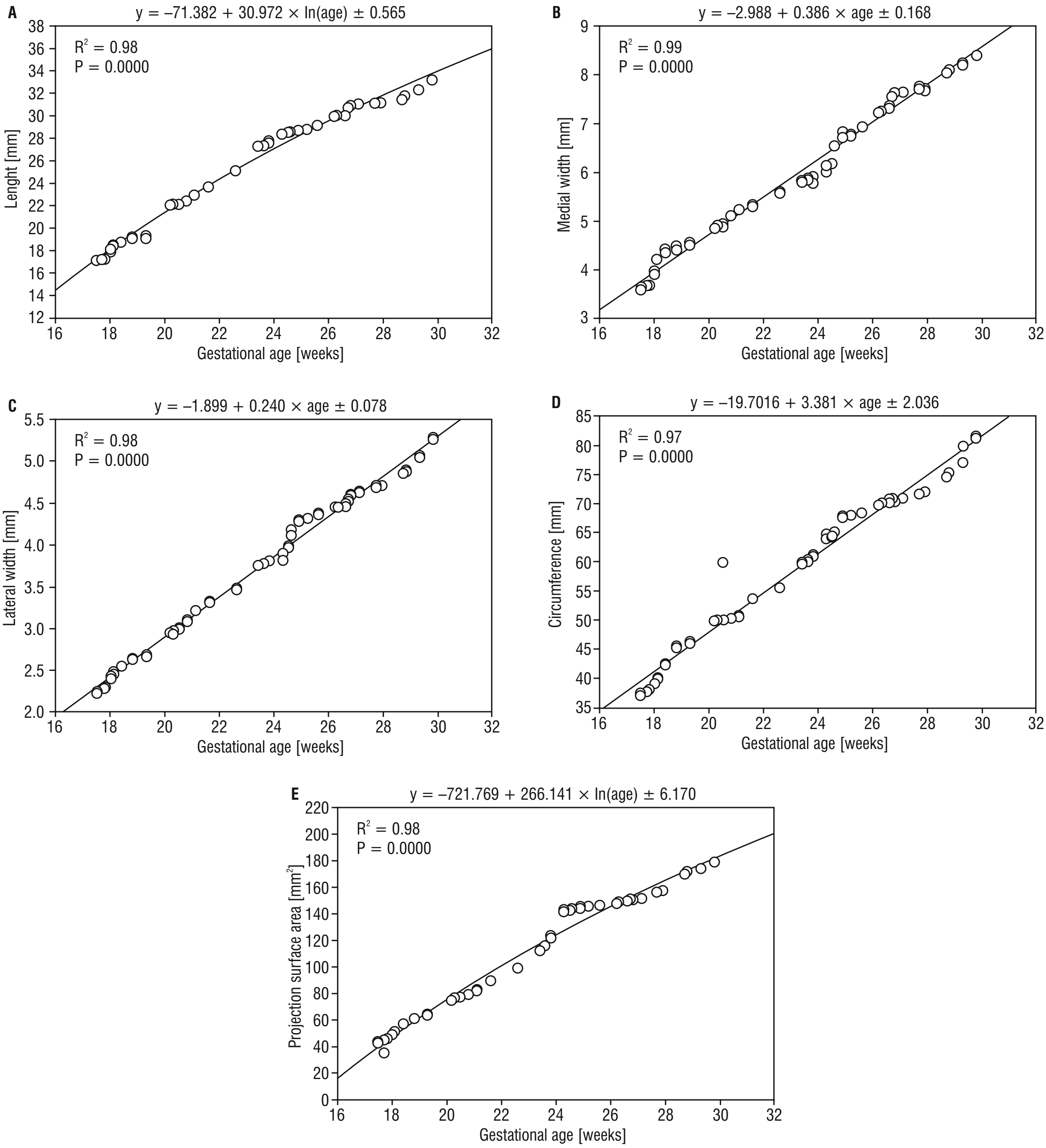

Figure 2. Regression lines for the length (**A**), widths (**B**, **C**), circumference (**D**) and projection surface area (**E**) of the supraspinatus muscle.

growth dynamics of the parameters of the supraspinatus muscle evaluated in the present study.

Abe et al. [1] found the supraspinatus tendon together with the tendons of the infraspinatus and subscapularis muscles to be separated from the articular cavity of the shoulder joint by the glenohumeral ligaments in week 9 of gestation, without explicit insertion to the humerus. Their connection to the anatomical neck of humerus occurred as late as week 12 of gestation. The authors concluded the superficial part of the supraspinatus tendon to be formed near the infraspinatus tendon until week 12 of gestation; the latter along with the coracohumeral ligament appear to compress the insertion of the supraspinatus tendon. Therefore, the authors suggested that the supraspinatus and infraspinatus tendons develop very close to each other and form one anatomical element.

Fealy et al. [5], who mostly focused on the shoulder joint in terms of its articular cavity and the glenohumeral ligaments described the ossification of the scapula that clearly affects the origin of the supraspinatus muscle and the force exerted by it. The authors concluded such an incorrect structure of the supraspinatus muscle to result in reduced muscle work and an inappropriate pull exerted on the humerus. This may produce the instability at the shoulder joint from an early fetal age.

There are no reports in the professional literature concerning the size and dimensions of the supraspinatus muscle in human fetuses, which precludes a more comprehensive discussion on this topic.

In this study we found the supraspinatus muscle to demonstrate neither sex nor laterality differences in its morphometric parameters. Similar findings were emphasized by some authors, who deal with the development of other skeletal muscles in human fetuses, i.e. triceps brachii muscle [7] biceps brachii muscle [14], biceps femoris muscle [15], trapezius muscle [2], deltoid muscle [13], semitendinosus muscle [4], semimembranosus muscle [3] and quadratus lumborum muscle [8].

To our best knowledge the present study is the first one in the professional literature to evaluate mathematical growth dynamics of the supraspinatus muscle as a function of gestational age in weeks. Morphometric parameters of the supraspinatus muscle increased either logarithmically or linearly in accordance with the following functions: $y = -71.382 + 30.972 \times \ln(\text{Age}) \pm 0.565$ for length, $y = -2.988 + 0.386 \times \text{Age} \pm 0.168$ for greatest width, $y = -1.899 + 0.240 \times \text{Age} \pm 0.078$ for width perpendicular to the scapular notch, $y = -19.7016 + 3.381 \times \text{Age} \pm 2.036$ for circumference, and $y = -721.769 + 266.141 \times \ln(\text{Age}) \pm 6.170$ for projection surface area.

Numerical data for the supraspinatus muscle may be conducive in the assessment of the development of both the musculoskeletal systems and the fetus, with a potential relevance in surgery. We believe that the age-specific normative values for the growing supraspinatus muscle in human fetuses at varying gestational weeks obtained in this study will provide an introductory basis for future autopsy studies.

The main limitation of this study is a relatively narrow gestational age range from 18 to 30 weeks, and a small number of cases, including 34 human fetuses.

CONCLUSIONS

Neither sex nor laterality differences are found for all studied morphometric parameters of the supraspinatus muscle.

The growth dynamics of the length and projection surface area of the supraspinatus muscle increase logarithmically, while its widths and circumference increase proportionately to gestational age.

Conflict of interest: None declared

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