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Quantitative anatomy of the infraspinatus muscle in the human fetus

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ABSTRACT

Background: The study presents one of the six scapulohumeral muscles, which occupies most of the osteofibrous infraspinatus compartment. Along with the supraspinatus, teres minor and subscapularis muscles, the infraspinatus muscle contributes to the rotator cuff. It protects the posterior aspect of the articular capsule of the shoulder joint, adducts and externally rotates the arm. The aim of the study was to perform the quantitative analysis of the infraspinatus muscle in human fetuses and to elaborate growth dynamics for its morphometric parameters.

Materials and methods: Using anatomical dissection, digital image analysis (NIS Elements AR 3.0) and statistics (Student's t-test, regression analysis), the vertical, transverse and oblique diameters, muscle circumference and projection surface area of the infraspinatus muscle were measured in 36 human fetuses of both sexes (17♂, 19♀) aged 18–30 weeks. The infraspinatus muscle revealed neither sex nor laterality differences.

Results: All examined morphometric parameters of the infraspinatus muscle increased commensurately in accordance with the following linear functions: y = –4.024 + 0.903 × Age

± 0.621 (R^2 = 0.96) for transverse diameter, y = –3.089 + 1.321 × Age ± 0.897 (R^2 = 0.97) for vertical diameter, y = –1.161 + 0.632 × Age ± 0.444 (R^2 = 0.97) for oblique diameter, y = –13.575 + 3.851 × Age ± 1.938 (R^2 = 0.98) for muscle circumference and y = –293.512 + 23.228 × Age ±19.650 (R^2 = 0.95) for projection surface area.

Keywords: infraspinatus muscle, morphometric parameters, growth dynamics, fetal development

INTRODUCTION

The infraspinatus muscle, one of the six scapulohumeral muscles, occupies most of the osteofibrous infraspinatus compartment on the posterior surface of scapula, being posteriorly covered with the infraspinatus fascia [31]. The infraspinatus muscle originates from the three-fourths of the infraspinous fossa. Its tendon runs laterally below the spine of scapula, is secured with the posterior aspect of the articular capsule of the glenohumeral joint, and finally inserts onto the middle of the posterior aspect of the greater tubercle, between the insertions of the supraspinatus muscle above and the teres minor below.

Along with the supraspinatus, teres minor and subscapularis muscles, the infraspinatus muscle is involved in the rotator cuff. This musculotendinous cuff plays an essential role in both the protection and mobility of the shoulder joint. The rotator cuff provides opposing forces to hold the head of humerus at the shallow glenoid cavity during excessive movements at the shoulder joint. The infraspinatus muscle is involved in the anterior-posterior force balance and posteriorly protects the shoulder joint, while the anterior protection of shoulder joint is provided by the subscapularis muscle. The infraspinatus and teres minor muscles act in a synergistic manner, resulting in adduction, exorotation and extension at the shoulder joint [34]. When the arm is fixed in the anatomical position, the infraspinatus muscle allows for the abduction of the inferior angle of scapula, thus imparting the greater mobility to both the scapula and the shoulder joint [34].

Dysfunctions within the shoulder joint are often associated with damage to the rotator cuff muscles [25], and most commonly refer to the supraspinatus muscle [11, 26]. Nevertheless, dysfunctions of the infraspinatus muscle may also generate a pain and disorders of the biomechanics at the shoulder joint [20]. When the infraspinatus tendon is ruptured, the head of humerus may partially leave the glenoid fossa that decreases the efficiency of the deltoid muscle to abduct the arm [34].

After reviewing the professional literature in terms of morphometric parameters of the infraspinatus muscle we found some its numerical data only in adults with the use of various imaging methods, such as ultrasound, magnetic resonance imaging and computed tomography [18, 22, 33], and autopsy studies [4, 24]. To the best of our knowledge, the present study constitutes the first report in professional literature to endow us with the quantitative analysis of the infraspinatus in the human fetus.

The aim of the present study was:

- to perform morphometric analysis of the infraspinatus muscle in human fetuses with respect to linear and planar parameters in order to determine the scope of normative values,
- to examine possible sex and laterality differences for the five analyzed morphometric parameters, and
- to develop the best-matched growth dynamics for all the analyzed morphometric parameters.

MATERIAL AND METHODS

The study material comprised 36 human fetuses (17 males and 19 females) aged 18–30 weeks of gestation which originated from spontaneous miscarriages and preterm deliveries. The fetuses were acquired before the year 2000 and constitute part of the specimen collection of the Department of Normal Anatomy of the Ludwik Rydygier Collegium Medicum in Bydgoszcz of the Nicolaus Copernicus University in Toruń. This experiment was approved by the Bioethics Committee of the Ludwik Rydygier Collegium Medicum in Bydgoszcz (KB 275/2011). The gestational ages were based on the crown-rump vertical diameter. Table 1 lists the characteristics of the study group, including the age, number and sex of the fetuses studied.

Using anatomical dissection, each infraspinatus muscle was bilaterally visualized, then imaged with Canon EOS 70D(W) digital camera and finally subjected to morphometric analysis with the use of the NIS Elements AR 3.0. digital image system. For every infraspinatus muscle, the following five parameters were measured in the frontal projection (Fig. 1B):

1. transverse diameter based on the determined greatest distance between its lateral borderline on the greater tubercle and the medial border of scapula,
2. vertical diameter based on the determined greatest distance between its superior and inferior borderlines,

3. oblique diameter based on the determined distance between its superior borderline in the area of the trigonum spinae and its lateral borderline reached at right angle,
4. muscle circumference based on the contour of the entire muscle, and
5. projection surface area outlined by the muscle circumference.

The individual numerical data of the infraspinatus muscles was statistically analyzed. The distribution of variables was checked using the Shapiro–Wilk test, while the homogeneity of variance was checked using Fisher's test. Because of the normal distribution of all variables the results were expressed as arithmetic means with standard deviations (SD). So as to compare the means of morphometric parameters, Student's t-test for independent variables and one-way analysis of variance were used. Tukey's test was used for *post-hoc* analysis. The growth dynamics of the analyzed parameters were based on linear and non-linear regression analysis. The match between the estimated curves and measurement results was evaluated based on the coefficient of determination (R^2).

RESULTS

In all fetuses the infraspinatus muscle was typically extended, without any macroscopic variations. The statistical analysis of all the morphometric parameters revealed neither sex nor laterality differences ($p > 0.05$). As a result, their means and standard deviations have aggregately been presented in Table 2 for the right infraspinatus muscle and in Table 3 for the left infraspinatus muscle. Consequently, we could evaluate one growth dynamics for each morphometric parameter without taking into account the sex or age. All morphometric parameters of the infraspinatus muscle revealed a proportionate increase with fetal age in accordance with linear functions.

The mean transverse diameter of the infraspinatus muscle increased from 19.15 ± 0.92 mm at 18 weeks of gestation to 35.42 mm at 30 weeks of gestation on the right side, and from 19.2 ± 0.86 to 35.41 mm respectively on the left side, following the linear function: $y = -4.024 + 0.903 \times Age \pm 0.621$ ($R^2 = 0.96$) – (Fig. 2A).

The mean vertical diameter of the infraspinatus muscle at 18–30 weeks of gestation increased from 11.64 ± 0.18 to 22.25 mm on the right side, and from 11.56 ± 0.27 to 22.23 mm on the left side, resulting in the linear function: $y = -3.089 + 1.321 \times Age \pm 0.897$ ($R^2 = 0.97$) – (Fig. 2B).

The mean oblique diameter of the infraspinatus muscle grew from 9.44 ± 0.24 mm at week 18 to 17.65 mm mm at week 30 on the right side, and from 9.47 ± 0.21 to 17.66 mm correspondingly on the left side, as the linear function: $y = -1.161 + 0.632 \times Age \pm 0.444$ ($R^2 = 0.97$) – (Fig. 2C).

In the analyzed age range of 18 – 30 weeks of gestation, the mean muscle circumference of the infraspinatus muscle increased from 53.13 ± 2.2 to 100.69 mm on the right, and from 52.95 ± 2.16 to 100.64 mm on the left, thus generating the linear model: $y = -13.575 + 3.851 \times Age \pm 1.938$ ($R^2 = 0.98$) – (Fig. 2D).

The mean projection surface area of the infraspinatus muscle at weeks 18–30 of gestation revealed an increase from 116.16 ± 6.48 to 389.35 mm^2 on the right side, and from 116.66 ± 5.65 to 389.21 mm^2 on the left side, in accordance with the linear function: $y = -293.512 + 23.228 \times Age \pm 19.650$ ($R^2 = 0.95$) – (Fig. 2E).

DISCUSSION

Despite dysfunctions of the rotator cuff most commonly refer to the supraspinatus muscle [26], an improper function or damage to the supraspinatus muscle may surprisingly result in atrophy of the infraspinatus muscle [23]. Injuries of the infraspinatus muscle typically display the acute initial phase with musculotendinous disruptions and oedema.

A consecutive muscle repair with a fatty infiltration and modified muscle fibers is typical of the chronic phase, usually without lesions in the tendon insertion [32].

The professional literature on the numerical data of the infraspinatus muscle is limited to data performed on adult cadavers alone that does not allow for a comprehensive discussion.

Kato et al. [19] found the infraspinatus muscle to be consisted of the transverse and oblique parts. The oblique part of infraspinatus muscle is fan-shaped, originates from the infraspinous fossa and inserts onto the greater tubercle. The transverse part of infraspinatus muscle starts with the inferior surface of the spine of scapula and inserts onto the tendon of the oblique part of infraspinatus muscle. According to Snow et al. [27], the infraspinatus muscle reveals the greatest variability among the rotator cuff muscles. The infraspinatus muscle may comprise two bellies, named the infraspinatus major muscle and the infraspinatus minor muscle, which both occupy the osteofibrous infraspinatus compartment. Such a rotator cuff consisting of the infraspinatus major and infraspinatus minor muscles was described by Ashaolu et al. [3]. Of note, the infraspinatus major muscle occupied most of the infraspinous fossa and its tendon inserted onto the superior aspect of the greater tubercle. The infraspinatus minor muscle was located inferiorly to the infraspinatus major muscle, at the lower part of the infraspinous fossa, lacked any tendinous components and inserted onto the posterior aspect of the greater tubercle. Koptas et al. [21] presented a rotator cuff variation consisting of a two-headed infraspinatus minor muscle and three muscle bundles which form a three-headed fusion between the infraspinatus and teres minor muscles. Another existing variation is presented by the infraspinatus superficialis muscle which originates from the medial border of scapula, runs superficially towards the belly of typical infraspinatus muscle and inserts distally onto the greater tubercle [21].

Clavert et al. [9] analyzed frontal cross-sections of the shoulder complex in human fetuses and found an intimate relationship between the developing articular capsule of the shoulder joint and its surrounding muscles, i.e. the rotator cuff muscles and the biceps brachii muscle. According to these authors, the rotator cuff was individually developed at weeks 13 and 14 of gestation [9]. At that time the articular capsule of shoulder joint showed signs of a distinct structural thickening due to the fusion with tendons of the supraspinatus, infraspinatus teres minor and subscapularis muscles. Another group of researchers [15] concentrated on the development of the shoulder joint during the embryonic and prenatal periods. Their findings present in detail the chronological order of appearance of key intrinsic structures of the shoulder complex such as its articular capsule [1, 10], glenoid labrum [2] and tendon apparatus [1].

Our study found the infraspinatus muscle to demonstrate neither sex nor laterality differences in its morphometric parameters. Analogous findings were observed in human fetuses in relation to other skeletal muscles, such as the supraspinatus muscle [8], triceps brachii muscle [12], biceps brachii muscle [29], trapezius muscle [5], deltoid muscle [28], biceps femoris muscle [30]. semimembranosus muscle [6], semitendinosus muscle [7] and quadratus lumborum muscle [13].

This study is the first in professional literature to evaluate mathematical growth dynamics of the infraspinatus muscle as a function of gestational age. All morphometric parameters of the infraspinatus muscle increased proportionately in accordance with the following linear functions: $y = –4.024 + 0.903 \pm \times \text{Age} \pm 0.621$ (R^2=0.96) for transverse diameter, $y = –3.089 + 1.321 \times \text{Age} \pm 0.897$ (R^2=0.97) for vertical diameter, $y = –1.161 + 0.632 \times \text{Age} \pm 0.444$ ($R^2 = 0.97$) for oblique diameter, $y = –13.575 + 3.851 \times \text{Age} \pm 1.938$ ($R^2 = 0.98$) for muscle circumference, and $y = –293.512 + 23.228 \times \text{Age} \pm 19.650$ ($R^2 = 0.95$) for projection surface area. Numerical data for the growing infraspinatus muscle may be conducive in the assessment of the development of both the musculoskeletal system and the fetus, with potential relevance for surgery [35]. We believe that age-specific normative values for the infraspinatus muscle in human fetuses at varying gestational weeks obtained in this study will provide a valuable contribution for future autopsy studies.

The main limitation of this study may be a relatively narrow gestational age range from 18 to 30 weeks and a small number of cases, comprising 36 human fetuses.

CONCLUSIONS

1. In terms of morphometric parameters the infraspinatus muscle displays neither sex nor laterality differences.
2. The infraspinatus muscle grows proportionately in its transverse, vertical and oblique diameters, muscle circumference and projection surface area.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

Any additional data supporting this study are available from the corresponding author (M.B.) upon reasonable request.

Ethics statement

This material has not been published in whole or in part elsewhere. The manuscript is not currently being considered for publication in another journal. The anatomical protocol of the study was accepted by the Bioethics Committee of Ludwik Rydygier Collegium Medicum in Bydgoszcz (KB 275/2011). The fetuses were obtained from spontaneous abortions after parental consent and were from Department of Anatomy of Ludwik Rydygier Collegium Medicum of Nicolaus Copernicus. Everything was in accordance with the legal procedures in force in Poland and in accordance with the program Donation Corpse both adults and fetuses. This study was performed in line with the principles of the Declaration of Helsinki.

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overall knowledge that can then improve patient care. Therefore, these donors and their families deserve our highest gratitude [14–16].

Conflict of interest

The authors declare that they have no conflict of interest.

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

Gestational age (weeks)	Crown-rump length [mm]				Number of fetuses	Sex	
	Mean	SD	Min	Max	N	♂	♀
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	0
Total					36	17	19

SD — standard deviation.

Table 2. Statistical analysis of numerical data (mean ± SD) of the right infraspinatus muscle.

Gestational age (weeks)	N	Right infraspinatus muscle: Transverse diameter [mm]		Vertical diameter [mm]		Oblique diameter [mm]		Circumference [mm]		Projection surface area [mm^2]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
18	6	19.15	0.92	11.64	0.18	9.44	0.24	53.13	2.20	116.16	6.48
19	2	21.85	2.04	12.30	0.46	10.91	0.72	58.06	3.90	134.91	13.74
20	2	24.55	0.53	15.54	0.09	12.11	0.27	68.53	0.11	190.65	1.74
21	3	25.55	0.40	15.68	0.13	12.56	0.10	69.75	0.48	203.53	7.84
22	1	26.11		15.99		12.81		71.29		208.03	
23	2	27.90	0.74	16.42	0.16	13.66	0.12	75.29	2.26	238.95	5.10

24	3	29.20	0.34	17.05	0.31	14.30	0.37	79.03	0.99	263.44	12.06
25	4	30.25	0.41	18.50	0.73	14.85	0.15	81.13	1.28	282.57	5.28
26	3	31.56	0.51	20.01	0.40	15.19	0.15	86.08	1.99	314.05	15.57
27	4	32.09	0.14	20.51	0.19	15.43	0.11	89.47	2.03	319.03	63.75
28	2	33.03	0.42	20.94	0.16	16.04	0.51	93.34	0.91	359.92	4.16
29	3	34.39	0.02	21.54	0.35	17.15	0.18	97.86	0.88	381.95	1.36
30	1	35.42		22.25		17.65		100.69		389.35	

Table 3. Statistical analysis of numerical data (mean ± SD) of the left infraspinatus muscle.

Gestational age (weeks)	N	Left infraspinatus muscle									
		Transverse diameter [mm]		Vertical diameter [mm]		Oblique diameter [mm]		Circumference [mm]		Projection surface area [mm^2]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
18	6	19.20	0.86	11.56	0.27	9.47	0.21	52.95	2.16	116.66	5.65
19	2	21.82	2.06	12.24	0.45	10.94	0.76	58.01	3.92	134.55	13.38
20	2	24.86	0.11	15.54	0.08	12.32	0.02	68.68	0.09	192.08	0.27
21	3	25.49	0.41	15.63	0.12	12.58	0.10	69.60	0.50	203.36	7.90
22	1	26.01		16.04		12.88		71.40		208.29	
23	2	27.82	0.73	16.37	0.14	13.55	0.30	75.05	2.23	238.71	4.95
24	3	29.18	0.33	17.04	0.32	14.32	0.35	79.11	0.94	263.61	12.15
25	4	30.23	0.44	18.49	0.75	14.82	0.13	81.22	1.20	283.1	5.05

										1	
26	3	31.54	0.48	19.98	0.37	15.17	0.14	85.99	1.88	313.66	14.94
27	4	32.11	0.14	20.50	0.16	15.46	0.13	89.49	1.90	319.44	63.85
28	2	33.03	0.43	20.96	0.14	16.09	0.49	93.41	1.02	360.11	4.22
29	3	34.53	0.06	21.56	0.44	17.24	0.17	98.78	0.44	383.95	3.12
30	1	35.41		22.23		17.66		100.64		389.21	

SD — standard deviation.

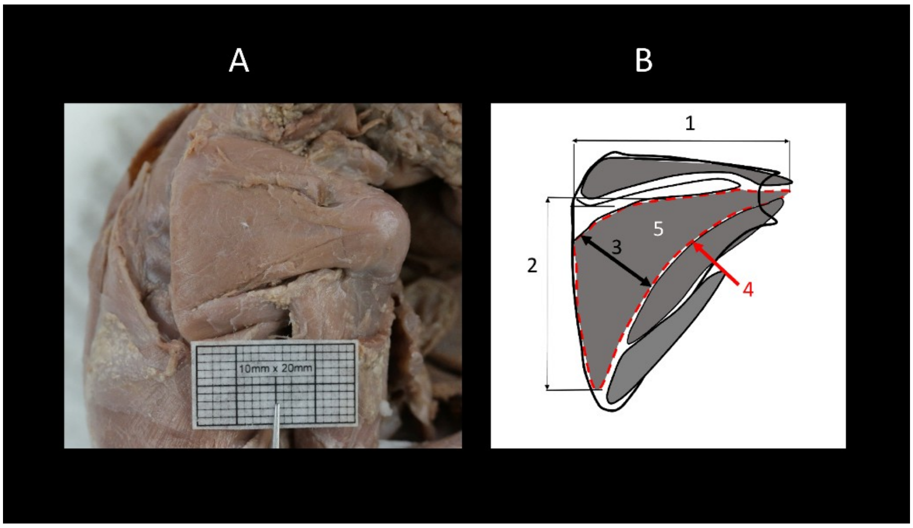

Figure 1. The infraspinatus muscle (**A**) in a male fetus aged 24 weeks showing the measured parameters (**B**); 1 — transverse diameter, 2 — vertical diameter, 3 — oblique diameter, 4 — muscle circumference, 5 — projection surface area.

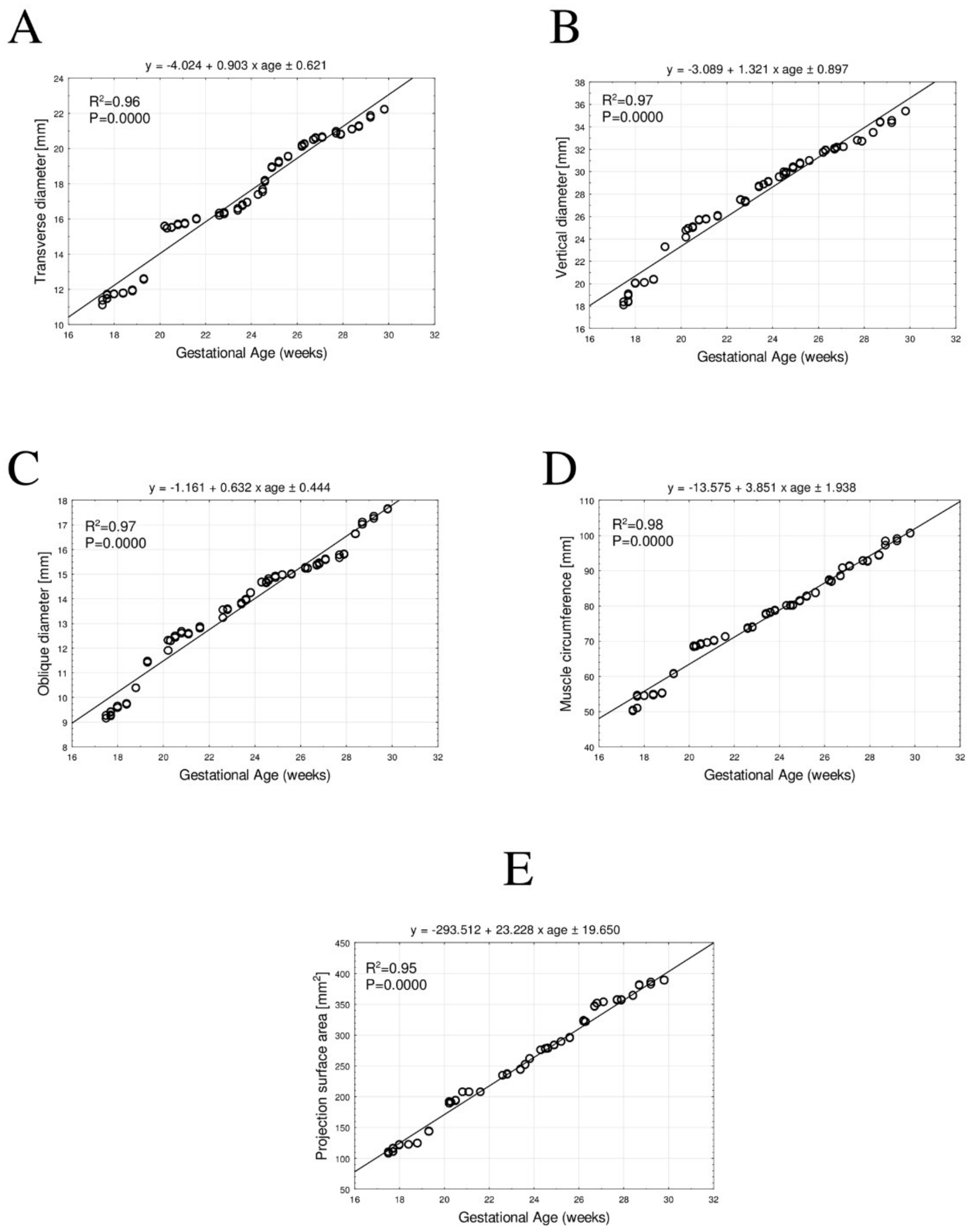

Figure 2. Regression lines for the transverse diameter (**A**), vertical diameter (**B**), oblique diameter (**C**), muscle circumference (**D**) and projection surface area (**E**) of the infraspinatus muscle.