

EDITORIAL

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Analysis of Human Scapula Morphometry in the Fetal Period*

Morfometria łopatki człowieka w okresie prenatalnym

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Abstract

Background. This paper presents a correlation analysis of results for 22 linear measurements describing scapular geometry in the human fetal period. The analysis aimed at selecting sizes correlating most with fetal age. The mathematical model appears suitable for assessing fetal age on the basis of only two scapular sizes and can be applied in forensic medicine or archaeology. During life, scapular measurements can constitute a fetal age assessment parameter of hypotrophy.

Objectives. The goal of the study was to analyze the metrology and anatomy of the human scapula in the fetal period.

Material and Methods. The material consisted of 63 fetuses (28 males, 35 females) aged 4–7 months of fetal life with a crown-rump length of 85–235 mm. The distances between characteristic points of the scapula were measured using the Gimp 2.0 and Scion for Windows computer programs on the basis of previously prepared scapulae photographs. Statistical analysis of the results excluded sexual dimorphism and left-right asymmetry. The analysis was followed up by the Shapiro-Wilk test for normality, Wilcoxon's signed-rank test for two related samples, the Mann-Whitney U test for independent samples, as well as nonlinear and multiple regression. The coefficient R^2 was determined to evaluate the goodness of fit of nonlinear mathematical models.

Results. The majority of the analyzed sizes strongly correlated with one another and with fetal age. Irregular increases in particular sizes were detected. The decreased rate in scapular development between the 17th and 25th weeks suggests the use of nonlinear models in its description in the prenatal period. The most considerable increase was noted in the lateral margin of the scapula. A correlation matrix was incorporated in all measurements and all features proved to correlate with age. The distance between glenoid labrum and coracoid process did not reveal any statistical correlation with age and was the only exception to the above observation. In the first weeks (14th–17th), the rate of scapular spine growth was greater than that of the distance between the superior angle and osseous margin, thus making the height-length index $D/L2$ correlate negatively with age. Starting from the 19th week the proportions become stable.

Conclusions. Faster growth of the length of the spine crest than the distance between the superior angle and the osseous margin in the 14th–17th weeks of fetal life makes height-length index W_l correlate positively with age, which means that scapular bone width increases faster than its length. The linear sizes helped to determine the bone and cartilage areas. The largest increase in osseous surface was observed in the 28th week of fetal life. In the analyzed period of fetal life, the increase in bone surface area A_B is sigmoid (rapid growth at the initial and final stages), whereas the increase in cartilage surface area A_C is characterized by a sharp rate only in the first stage (14th–17th week) (Adv Clin Exp Med 2009, 18, 3, 197–204).

Key words: human scapula morphometry, prenatal period.

Streszczenie

Wprowadzenie. W pracy przedstawiono wyniki analizy współzależności 22 wymiarów liniowych opisujących geometrię łopatki w okresie płodowym człowieka, mającą na celu wybór wymiarów najsilniej korelujących z wiekiem płodu. Zaproponowano model matematyczny umożliwiający oszacowanie wieku płodu na podstawie jedynie

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dwóch wymiarów łopatki. Model ten może być wykorzystany w medycynie sądowej lub archeologii. Przyżyciowo pomiary łopatki mogą być jednym z parametrów oceny wieku płodu w hipotrofii.

Cel pracy. Analiza metrologii i anatomii ludzkiej łopatki w okresie płodowym.

Materiał i metody. Materiał składał się z 63 płodów (28 męskich i 35 żeńskich w wieku 4–7 miesięcy, wymiar v-tub wyniósł 85–235 mm. Odległości między charakterystycznymi punktami łopatki mierzono, wykorzystując program komputerowy Gimp 2.0 oraz Scion for Windows na podstawie fotografii wcześniej wypreparowanych łopatek. Analiza statystyczna wyników pomiarów wykluczyła na poziomie $p < 0,05$ występowanie dymorfizmu płciowego i asymetrii między stroną lewą i prawą. W analizie korzystano z testu normalności Shapiro-Wilka, testu Wilcoxon dla zmiennych zależnych, testu *U* Manna-Whitneya dla zmiennych niezależnych regresję nieliniową i regresję wieloraką. Do oceny dokładności dopasowania nieliniowych modeli matematycznych do wyników pomiarów wykorzystano współczynnik determinacji R^2 .

Wyniki. W badanym okresie większość z analizowanych wymiarów silnie korelowało między sobą oraz z wiekiem płodu. Stwierdzono nierównomierne tempo wzrastania poszczególnych wymiarów. Wolniejsze tempo między 17. i 25. tygodniem sugeruje, że do opisu rozwoju łopatki w okresie prenatalnym są przydatne modele nieliniowe. Największy przyrost występował w obrębie brzegu bocznego łopatki. Dla wszystkich pomiarów wyznaczono macierz korelacji – wszystkie cechy korelowały z wiekiem. Wyjątkiem była odległość między obrąbkiem stawowym a wyrostkiem kruczym, która nie wykazała istotnego statystycznie związku z wiekiem. W pierwszych tygodniach (14.–17.) tempo wzrostu długości grzebienia łopatki było większe od tempa wzrostu odległości między kątem górnym a końcem kostnym łopatki, co powodowało, że wskaźnik wysokościowo-długościowy $D1/L2$ koreluje ujemnie z wiekiem. Od 19. tygodnia proporcje łopatki ustalają się.

Wnioski. Szybsze tempo wzrostu wymiaru długości grzebienia łopatki od odległości między kątem górnym a końcem kostnym łopatki w pierwszych tygodniach (14.–17.) powoduje, że wskaźnik wysokościowo-długościowy W_1 koreluje ujemnie z wiekiem, tzn. szerokość łopatki rośnie szybciej niż jej długość. Wymiary liniowe posłużyły do wyznaczenia pola powierzchni kości i chrząstki. Największe tempo wzrostu powierzchni kostnej zaobserwowano w 28. tygodniu życia płodowego. W analizowanym okresie życia płodowego wzrost pola powierzchni kości A_B ma charakter sigmoidalny (szybki wzrost w początkowym okresie i końcowym, wzrost pola powierzchni chrząstki A_C natomiast charakteryzuje się szybszym tempem jedynie w pierwszym okresie (14.–17. tygodniu) (*Adv Clin Exp Med* 2009, 18, 3, 197–204).

Słowa kluczowe: morfometria ludzkiej łopatki, okres prenatalny.

Human scapula development during the fetal period is hardly presented in the majority of handbooks or anatomical papers. The papers usually discuss either the embryonic or post-partum periods [8]. Most surveys concerning fetal periods were performed using ultrasound [6]. Only single developmental studies of the scapula presented in the available literature were based on a very large amount of material [5, 18]. Also, surveys focusing on this anatomical region prove very poor as they usually concentrate on one particular part of the scapula or changes in only one dimension [2–4, 9, 10, 12, 16, 21]. Only some anatomical and ultrasound-based papers discuss the scapula as a whole. According to Mal [17], the first centers of scapular ossification appear on the 55th day. On the 58th day, their cross-sectional diameter amounts to 2.5 mm and on the 85th 9 mm [6, 7]. Fawcett [9] developed a scapular bone model in a 19-mm embryo. He described the acromion, scapular spine, and sub- and suprapectinate areas. Dijkstra [5] studied human scapular development based on material including 18 fetuses with CR length of 16–120 mm. He discussed the moment of scapular spine crest as well as suprapectinate surface formation in fetuses with a CR length of over 40 mm. In a 16-mm-long embryo he detected the presence of fovea, foramen, and superior angle and the suprapectinate foramen was noted in a 25-mm-long embryo. Dijkstra confirmed the formation of the

scapula in fetuses with a CR length of 16 mm. Gardner and Gray [11], based on material with CR length of 12–28 mm, observed scapula formation beginning at a CR length of 12 mm, scapular spine crest formation at 20 mm, and shoulder joint margin area ossification at 28 mm. In his description of upper limb development, Andersen [2] examined 49 human fetuses with CR length of 11–34 mm and discovered that the most mature cartilage was located in the very center of the scapula. He confirmed the observations of other authors [11] who had detected scapula presence even at a CR length of 12 mm. Drexler [7] examined 51 scapulas of both fetuses and neonates. He compared the dimensions and sizes of the scapula at three stages of human life, fetal, infantile, and adult, taking into account its location and shape. He measured the length and width of the scapula as well as glenoid fossa measurements and angles found in this organ. The authors of ultrasound-based papers [6] dealt only with scapular bone length measurement. Ultrasound was performed in 343 women. The fetuses' ages varied from 16 to 41 weeks. Biparietal measurements were made as well as scapular length, abdominal circumference, and femoral length. The most considerable growth was observed in the 28th week of fetal life. Correlation between age and scapular size increase was noted and scapular length was suggested as one of the possible parameters of fetal growth.

The goal of the present study was a more thorough analysis of scapular metrology and anatomy in the fetal period. The mathematical model appeared suitable to assess fetal age on the basis of two scapular sizes only. This model can be applied in forensic medicine or archaeology. During life, scapular measurements can constitute a fetal age assessment parameter of hypotrophy.

Material and Methods

The material consisted of 63 human fetuses of both sexes (28 male, 35 female) aged 14–28 weeks of fetal life with crown-rump (C-R) length of 85–235 mm (Fig. 1). The fetuses were examined bilaterally with special concern for symmetry and sexual dimorphism of the scapula or lack of these features. Morphological age was assessed with the use of an anthropological method based on CR length size and Scammon-Calkins tables [20]. One hundred twenty-six bones were prepared and exculpated of soft tissues. Digital photographs of the scapulae were taken on both sides perpendicular to the osseous surfaces. They were preliminarily processed with the Gimp 2.0 program. Image digital activation enabled repeated measurements without the danger of excessive devastation of the fetal material. The program Scion for Windows helped to determine the distances between characteristic points describing the scapular bone and cartilage geometry.

For each specimen, 22 linear measurements were established (Table 1, Fig. 2). The results were statistically analyzed. The significance of differences between male and female fetal features was verified with the Mann-Whitney *U* test. The significance of the difference between scapular para-

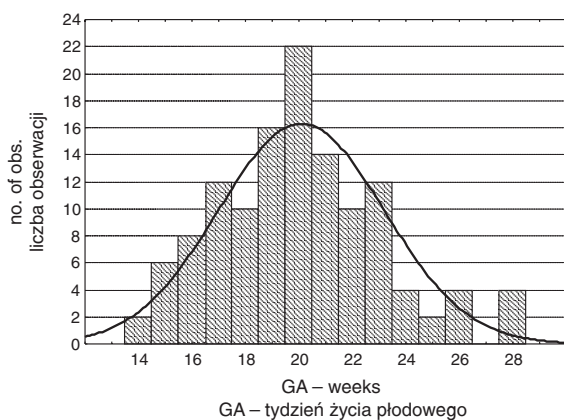


Fig. 1. Bar chart of the fetuses' ages with a superimposed normal distribution

Ryc. 1. Histogram wieku badanych płodów na tle rozkładu normalnego

meters on the left and right side was assessed with the Wilcoxon test for ranked pairs. As (at the level of $p < 0.05$) no dimorphism or asymmetry of the examined dimensions was found, the regression coefficient was determined on the basis of the 126 scapulae results (male and female fetuses, left and right sides). Dispersion graphs of the parameters as functions of age were analyzed. Nonlinear dependencies were considered when describing the relationships of fetal age and linear and superficial scapular sizes. In curvilinear regression models, exponential and polynomial functions were taken into account. The relation between analyzed size pairs was established with Spearman's rank correlation coefficient. In all tests, $p = 0.05$ was accepted as the level of statistical significance. Multiple regression analysis was used to form the model predicting fetal age on the basis of the measurements. A backwards stepwise method of multiple regression enabled building a model in which the number of independent variables was reduced from 22 to 2.

Results

The following features were analyzed: sex dimorphism, symmetry, growth rate, linear increases in features and surfaces in particular weeks, and the length-width index.

The results of 2772 measurements of dimensions defining scapular geometry were statistically analyzed (Fig. 2). The analysis aimed at assessing sex dimorphism, dimensional symmetry on the right and left sides, and growth rate analysis (Tab. 1). The correspondence of the dimensions' empirical distributions and a theoretical normal distribution was analyzed with the Shapiro-Wilk test with $p = 0.05$ as the critical level. In the particular age groups, the measurement distributions were close to normal. The *t* test for paired dependent samples was used to verify the significance of differences in measurements on the left and right sides and no statistically significant differences (at the $p < 0.05$ level) were noted in the analyzed dimensions. Sex dimorphism was verified with the *t* test for independent samples and none of the 22 dimensions revealed any statistically significant difference with respect to fetal sex ($p > 0.05$). Due to the lack of sex dimorphism and the presence of symmetry, the growth rate analysis incorporated the results of right and left scapula measurements in male and female fetuses jointly. Some dimensions were used in bone and cartilage area evaluation and in length-width index determination.

The increases in the majority of the dimensions were unstable. The increased rate in the first

Table 1. Scapular quantitative features and the adopted designations**Tabela 1.** Parametry ilościowe łopatki i ich oznaczenia

Symbol	Scapula dimension – mm (Wymiar łopatki – mm)
D1	distance between scapula superior angle and osseous margin odległość między kątem górnym a końcem kostnym łopatki
L2	scapular spine length długość grzebienia łopatki
W3	crest width on its osseous part szerokość grzebienia na jego części kostnej
D4	distance between scapula superior angle on the bone and the beginning of scapular spine odległość między kątem górnym łopatki na kości a początkiem grzebienia łopatki
D5	distance between scapula inferior angle on the bone and the beginning of scapular spine odległość między kątem dolnym łopatki na kości a początkiem grzebienia łopatki
D6	distance between lateral angle on the bone and inferior angle of scapular spine odległość między kątem bocznym łopatki na kości a kątem dolnym grzebienia łopatki
W7	cartilage width at the height of the inferior angle szerokość chrząstki na wysokości kąta dolnego
D8	distance between scapula lateral angle on the bone and inferior angle on the cartilage odległość między kątem bocznym łopatki na kości a kątem dolnym łopatki na chrząstce
D9	distance between scapular inferior angle on the cartilage and the beginning of the spine on the cartilage odległość między kątem dolnym łopatki na chrząstce a początkiem grzebienia na chrząstce
W10	cartilage width at the scapular spine level szerokość chrząstki na wysokości grzebienia łopatki
D11	distance between scapular superior level on the cartilage and the beginning of the scapular spine in the cartilage odległość między kątem górnym łopatki na chrząstce a początkiem grzebienia łopatki na chrząstce
W12	cartilage width at the height of the superior angle szerokość chrząstki na wysokości kąta górnego
W13	scapular incisure width szerokość wcięcia łopatki
D14	scapular incisure maximum depth największa głębokość wcięcia łopatki
D15	distance between scapular superior angle on the bone and scapular lateral angle odległość między kątem górnym łopatki na kości a kątem bocznym łopatki
W16	scapular spine cartilage width szerokość chrząstki grzebienia łopatki
W17	coracoid process width szerokość wyrostka kruczego
H18	coracoid process height wysokość wyrostka kruczego
H19	glenoid fossa height wysokość jamy stawowej
W20	glenoid fossa width szerokość jamy stawowej
D21	minimum distance between glenoid labrum and coracoid process najmniejsza odległość między obrąbkami stawowym a wyrostkiem kruczym
D22	minimum distance between glenoid labrum and acromion najmniejsza odległość między obrąbkami stawowym a wyrostkiem barkowym

weeks (Fig. 3) suggests the application of a non-linear model to describe scapular development in the prenatal period. Dispersion graph analysis showed that the majority of the linear size growth rates were smaller in the 18th and 26th weeks of fetal life than in the other analyzed periods. The coefficients of the values for nonlinear regression are significantly higher than the correlation coefficients for classical linear regressions. This proves that nonlinear models match measurements results better. Snedecor's *F* test results ($p < 0.05$) proved this observation as well.

Table 2 presents the distribution of the mathematical coefficients which enable assessment of the analyzed dimensions, indices, and bone and cartilage areas in the period from 14th to 28th weeks. The best match of the model and measurement results was acquired in the case of the dimension D8 (the distance between the scapula's lateral angle on the bone and the cartilage superior angle, $R = 0.704$) and D6 (the distance between the scapula's lateral angle on the bone and the superior angle of the scapular spine, $R = 0.637$). Knowledge of these dimensions pro-

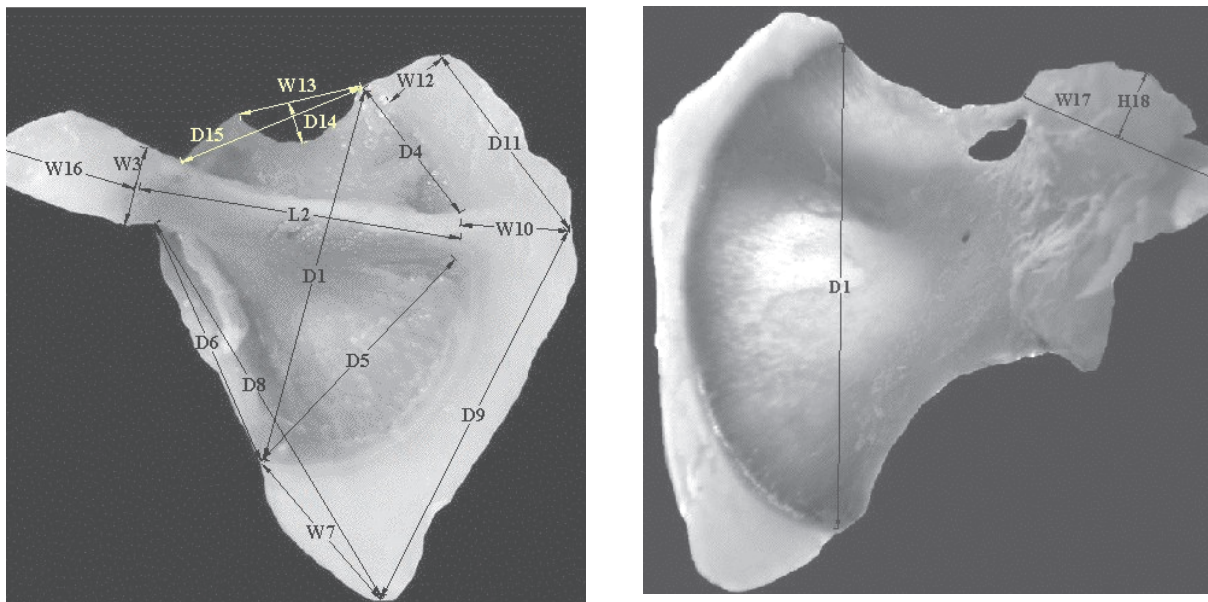


Fig. 2. Designations of the scapula's geometric dimensions

Ryc. 2. Oznaczenia wymiarów opisujących geometrię łopatki

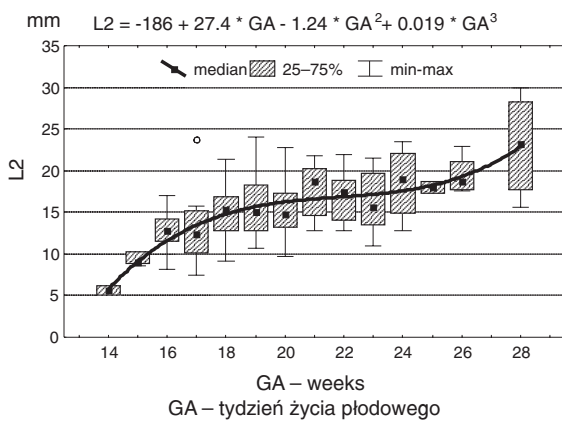
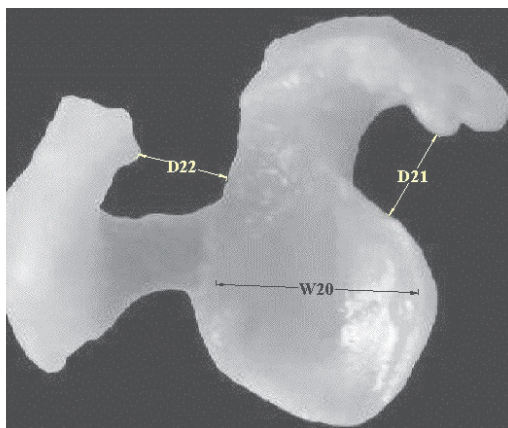


Fig. 3. Box diagram of the regression model of the L2 dimension with prenatal age

Ryc. 3. Diagram i model regresyjny zmiany wymiaru L2 w funkcji wieku płodu

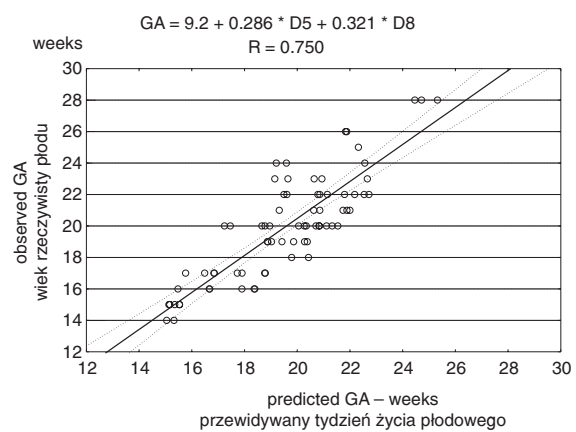


Fig. 4. Observed and predicted fetal age based on the multiple regression model using a backwards stepwise method

Ryc. 4. Współzależność rzeczywistego wieku płodu z wiekiem oszacowanym na podstawie modelu uzyskanego na drodze regresji wielorakiej metodą krokową wsteczną

Table 2. Extreme values of scapular dimensions, surface area, and mathematical model coefficients**Tabela 2.** Zakres zmienności wymiarów i powierzchni łopatki oraz współczynniki modeli matematycznych

Dimension (Wymiar) <i>Y</i>	<i>Y</i> _{min} [mm]	<i>Y</i> _{max} [mm]	Model	Coefficients (Współczynniki)				<i>R</i>
				<i>b</i> ₀	<i>b</i> ₁	<i>b</i> ₂	<i>b</i> ₃	
D1	10.1	36.1	1	-90.5	130.63	-3.298	-	0.563
L2	5.1	30.0	3	-186.3	27.42	-1.245	0.019	0.798
W3	0.9	5.7	1	-6.5	12.60	-4.836	-	0.324
D4	2.3	12.6	1	-35.7	46.76	-2.004	-	0.351
D5	7.9	30.1	2	3.715	-19.40	-	-	0.562
D6	5.2	24.1	2	3.596	-21.8	-	-	0.637
W7	1.4	16.4	2	2.958	-17.86	-	-	0.500
D8	8.4	43.5	1	-77.6	120.10	-4.200	-	0.704
D9	10.7	35.3	1	-126.6	168.41	-2.532	-	0.604
W10	0.1	9.0	1	-14.0	18.84	-1.743	-	0.196
D11	5.2	31.3	2	3.237	-19.21	-	-	0.526
W12	0.6	6.0	1	-10.9	15.21	-2.106	-	0.249
W13	2.1	15.2	2	3.030	-19.66	-	-	0.534
D14	0.3	12.1	1	-5.9	10.30	-5.829	-	0.439
D15	2.9	23.7	2	3.606	-17.82	-	-	0.503
W16	0.8	20.7	1	-29.9	43.96	-3.460	-	0.360
W17	1.2	15.0	2	2.998	-20.91	-	-	0.381
H18	0.8	7.2	1	-4.5	9.66	-4.658	-	0.271
H19	2.1	12.6	2	2.888	-17.90	-	-	0.528
W20	1.5	7.6	1	-37.3	47.11	-2.210	-	0.562
D21	0.3	6.3	1	-18.6	22.21	-1.424	-	0.215
D22	0.1	8.1	1	-5.2	10.33	-5.652	-	0.258
D1/L2	62%	219%	3	159	-1.46	0.000	-	0.232
D4/D5	21%	84%	-	-	-	-	-	-
H19/W20	77%	398%	-	-	-	-	-	-
A _B [mm ²]	27.8	474.5	3	-3012	434.3	19.84	0.310	0.691
A _C [mm ²]	27.5	357.5	4	-427	417.4	-	-	0.532

Model 1: $Y = b_0 + b_1 * \exp(b_2 * X^{-1})$;

Model 2: $Y = \exp(b_0 + b_1 * X^{-1})$;

Model 3: $Y = b_0 + b_1 * X + b_2 * X^2 + b_3 * X^3$;

Model 4: $Y = b_0 + b_1 * \exp(X)$;

where X = week of fetal life, Y = scapular dimension [mm], R = correlation coefficient.

gdzie: X – tydzień życia płodowego; Y – wymiar łopatki [mm]; R – współczynnik korelacji.

vides the basis for defining fetal age with a very small error (Fig. 4). In the analyzed period of fetal life, the increase in bone area (A_B) is of sigmoid character (rapid at the initial and final stages), whereas the increase in cartilage area (A_C) has a more intensive rate at the initial stage only (from 14th to 17th week), hence the conclusion that the cartilage area portion of the whole scapula area decreases nonlinearly with age. Regression in the analyzed period is poor, but statistically significant ($p < 0.05$, Fig. 5). The

more considerable growth rate of the L2 dimension (the scapular spine length) than that of the D1 dimension (the distance between the superior angle and osseous end) in the first weeks (14th–17th) causes a negative correlation of the height-length index D1/L2 with age (Fig. 6). This means that scapular width increases faster than scapular length. Other analyzed indexes, scapular diameter, as well as the articular cavity remain at constant levels (D4/D5 = 52% and H19/W20 = 195%).

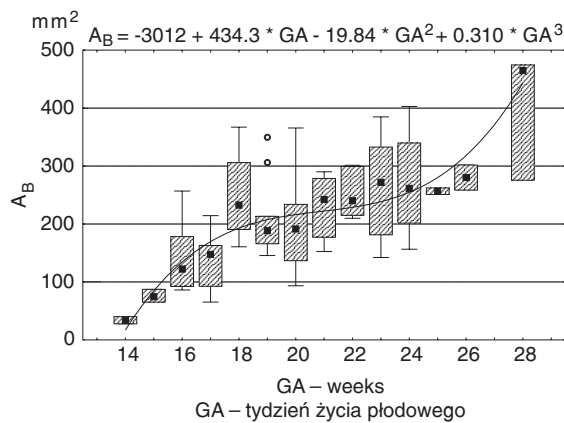


Fig. 5. Correlation box diagrams and osseous surface increase models (A_B – bone, A_C – cartilage areas)

Ryc. 5. Diagramy korelacyjne powierzchni i modele wzrostu (A_B – kość, A_C – chrząstka)

The proportion of cartilage surface of the scapula's total surface decreases from 140% in the 14th to 60% in the 19th week and remains at the same level until the 28th week (Fig. 7).

Discussion

Papers by Alverdes [1], Hertwig [13], and Rauber [19] largely contributed to understanding scapular development and they stressed the stability of scapular geometry for the whole human life. The present survey showed that scapular proportions undergo changes. The height-length coefficient $D1/L2$ decreases from 190% in the 14th week to 140% in the 18th week and remains stable until the 28th week. In the third month of fetal life, ossification begins in the area of the scapular lateral angle (shoulder joint area). Dijkstra [5] found the scapula in a 16-mm fetus which was similar in form to that observed in adults as it had a fossa and a superior angle present. On the basis of a study of

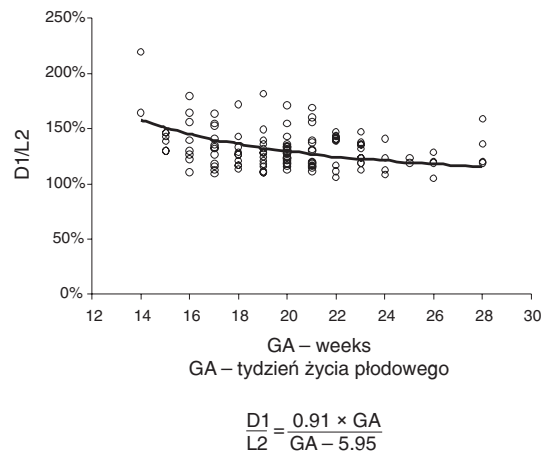


Fig. 6. Correlation diagram and change model of the scapular height-length coefficient with fetal age

Ryc. 6. Diagram korelacyjny i model współczynnika wysokościowo-długościowego łopatki z wiekiem płodu

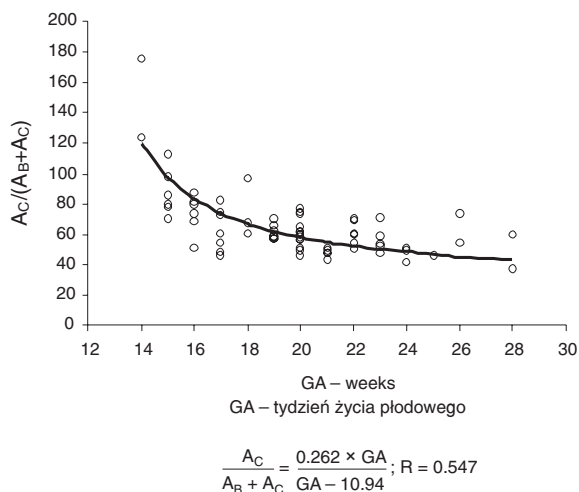


Fig. 7. Change in the proportion of cartilage area (A_C) in total scapular area (A_B+A_C) with fetal age and the regression model.

Ryc. 7. Zmiana udziału pola powierzchni chrząstki (A_C) w całkowitej powierzchni łopatki ($A_B + A_C$) i nieliniowy model regresji

the cartilaginous skeleton of an embryo with a C-R length of 17 mm, Hagen [12] stated that as early as at this developmental stage, except for an almost absolutely undeveloped scapular spine, all scapular parts corresponded with an adult scapula as far as their shape was concerned. Lewis [16] concentrated on the development of the upper limbs in 9 fetuses with C-R length of 3.5–20 mm and in an 11-mm embryo the acromion and coracoid process were found. Available literature does not include any studies incorporating the Scion for Windows program. This option enables precise measurement exact to 0.01 millimeter and repeatability of results. The elicited results concerning the

invariability of scapular geometry during the whole life correspond with the papers by Alveders, Hertwig, and Rauber. On the basis of their material the authors observed that the scapula's most intensive growth begins in the 28th week of fetal life. Dilmen et al. [6] concentrated mainly on scapular length measurement with the use of ultrasound examination of 343 fetuses and they observed correlation between age and scapular size increase.

The authors concluded that in scapular bone morphometry, no difference connected with sex was found and symmetry as well as particular features of unstable growth rate were detected. The growth rate of the scapula's linear sizes between the 17th and 25th week is slower than in other analyzed periods of fetal life. The proportion of cartilage surface in the scapula's total surface decreases from 140% in the 14th to 60% in the 19th week and stays the same till the 28th week.

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