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Development of Individual Growth Curve Standards for Estimated Fetal Weight: I. Weight Estimation Procedure

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Abstract: In this investigation the weight estimation procedure of Rossavik was reassessed with particular emphasis on parameter estimation and performance over a wide weight range. Using a cross-sectional data set (193 patients), a longitudinal data set (20 patients), and an iterative procedure, parameter estimates were obtained based solely on regression analysis. Comparison of weight estimates obtained using a function based on these parameter values with actual birth weights indicated virtually no systematic errors over a 250-g to 4750-g weight range and random errors (±1 SD) of 10% to 13% below 200 g and 6% to 8% above 2000 g. The weights of small- and large-for-gestational age fetuses were systematicly overestimated (4.1%) and underestimated (−3.0%), respectively, but systematic errors were not found in average-for-gestational age fetuses. No differences in random errors were seen in these three growth categories. Comparison with other weight estimation procedures indicated that the Rossavik procedure gives weight estimates that are at least as accurate as those obtained with other methods over a wide range of weight and growth categories. However, the Rossavik procedure can be used to generate individual growth curve standards for weight estimates, a characteristic not shared with other weight estimation procedures. **Indexing Words:** Weight estimation procedure • Individual growth curve standard

In assessing the growth of a fetus, the ideal standard against which to compare any set of measurements would be the expected parameter growth curve if fetal growth were normal. The use of such a standard individualizes the growth-assessment process and eliminates the effects of biological variability present in population standards. As shown by Deter et al.,[1–4] individual growth curve standards for 9 anatomic parameters can be obtained through the use of the growth model described by Rossavik and Deter.[5]

Fetal weight has long been a parameter used in obstetrical management decision making and its estimation is part of any comprehensive assessment of fetal growth.[6] Therefore development of individual growth curve standards for this parameter is of considerable interest and is possible through use of a weight estimation procedure based on the Rossavik growth model. A weight estimation procedure of this type has been described by Rossavik[7,8] (see the appendix), and was used to evaluate normal growth[9] and growth abnormalities.[10] However, the methods employed to obtain values for the coefficients used in this procedure have not been described in detail and appear to lack statistical rigor. Also, the range over which the Rossavik procedure has been tested is limited, particularly with respect to fetal weights below 1000 g. For these reasons we have reinvestigated this procedure, with particular emphasis on coefficient estimation and the testing of the procedure over a broad weight range.

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MATERIALS AND METHODS

Patient Samples

This investigation was carried out using two patient samples. The first of these, called the "cross-sectional sample," consisted primarily [179/193 (92.7%)] of middle-class Caucasian women studied in Oslo, Norway. An additional 14 (7.3%) similar women studied in Houston, Texas, were included in this sample. The birthweight and birth-age distributions of the cross-sectional sample are given in Figure 1. Of these birth weights, 14.5% were above the 90th percentile and 16.1% below the 10th percentile for age at birth.[11]

The second sample, called the "longitudinal sample," consisted of 20 middle-class women, primarily Caucasian, studied in Houston, Texas.[2] All of the fetuses in this sample were delivered at term and were considered normal by a variety of pediatric criteria.

Fetal Age Determination

In the cross-sectional sample, fetal age at the time of the ultrasound examination was determined from the first day of the last menstrual period (LMP). All patients had normal menstrual histories and in 30% of the cases fetal age was confirmed by ultrasound examination in the first or early second trimester.

As described previously,[2] fetal age estimates in the longitudinal study were based on the date of the beginning of the last menstrual period or early ultrasound examinations. In 55% of the women the date of ovulation, determined from basal body temperature and intercourse records,[12] was known.

Ultrasound Examination

In the cross-sectional sample, ultrasound examinations were performed within one week of de-

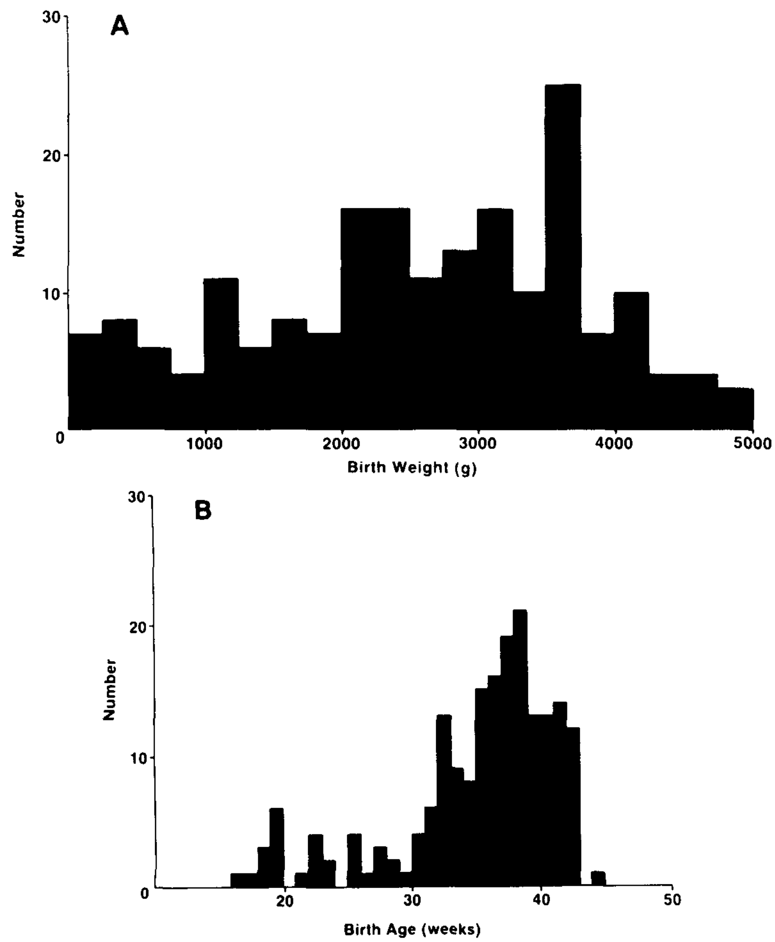

FIGURE 1. Birth-weight and birth-age distributions in cross-sectional sample. This figure presents the distributions of birth weight **(A)** and birth age **(B)** in the cross-sectional sample used in this investigation.

livery, with 89% carried out within 3 days of delivery. These examinations were made using an ADR 2130 scanner with a 3.5-MHz transducer. The head and abdominal cubes were measured once in each fetus using methods described previously.[13] Head cube *(A)* values before 26 weeks menstrual age *(MA)* were determined from diameters measured from the outer edge of the skull echos while those after 26 weeks were determined from diameters measured from the middle of the skull echos. Abdominal cube *(B)* values were determined from diameters measured from the outer edge of the abdominal profile in all cases.

In the longitudinal sample, ultrasound examinations were performed at 2-week to 3-week intervals from 15 weeks until delivery (after 37 weeks), as described previously.[2] A variety of parameters were measured, including the head and abdominal cubes, using methods previously described.[6,13] Head and abdominal cube values were determined as described in the previous paragraph.

Data Analysis

As indicated in the appendix, a function relating A and B to weight can be written in the following form:

$$EWT = b_A \cdot WT_A + b_B \cdot WT_B \qquad (1)$$

where EWT is the estimated weight, b_A and b_B the weighting factors, and WT_A and WT_B the weight estimates based on A only and on B only. Substituting the functions for WT_A and WT_B, Eq. (1) has the following form:

$$EWT = b_A \cdot \left[\frac{c_{wA}}{c_A} \cdot (MA - SP_A)^{(k_{wA} - k_A) + (s_{wA} - s_A)\cdot(MA - SP_A)}\right] \cdot A + b_B \cdot \left[\frac{c_{wB}}{c_B} \cdot (MA - SP_B)^{(k_{wB} - k_B) + (s_{wB} - s_B)\cdot(MA - SP_A)}\right] \cdot B \qquad (2)$$

where c_{wA}, k_{wA}, and s_{wA} are the coefficients of the weight growth model related to A; c_{wB}, k_{wB}, and s_{wB} the coefficients of the weight growth model related to B, c_A,k_A, s_A, and c_B, k_B s_B the coefficients of the A and B growth models, respectively; and SP_A and SP_B the A and B start points. If values for WT_A and WT_B are available, estimates of b_A and b_B can be obtained by regression analysis[14] (without a constant term) using the cross-sectional sample. However, calculation of WT_A and WT_B requires values for various coefficients and start points. Those for A and B can be obtained by regression analysis using the longitudinal sample as described previously.[1] Those for w_A and w_B can also be obtained by regression analysis, using the appropriate start points (SP_A: c_{wA}, k_{wA}, s_{wA}; SP_B: c_{wB}, k_{wB}, s_{wB}), and the longitudinal sample, if weight values at different time points were available. However, as direct weighing of the fetus is not possible, such analyses must be carried out with weight estimates, which can only be calculated if the coefficient values for w_A and w_B are known.

This type of problem is well known in statistics and can be solved by an iterative procedure. In this procedure, values for the needed coefficients were estimated from the work of Rossavik,[8] WT_A and WT_B calculated using average SP_A and SP_B values obtained from studies on the longitudinal sample, and b_A and b_B determined by regression analysis using the cross-sectional data set. Two sets of estimated weights for each fetus in the longitudinal sample were then calculated using Eq. (2), the estimated coefficient values, and the appropriate start points (SP_A and SP_B). In all of these weight estimation calculations, 37 weeks was used for fetal ages greater than 37 weeks. Regression analysis, with the appropriate set of estimated weights, was then carried on each fetus to obtain individual values for c_{wA}, k_{wA}, s_{wA}, c_{wB}, k_{wB}, and s_{wB}. The average values for k_{wA} and k_{wB} were determined, and the regression analyses repeated with fixed values for k_{wA} and k_{wB} (average values were used).[1] The new individual c_{wA}, s_{wA}, c_{wB}, and s_{wB} values were then used, together with the corresponding individual c_A, s_A, c_B, and s_B values, to calculate c_{wA}/c_A, $s_{wA} - s_A$, c_{wB}/c_B, and $s_{wB} - s_B$ values for each fetus. The individual ratio and difference values were averaged, and values for $k_{wA} - k_A$ and k_{wB} obtained using averaged values for the different k coefficients (average k_A and k_B values: 3.856, 3.284[4]). The average values for c_{wA}/c_A, $s_{wA} - s_A$, c_{wB}/c_B, $s_{wB} - s_B$, SP_A and SP_B, together with the values for $k_{wA} - k_A$ and $k_{wB} - k_B$ as well as the appropriate A and B values, were then used to recalculate the WT_A and WT_B values [see Eqs. (6) and (7) of the appendix] for the cross-sectional sample. With these new

WT_A and WT_B values, the process was then repeated. Longitudinal sample weight estimates in subsequent cycles were calculated using average ratio and difference values obtained in preceding cycles. This iterative procedure was continued until average ratio and difference values were relatively stable, and all calculations were made using weight estimates based only on ratio and difference values derived from regression analysis.

Evaluation of each weight estimation procedure was carried out using the cross-sectional data set. After each iteration a weight estimate was calculated for each fetus (fetal age was taken as 37 weeks for all fetuses delivering after 37 weeks) and compared to the actual birth weight. The difference obtained was expressed as a percent of the birth weight and the mean and standard deviation of these signed percent differences calculated. To facilitate comparisons with other weight estimation procedures, mean and standard deviation values were calculated for all fetuses and for fetuses in various weight classes or growth categories. Mean percent differences were compared to zero using the t test to detect systematic errors and variances were compared using the F test to detect differences in random errors. A p value of less than 0.05 was considered evidence of a statistically significant difference.

RESULTS

As can be seen in Table 1, model parameters appeared to stabilize by the third iteration. The largest change (−37%) between the 2nd and 3rd iteration was seen with $s_{wB} - s_B$, all other changes being 12% or less. As shown previously by Rossavik,[8] the comparable parameters required to calculate WT_A and WT_B were substantially different except for $k_{wA} - k_A$ and $k_{wB} - k_B$. Parameter values obtained by regression analysis were similar to those given by Rossavik except for the mean $s_{wA} - s_A$ and $s_{wB} - s_B$ values. It should be noted that in iteration 3, all weight estimates used in the regression analyses were determined with a weight estimation function in which all of the parameters were derived from previous regression analyses.

Table 2 presents an assessment of the effectiveness of the functions obtained in different iterations in estimating fetal weight at birth. As can be seen, all mean percent deviations were close to zero (none were significantly different from zero by t test), indicating no systematic er-

TABLE 1
Coefficients of Weight Estimation Function Determined by Iteration Procedure

Parameter	Iteration 1[a] Mean+ or Expected++ Value	1[a] SD	2 Mean+ or Expected++ Value	2 SD	3 Mean+ or Expected++ Value	3 SD	Percent Change Between 2nd and 3rd Iteration
							%
WT_A							
c_{w_A}	—	—	.01525++	±.00535	.01714++	±.00595	+12.4
k_{w_A}	—	—	3.862++	±.325	3.815++	±.332	−1.2
s_{w_A}	—	—	−.00974++	±.00268	−.00926++	±.00270	−4.9
c_{w_A}/c_A	1.29+	±0.44	1.189+	±.100	1.337+	±.123	+12.5
$k_{w_A} - k_A$	0.0	—	.006	—	−.041	—	—[b]
$s_{w_A} - s_A$	.00072+	±.00032	.00869+	±.00130	.00917+	±.00107	+5.5
b_A	.47165++	±.02146	.46461++	±.02143	.46138++	±.02129	−0.7
WT_B							
c_{w_B}	—	—	.09489++	±.03250	.10530++	±.03580	+11.0
k_{w_B}	—	—	3.253++	±.712	3.210++	±.710	−1.3
s_{w_B}	—	—	−.00625++	±.00289	−.00581++	±.00285	−7.0
c_{w_B}/c_B	2.87+	±0.94	3.168+	±.212	3.517+	±.211	+11.0
$k_{w_B} - k_B$	0.0	—	−.031	—	−.074	—	—[b]
$s_{w_B} - s_B$	−.000011+	±.000306	−.00118+	±.00088	−.00074+	±.00083	−37.4
b_B	.49314++	±.02014	.55215++	±.02271	.55029++	±.22670	−0.3

[a]Values are those given by Rossavik except for b_A and b_B.
[b]Values too close to zero.

TABLE 2
Comparison of Weight Estimates with Birth Weights Using Different Weight Estimation Functions

Weight Groups	Number	Percent Deviations 1[a] Mean	SD	2[a] Mean	SD	3[a] Mean	SD
		%	%	%	%	%	%
All	193	.02	8.5	.05	8.5	.07	8.5
≥1000 g	167	.08	7.9	.03	7.9	.06	7.9
<1000 g	26	.10	11.6	.59	11.7	.91	11.9

[a]Weight estimation functions derived from 1st, 2nd, and 3rd iterations used to calculate estimated birth weights.

rors. The standard deviations (indicators of random error) showed very little change with successive iterations in all weight groups. As determined by F test, the random error in the less-than-1000 g group was significantly larger than that in the greater-than-1000 g group with all three weight estimation functions.

Table 3 presents a comparison of estimated birth weights (obtained using the function based on the 3rd iteration) with measured birth weights in different weight classes. In only one (2001 g to 2500 g) of the 10 classes was there statistical evidence of a systematic error, although in some classes (e.g., 4501 g to 5000 g) small sample sizes made detection of such errors difficult. The random error (± 1 SD) was 10% to 13% below 2000 g and 6% to 8% above 2000 g.

Table 4 presents an evaluation of the effectiveness of the weight estimation function derived from the 3rd iteration in estimating birth weight in different growth categories. In average-for-gestational age (AGA) fetuses there was no evidence of a systematic error but, weights in the small-for-gestational age (SGA) and large-for-gestational age (LGA) groups were systematically overestimated and underestimated, respectively. No statistically significant difference in random errors was found in these three groups.

DISCUSSION

Choice of Model

The development of individual growth curve standards for estimates of fetal weight requires the ability to predict future weight estimates from growth patterns in the second trimester. At present only the Rossavik model is able to predict the future values of any anatomic parameter.[1,4] It is therefore necessary to utilize a weight estimation procedure based on this model if individual growth curve standards for estimated fetal weight are to be generated.

TABLE 3
Comparison of Estimated and Measured Birth Weights in Different Weight Classes

Weight Class	Number	Birth Weight Mean	SD	Percent Deviation Mean	SD
g		g	g	%	%
0–500	15	278	±102	2.0	±11.4
501–1000	11	765	±164	−0.5	±12.8
1001–1500	16	1229	±124	1.3	±10.1
1501–2000	15	1750	±161	2.9	±9.6
2001–2500	32	2268	±154	−2.9[a]	±6.8
2501–3000	25	2787	±148	1.4	±6.1
3001–3500	26	3248	±153	0.8	±6.6
3501–4000	32	3709	±144	0.5	±8.3
4001–4500	13	4191	±130	−0.7	±8.2
4501–5000	7	4733	±123	−4.5	±7.3
<1000	25	463	±262	1.2	±12.0
<1500	42	768	±432	1.1	±11.1
1500–3999	129	2850	±675	0.1	±7.6
>4000	22	4413	±374	−2.2	±7.8
Total	193	2575	±1229	0.0	±8.5

[a]Mean value significantly different from zero by *t* test; all other mean values not significantly different from zero.

TABLE 4
Comparison of Estimated and Measured Birth Weights in Different Growth Categories

Growth Category[a]	Number	Birth Weight Mean	Birth Weight SD	Percent Deviation Mean	Percent Deviation SD
		g	g	%	%
SGA	31	1772	±695	4.1[c]	±7.4[b]
AGA	134	2429	±1139	−0.2[b]	±8.8[b]
LGA	28	4162	±602	−3.0[c]	±6.7[b]

[a]SGA, small-for-gestational age (<10th percentile); AGA, appropriate-for-gestational age (>10th percentile, <90th percentile); LGA, large-for-gestational age (>90th percentile).
[b]$p > 0.05$, not significant.
[c]$p < 0.05$.

Specification of a Rossavik model for any fetal parameter requires determination of the values for the start point and the coefficients c, k, and s.[1,5] For weight, the most direct approach would be to calculate fetal weight estimates for the longitudinal data set, use regression analysis and the cube roots of weight estimates obtained before 26 weeks to obtain weight start points, and then determine c_w, k_w, and s_w by regression analysis using the data obtained before 26 weeks.[1,4] In preliminary studies this approach was investigated using weight estimates calculated from Eq. (2) with Rossavik parameter values. As a check, the iterative procedure described here was used. In contrast to the results given in Table 2, Iteration 2 results were inferior to those obtained in Iteration 1. Use of A, B, or $(A + B)/2$ start points instead of the weight start point values did not improve the results and this approach was abandoned.

Even though the direct approach was unsuccessful, the ability to predict a variety of anatomic parameters related to weight[1,4] offers an indirect way to predict weight estimates. By use of the appropriate function, weight estimates could be calculated from other anatomic parameters (BPD, HC, AC, FDL, A, B) whose expected values can be predicted. As reviewed by Hadlock,[15] head and trunk parameters, as well as length-related parameters in some investigations, are needed to obtain optimal weight estimates. Although head circumference (HC), abdominal circumference (AC), and femur diaphysis length (FDL) have been most widely used in weight estimation functions, these parameters are not as directly related to weight as the head cube *(A)* and abdominal cube *(B)*, which are related to volume and thus to weight.[5] Also, the cubes are calculated directly from diameters. The use of diameters in HC and AC calculations gives only *estimated* HC and AC values,[16] which can be affected by shape changes.[17] As most weight estimation procedures have been developed and evaluated using directly measured HC and AC values,[15] the effect of this circumference estimation procedure on weight estimations is currently unknown. It should also be noted that optimal weight estimation functions have often required three linear parameters (HC, AC, FDL) but only two cube parameters (A, B) in previous investigations.[15] We concluded from these observations that a weight estimation function involving the cubes would be the most appropriate for developing individual growth curve standards. The unsatisfactory results obtained using HC and AC, or HC, AC, and FDL, in a preliminary study similar to that reported here has supported this decision.

The simplest use of projected values of A and B to predict fetal weight would be through a simple linear combination of these two parameters. Coefficients for the appropriate polynominal function in A and B can be obtained by regression analysis, as has been done with other anatomic parameters.[15] However, the function determined in this way using our cross-sectional data set gave results inferior to those obtained with Eq. (2) and Rossavik parameter values [mean percent deviation (± SD): all, 4.1 (± 12.7)%; greater-than-1000g, 0.9 (± 8.1)%; less-than-1000 g, 24.8 (± 16.8)%]. For this reason we chose to investigate the Rossavik weight estimation function.[8]

Comparison with Previous Weight Estimation Procedures

The work presented here is most closely related to that of Rossavik.[8] As can be seen in Table 2, the performance of the functions obtained by the iteration procedure was essentially the same as that of the Rossavik function even though significant differences in parameter values were seen (Table 1). In view of their similar abilities in estimating fetal weight, the primary reason for favoring the function obtained from Iteration 3 is the rigor of the statistical analysis used to determine parameter values. This analysis provides a stronger mathematical basis for asserting that the parameter estimates are valid.

The investigation reported here can be compared in a variety of ways to those published previously. The anatomic parameters *(A, B)* used in the Rossavik weight estimation procedure are three dimensional while those used in all other procedures were one dimensional.[15] Time is included as a parameter in this weight estimation procedure while it has been ignored in all previous weight estimation procedures.[15] Previous functions relating weight to anatomic parameters have been empiric in character while the Rossavik weight function is based on growth models in which the coefficients have biological meaning.[18,19] The cross-sectional sample studied was larger, with more fetuses over 4000 g (22) and under 1500 g (42), than any previous investigations except those of Ott[20] and Simon.[21] Our data on the 25 fetuses with birth weights below 1000 g represent one of only three studies (Eden[22]—11 fetuses; Ott[20]—90 fetuses) that have provided direct information on weight estimation in these small fetuses. Weight estimation in SGA, AGA, and LGA fetuses has been evaluated previously only for the weight estimation procedures of Shepard,[21] Hadlock,[21] and Woo.[23]

Comparison of Performance with Different Weight Estimation Procedures

The most extensively studied weight estimation procedures are those of Campbell, Warsoff, and Shepard, as well as the six procedures of Hadlock et al.[15] Ott,[24] Thurnau,[25] Weinberger,[26] Roberts,[27] and Woo[23] have also presented procedures of this type that have been evaluated to some extent. Other weight estimation procedures have been developed,[28–30] but failure to use percent deviations in evaluating the results obtained makes comparison with our results and those of others difficult. Other differences in data presentation have also created comparison problems, but these can be reduced considerably by using the data presented to calculate mean and standard deviation values for percent differences in the four subgroups given in Table 3 (>4000 g, 1500 g to 3900 g, <1500 g, <1000 g) whenever possible.

For fetuses weighing more than 4000 g at birth, the mean percent difference (systematic error) given in Table 3 for the Rossavik procedure is lower than those obtained with all other procedures except that of Shepard (Table 5).[20,21,31,32] The standard deviation of $\pm 7.8\%$ is similar to those obtained with other procedures. In the 1500 g to 3999 g group the systematic error obtained with the Rossavik procedure was smaller than those for all other procedures, although the four-parameter procedure of Hadlock et al. was similar.[21,30,31] The random error for this group was smaller than those obtained with all other procedures, except the three- and four-parameter procedures of Hadlock et al.[30,31] and Ott,[20] which gave similar results.

For fetuses weighing less than 1500 g, the lowest systematic error was obtained with the Rossavik procedure. However, the random error associated with this procedure was greater than those obtained with the Warsoff,[20,22,26,31,33,34] Shepard,[20,21,31,32,35,36] and Hadlock[20,27,31,32] procedures. These results may be explained in part by the fact that in some studies (e.g., Hadlock et al.[31]), the less-than-1500 g group contained fewer fetuses below 1000 g (as indicated by the higher mean birth weight of 1042 g[31]) than did the sample used to evaluate the Rossavik procedure (mean birth weight: 768 g). Support for this concept is seen in the results of Ott et al.,[20] who found high random errors in this group using the Warsoff, Shepard, and Hadlock procedures (Table 5). Their sample had a large proportion of fetuses below 1000 g (41%).

The results of the limited number of studies on fetuses weighing less than 1000 g indicate that the Rossavik procedure gives a much smaller systematic error than those of Campbell,[20] Shepard,[20,22] and Thurnau,[20,22] but this error is similar to that seen with the Warsoff[20,22] procedure. The results for the random error are contradictory. Eden[22] obtained random errors using the Warsoff, Shepard, and Thurnau procedures that were smaller than those seen with the Rossavik procedure. However, Ott,[20] using a much larger sample (90 vs 11), obtained random errors for these procedures that were considerably greater than those found with the Rossavik procedure.

The performance of the Rossavik procedure with SGA, AGA, and LGA fetuses is compared to those of other procedures in Table 6. All procedures tested (Rossavik, Shepard,[20,21,23] various Hadlock,[21,23] and Woo[23]) gave about the same systematic over-estimation of the weight in SGA fetuses. The systematic errors were small in AGA fetuses with all procedures. In LGA fetuses these procedures systematically underestimated the weight to about the same degree. In all three growth categories the random error for the Rossavik procedure was smaller than those seen with the other procedures.

The results of these comparative studies indicate that, in general, the Rossavik procedure gives weight estimates that are at least as accurate as those provided by other weight estimation procedures over a wide range of weight and growth categories. However, the Rossavik procedure can be used to generate individual growth curve standards for weight estimates (including

TABLE 5
Performance of Fetal Weight Estimation Procedures in Different Weight Classes

	Weight Estimation Procedures													
	Rossavik	Campbell	Warsof	Shepard	Hadlock						Ott	Thurnau	Roberts	Weinberger
Weight Class	A, B	AC	BPD, AC	BPD, AC	BPD, AC	HC, AC	AC, FDL	BPD, AC, FDL	HC, AC, FDL	BPD, HC, AC, FDL	HC, AC, AC/FDL	BPD × AC	BPD, HC, AC, FDL	BPD × AC
>4000 g														
N[a]	1	5	4	6	1	3	3	3	4	3	1	1	—	—
Mean (%)[b]	−2.2	−10.2 to 10.4	−8.4 to −1.2	−7.0 to 2.5	−2.7	−2.9, 5.1, −2.7	−1.9, 5.2, −4.8	−1.5, −4.8, −5.8	−5.3 to 6.3	−1.5, −4.0, −5.5	−4.5	−29.3	—	—
SD (%)[b]	7.8	5.2 to 9.6	4.3 to 14.3	4.0 to 14.0	8.4	9.8, 5.9, 10.9	9.2, 5.2, 10.6	8.8, 5.1, 10.0	5.1 to 11.2	8.9, 5.2, 10.3	7.8	4.8	—	—
1500 g to 3999 g														
N[a]	1	5	4	5	1	2	2	2	3	2	1	1	—	—
Mean (%)[b]	0.1	−5.0 to 10.7	−5.6 to −2.8	−1.5 to 2.3	1.0	0.9, 0.8	0.7, 0.0	0.7, 1.6	−0.7, 2.5, −1.0	0.7, 0.9	0.3	5.7	—	—
SD (%)[b]	7.6	9.1 to 14.2	8.2 to 12.1	8.4 to 12.5	8.5	8.3, 9.8	7.8, 7.5	7.4, 6.8	7.9, 6.6, 9.0	7.1, 6.8	7.9	7.8	—	—
<1500 g														
N[a]	1	5	7	8	1	2	2	2	4	3	1	4	1	1
Mean (%)[b]	1.1	−5.1 to 14.0	−7.5 to 3.0	−3.9 to 7.5	1.2	2.6, 0.6	1.9, −3.9	0.9, −5.3	−4.6 to 8.0	0.9, 5.4, 1.6	3.7	6.6 to 9.5	0.7	1.6
SD (%)[b]	11.1	12.7 to 25.8	5.1 to 15.8	5.2 to 16.8	8.2	11.2, 10.6	6.6, 8.3	6.0, 9.0	6.9 to 11.2	6.7, 9.0, 6.1	9.5	7.1 to 17.1	9.9	6.1
<1000 g														
N[a]	1	1	2	2	—	—	—	—	—	—	—	—	—	—
Mean (%)[b]	1.2	10.8	−1.9, 1.0	5.4, 16.3	—	—	—	—	—	—	—	—	—	—
SD (%)[b]	12.0	27.7	5.5, 15.2	2.9, 5.5	—	—	—	—	—	—	—	—	—	—
Total														
N[a]	1	5	4	6	1	3	3	3	4	3	1	1	—	—
Mean (%)[b]	0.0	−2.8 to 5.3	−6.0 to −2.0	−1.2 to 1.9	0.4	0.4, 1.5, −0.2	0.3, 0.4, 1.1	0.3, 1.4, 0.9	−1.5 to 2.7	0.3, −0.7, 0.8	0.3	−9.7	—	—
SD (%)[b]	8.5	8.5 to 18.1	8.4 to 10.8	8.8 to 13.5	9.1	9.1, 9.8, 13.1	8.2, 7.7, 12.7	7.7, 7.3, 11.8	7.4 to 11.9	7.5, 7.3, 11.7	8.8	16.1	—	—

[a]Number of investigations.
[b]Data presented are means and standard deviations for differences (expressed as percent of the birth weight) between the estimated fetal weight (determined within a week of delivery) and the actual birth weight.

TABLE 6
Performance of Weight Estimation Procedures in Different Growth Categories

	Weight Estimation Procedures										
	Rossavik	Shepard	Hadlock					Woo			
Growth Category	A, B	BPD, AC	HC, AC	AC, FDL	BPD, AC, FDL	HC, AC, FDL	BPD, HC, AC, FDL	BPD, AC	BPD, AC, FDL	BPD × AC	BPD × AC × FDL
LGA											
N[a]	1	2	1	1	1	1	1	—	—	—	—
Mean (%)[b]	−3.0	−3.1, −8.0	−6.1	−3.9	−5.3	−4.8	−5.4	—	—	—	—
SD (%)[b]	6.7	10.6, 12.5	13.3	12.2	11.1	11.7	11.3	—	—	—	—
AGA											
N[a]	1	3	1	2	2	1	1	1	1	1	1
Mean (%)[b]	−0.2	1.6, 1.1, 0.2	1.0	4.5, 1.7	3.7, 1.9	1.7	1.7	0.4	−0.7	0.8	−1.4
SD (%)[b]	8.8	13.2, 6.4, 11.6	12.2	8.2, 12.1	7.1, 11.1	11.2	10.9	6.0	6.0	6.1	6.8
SGA											
N[a]	1	3	1	2	2	1	1	1	1	1	1
Mean (%)[b]	4.1	6.8, 4.1, 1.1	2.7	10.5, 4.9	7.5, 4.9	5.4	5.2	5.5	3.2	3.2	0.9
SD (%)[b]	7.4	15.0, 10.9, 15.5	14.7	16.1, 14.0	10.9, 13.4	13.1	13.1	11.1	9.9	14.4	9.8

[a]Number of investigations.
[b]Data presented are means and standards deviations for differences (expressed as a percent of the birth weight) between the estimated fetal weight (determined within a week of delivery) and the actual birth weight.

the prediction of birth weight 14 weeks before delivery in normal fetuses), a capability not shared with any of the other weight estimation procedures. Evaluation of this aspect of fetal weight estimation will be the subject of a subsequent publication in this series.

APPENDIX

In his thesis published in 1982, Rossavik[8] presented a weight estimation function based on his growth model (described by Rossavik and Deter[5]). This function can be derived in the following manner.

The change in weight of a fetus can be described by a Rossavik growth model having the following general form:

$$WT = c_w(t)^{kw + sw(t)} \tag{1}$$

where WT is the fetal weight, t the duration of growth, and c_w, k_w, and s_w the model coefficients. As indicated previously,[5] this type of function can also be written in the following form:

$$WT = c_w(MA - SP_w)^{kw + sw\,(MA - SP_w)} \tag{2}$$

where MA is the menstrual age of the fetus and SP_w is the start point (beginning of growth). Since even the fertilized zygote has a weight, the logical start point for WT is the time of conception, making t equal to conceptual age (CA). However, the CA of a fetus is usually not known and cannot be determined from current prenatal measurements in most cases. Also, relating WT to an other anatomic parameter requires a common start point and the start points for such parameters are not the date of conception.[1–4] Therefore, in relating WT to head and trunk parameters such as the head (A) and abdominal (B) cubes, separate functions using different start points are required. These functions have the following form:

$$WT_A = c_{w_A}(MA - SP_A)^{kw_A + sw_A(MA - SP_A)} \tag{3}$$

$$WT_B = c_{w_B}(MA - SP_B)^{kw_B + sw_B(MA - SP_B)} \tag{4}$$

where the A and B subscripts indicate parameters derived using the specified start point (SP_A or SP_B). By dividing through by A and its Rossavik growth model, Eq. (A3), becomes

$$\frac{WT_A}{A} = \frac{c_{w_A}(MA - SP_A)^{kw_A + sw_A(MA - SP_A)}}{c_A\,(MA - SP_A)^{k_A + s_A(MA - SP_A)}} \tag{5}$$

where c_A, k_A, and s_A are the coefficients of the Rossavik growth model for A. This function can be rewritten to give the following expression:

$$WT_A = \left[\frac{c_{w_A}}{c_A}\cdot(MA - SP_A)^{(kw_A - k_A) + (sw_A - s_A)(MA - SP_A)}\right]\cdot A \tag{6}$$

In a similar way, a function relating WT to B can be derived:

$$WT_B = \left[\frac{c_{w_B}}{c_B} \cdot (MA - SP_B)^{(kw_B - k_B)} + (sw_B - s_B)(MA - SP_B)\right] \cdot B \quad (7)$$

To obtain the optimal fetal weight estimate *(EWT)*, these two estimates of the fetal weight need to be combined in some way with appropriate weighting factors. The simplest method would be a linear combination, which has the following form:

$$EWT = b_A \cdot WT_A + b_B \cdot WT_B \quad (8)$$

where b_A and b_B are the weighting factors. By substituting Eq. (6) for WT_A and Eq. (7) for WT_B in Eq. (8), one obtains the weight estimation function used in this investigation (p. 233).

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