Performance of 36 Different Weight Estimation Formulae in Fetuses with Macrosomia

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Key Words

Fetal weight estimation • Birth weight • Macrosomia • Accuracy, prenatal

Abstract

Introduction: The aim of this retrospective clinical study was to compare the accuracy of 36 commonly used weight estimation formulae in macrosomic fetuses. **Material and Methods:** Ultrasound estimation of fetal weight (FW) was carried out within 7 days up to delivery in 350 singleton fetuses with a birth weight (BW) of $\geq 4,000$ g. The accuracy of the different formulae for FW estimation was compared by, firstly, the mean percentage (MPE) and mean absolute percentage error (MAPE), secondly, by the frequency distribution of differences between estimated FW and fetal BW, and thirdly by comparing detection and false positive rates in screening for fetuses with a BW of 4,000, 4,300 and 4,500 g or more. **Results:** MPE ranged from -62.2 to 9.6% and was closest to 0 with the Hart formula. With 12 of 36 weight estimation formulae, MAPE was 10% or less, and was smallest with the Hart formulae (3.9%). The mean detection rate among all formulae for fetuses with a BW $\geq 4,000$, $\geq 4,300$ and $\geq 4,500$ g was 29, 24 and 22%, respectively, and the false positive rate was 12% (for $\geq 4,300$ g) and 7% ($\geq 4,500$ g). **Discussion:** Some

formulae showed advantages as far as mean and absolute percentage errors were concerned, but none reached a detection rate and false positive rate for fetuses $\geq 4,500$ g that could lead to clinical recommendation.

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Introduction

It is widely accepted that pregnancies with macrosomic fetuses have an increased risk for shoulder dystocia, brachial plexus injury, asphyxia, prolonged labour, surgical delivery and postpartum haemorrhage [1]. However, there is an ongoing controversy regarding the definition and antenatal prediction of macrosomic fetuses [2]. Some authors favour a fetal weight (FW) of 4,000 or 4,500 g or more, others prefer a centile-based threshold around the 90th or 95th centile [3–5]. In addition, there is no consensus whether the decision about macrosomia should be based on the fetal birth weight (FBW) or on the estimated FW (EFW).

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If a macrosomic fetus is clinically suspected, it is good practise to perform an ultrasound examination to estimate FW. For this purpose, regression formulae were developed within the last four decades which combine a certain number of easy and reproducible two-dimensional (2D) fetal measurements [6]. This estimation of FW has substantial impact on the further obstetric management as the fetomaternal risks raise with increasing FW. In view of the shoulder dystocia, the risk is about 0.2% in average sized fetuses. With a BW of 4,000–4,500 g, this risk increases to about 5% and it is about 30% above 4,500 g, respectively [7–9]. This association is of high forensic impact. Thus, obstetricians tend to counsel towards early induction of labour or caesarean section based on the results of the FW estimation [2]. These problems have become more obvious within the last years due to an increase in the FW [10].

In contrast to the high clinical impact the accuracy of FW estimation is low in macrosomic fetuses. Several studies demonstrated errors exceeding 10% of the BW or 500 g in macrosomic fetuses [11, 12]. The aim of our study was to compare 36 commonly used formulae on their accuracy in estimating FW in fetuses of 4,000 g or more. The study focuses on the performance of each formula in detecting fetuses with a BW above critical thresholds of 4,000, 4,300 and 4,500 g.

Material and Methods

For this retrospective study, the perinatal computer database was searched for all singleton pregnancies that resulted in a live-born fetus without structural or chromosomal defects with a BW of 4,000 g or more. As part of the routine perinatal management at the Department of Obstetrics and Gynaecology of the University of Tuebingen, every pregnant woman received an ultrasound examination shortly before delivery. In general, during this examination, fetal presentation was confirmed, amniotic fluid volume was assessed and FW (EFW) was estimated on the basis of one of the common weight estimation formulae. The biparietal and occipito-frontal diameters were measured at the transventricular level from the outer edge to the outer edge of the skull bone. The head circumference (HC) was either measured or calculated ($HC = 2.325 \times ((\text{occipito-frontal diameter})^2 + (\text{biparietal diameter})^2)^{1/2}$). The fetal abdominal transverse and antero-posterior diameters were measured at the level of the stomach and umbilical vein-ductus venosus complex. The abdominal circumference (AC) was calculated ($AC = \pi \times (\text{transverse diameter (ATD)} + \text{antero-posterior diameter (APD)})/2$). The femur length (FL) was measured from the proximal end of the greater trochanter to the distal metaphysis. The individual measurements (mm), FBW (g) and the maternal demographic characteristics were recorded into a perinatal computer database. BW was

assessed immediately after delivery by either the midwife, obstetrician or paediatrician.

In each of the included pregnancies the last ultrasound examination was identified which included the measurement of the biparietal and fronto-occipital diameter of the head, the antero-posterior and the transverse diameter of the abdomen and the femur length. Pregnancies with incomplete data or those pregnancies where the last ultrasound examination was not performed within 7 days before delivery were excluded from further analysis. Each pregnancy that fulfilled the inclusion criteria was only included once in the database.

Statistical Analysis

In each case the EFW was calculated on the basis of the published formulae from Birnholz, Combs, Campbell, Ferrero, Hadlock, Halaska, Hansmann, Hart, Higginbottom, Jordaan, Persson, Merz, Mielke, Ott, Rose and McCallum, Sabbagha, Schild, Schillinger, Scott, Shepard, Shinozuka, Siemer, Thurnau, Vintzileos, Warsof, Weiner and Woo [13–42]. A list of the tested 36 formulae is shown in table 1.

The accuracy of the different formulae for FW estimation was assessed and compared by (1) mean percentage error ($MPE = (EFW - BW)/BW \times 100$) and mean absolute percentage error ($MAPE = (|EFW - BW|/BW \times 100)$). MPE was considered as marker for the systematic error, the corresponding standard deviation as marker for the random error, respectively. The 95% confidence intervals (CI) for the MPE were calculated as mean $\pm 1.96 \times$ standard error and were used to test for a significant difference from 0. In addition, differences were compared by 95% limits of agreement according to the method described by Bland and Altman. (2) Frequency distribution of differences between EFW and BW: differences were calculated as $|EFW - BW|/BW$ and demonstrated as the proportion of cases with a discrepancy within ± 5 , ± 10 , ± 20 and $\pm 30\%$. (3) Detection and false positive rates in screening for fetuses with a BW of $\geq 4,000$, 4,300 and 4,500 g. The rates were calculated by taking the proportion of cases on and above certain thresholds.

Results

The search of the database identified 350 cases between 2004 and 2008 fulfilling the inclusion criteria. A summary of the maternal and fetal characteristics is given in table 2.

Mean Percentage Error and Absolute Percentage Error

MPE and MAPE for each of the 36 weight estimation formulae are shown in table 3. MPE was smallest with the Mielke I formula (MPE -62.2%), biggest with the Merz II formula (MPE 9.6%) and closest to 0 with the Hart formula (MPE 0.3%), respectively. The standard deviation of the MPE was between 4.1 (Siemer) and 18.2% (Hadlock IV) and it was 4.8% with the Hart formula, respectively. Only with the latter and with the

Table 1. Regression models for fetal weight estimation

First author	Components	Formula
Birnholz [36]	BPD, OFD, AD	$3.42928 * (BPD * OFD / 1.264)^{0.5} * AD^{2/1,000} + 41.218$ [g, mm]
Combs [37]	HC, AC, FL	$0.23718 * AC^2 * FL + 0.03312 * HC^3$ [g, cm]
Campbell [38]	AC	$e^{(-4.564 + 0.282 * AC - 0.00331 * AC^2)}$ [kg, cm]
Ferrero [39]	AC, FL	$10^{(0.77125 + 0.13244 * AC - 0.12996 * FL - 1.73588 * AC^2 / 1,000 + 3.09212 * FL * AC / 1,000 + 2.18984 * FL / AC)}$ [g, cm]
Hadlock I [41]	BPD, HC, AC, FL	$10^{(1.3596 + 0.0064 * HC + 0.0424 * AC + 0.174 * FL + 0.00061 * BPD * AC - 0.00386 * AC * FL)}$ [g, cm]
Hadlock II [41]	AC, FL	$10^{(1.304 + 0.05281 * AC + 0.1938 * FL - 0.004 * AC * FL)}$ [g, cm]
Hadlock III [41]	BPD, AC, FL	$10^{(1.335 - 0.0034 * AC * FL + 0.0316 * BPD + 0.0457 * AC + 0.1623 * FL)}$ [g, cm]
Hadlock IV [41]	HC, AC, FL	$10^{(1.326 - 0.00326 * AC * FL + 0.0107 * HC + 0.0438 * AC + 0.158 * FL)}$ [g, cm]
Hadlock V [40]	BPD, AC	$10^{(1.1134 + 0.05845 * AC - 0.000604 * AC^2 - 0.007365 * BPD^2 + 0.000595 * BPD * AC + 0.1694 * BPD)}$ [g, cm]
Hadlock VI [40]	HC, AC, FL	$10^{(1.5662 - 0.0108 * HC + 0.0468 * AC + 0.171 * FL + 0.00034 * HC^2 - 0.0003685 * AC * FL)}$ [g, cm]
Halaska [13]	BPD, AC, FL	$10^{(0.64041 * BPD - 0.03257 * BPD^2 + 0.00154 * AC * FL)}$ [g, cm]
Hansmann [14]	BPD, AD, GA	$-0.001665958 * AD^3 + 0.4133629 * AD^2 - 0.5580294 * AD - 0.01231535 * BPD^3 + 3.702 * BPD^2 - 330.1811 * BPD - 0.4937199 * (GA+1)^3 + 55.958061 * (GA+1)^2 - 2,034.3901 * (GA+1) + 3,2768.19$ [g, mm]
Hart [42]	HC, AC, FL, MW	$e^{7.6377445039 + 0.0002951035 * MW + 0.0003949464 * HC + 0.0005241529 * AC + 0.0048698624 * FL}$ [g, mm]
Higginbottom [15]	AC	$0.0816 * AC^3$ [g, cm]
Jordaan [16]	BPD, HC, AC	$10^{(2.3231 + 0.02904 * AC + 0.0079 * HC - 0.0058 * BPD)}$ [kg, cm]
Merz I [18]	BPD, AC	$-3,200.40479 + 157.07186 * AC + 15.90391 * BPD * BPD$ [g, cm]
Merz II [18]	AC	$0.1 * AC^3$ [g, cm]
Ott [21]	HC, AC, FL	$10^{(-2.0661 + 0.04355 * HC + 0.05394 * AC - 0.0008582 * HC * AC + 1.2594 * FL / AC)}$ [kg, cm]
Rose [22]	BPD, AD, FL	$e^{(0.143 * (BPD + AD + FL) + 4.198)}$ [g, cm]
Sabbagha (average sized fetuses) [23]	GA, HC, AC, FL	$-55.3 - 16.35 * (GA + HC + 2 * AC + FL) + 0.25838 * (GA + HC + 2 * AC + FL)^2$ [g, cm]
Schild I [25]	Female BPD, AC, FL	$-4,035.275 + 1.143 * BPD^3 + 1,159.878 * AC^{0.5} + 10.079 * FL^3 - 81.277 * FL^2$ [g, cm]
Schild I [25]	Male BPD, HC, AC, FL	$1,913.853 * \log_{10}(BPD) + 0.01323 * HC^3 + 55.532 * AC^2 - 13,602.664 * AC^{0.5} - 0.721 * AC^3 + 2.31 * FL^3$ [g, cm]
Schillinger [35]	BPD, AD	$397.7 * BPD + ATD - 4,387$ [g, cm]
Shepard [27]	BPD, AC	$10^{(-1.7492 + 0.166 * BPD + 0.046 * AC - 0.002546 * AC * BPD)}$ [kg, cm]
Shinozuka [28]	BPD, AC, FL	$1.07 * BPD^3 + 3.42 * AD^2 * FL$ [g, cm]
Warsof [32]	BPD, AC	$10^{(-1.599 + 0.144 * BPD + 0.032 * AC - 0.000111 * BPD^2 * AC)}$ [kg, cm]
Woo [34]	BPD, AC, FL	$10^{(1.13705 + 0.15549 * BPD + 0.0464 * AC - 0.00279682 * BPD * AC + 0.037769 * FL - 0.000494529 * AC * FL)}$ [g, cm]
Vintzileos [31]	BPD, AC	$10^{(1.879 + 0.084 * BPD + 0.026 * AC)}$ [g, cm]
Persson [17]	BPD, AD, FL	$BPD^{0.972} * ((AD1 + AD2)/2)^{1.743} * FL^{0.367} * 10^{(-2.646)}$ [g, cm]
Schild II [24]	HC, AC, FL	$5,381.193 + 150.324 * HC + 2.069 * FL^3 + 0.0232 * AC^3 - 6,235.478 * \log(HC)$ [g, cm]
Scott [26]	HC, AC, FL	$10^{(0.66 * \log(HC) + 1.04 * \log(AC) + 0.985 * \log(FL))}$ [g, cm]
Siemer [29]	BPD, AC, FL	$-5,948.336 + 2,101.261 * \ln(AC) + 15.613 * FL^2 + 0.0577 * BPD^3$ [g, cm]
Thurnau [30]	BPD, AC	$(9.337 * BPD * AC) - 229$ [g, cm]
Weiner I [33]	HC, AC, FL	$10^{(1.6961 + 0.02253 * HC + 0.01645 * AC + 0.06439 * FL)}$ [g, cm]
Weiner II [33]	HC, AC	$10^{(1.6575 + 0.04035 * HC + 0.01285 * AC)}$ [g, cm]
Mielke I [20]	BDP, AD, FL	$e^{(3.067510 + 0.01677 * BPD + 0.000412 * ATD^2 + 0.040611 * FL - 0.000000006027957 * BPD^2 * ATD^2 - 0.000005086 * ATD^2 * FL)}$ [g, cm]
Mielke II [19]	BPD, ATD, FL	$e^{(3.704706 + 0.033276 * BPD + 0.000093048 * ATD^2 + 0.010570 * FL - 0.00000002477864 * BPD^2 * ATD^2 + 0.000002009 * ATD^2 * FL)}$ [g, cm]

AC = Abdominal circumference; HC = head circumference; FL = femur length; BPD = biparietal diameter; AD = abdominal diameter; GA = gestational age, MW = maternal weight.

Fig. 1. MPEs, their 95% limits of agreement, and the MAPEs of 36 analysed formulae.

Table 2. Clinical parameters of the study population

Maternal age, years, median (range)	32.9 (17.1–46.0)
Maternal weight, kg, median (range)	81.0 (53.0–139.0)
Para, median (range)	1 (0–5)
Gestational age, weeks, median (range)	40.2 (36.0–42.3)
Fetal BW, g, median (range)	4,200.0 (4,000.0–5,080.0)
Fetal BW $\geq$ 4,000 g, n	350; 100%
Fetal BW $\geq$ 4,300 g, n	120; 34.3%
Fetal BW $\geq$ 4,500 g, n	29; 13.4%
Days between US examination and delivery in days, median (range)	1 (0–7)
Birth within 1 day after ultrasound examination, n	183 (52.3%)
Birth within 2–5 days after ultrasound examination, n	136 (38.9%)
Birth within 6–7 days after ultrasound examination, n	31 (8.8%)
Operators performing the ultrasound examination, n	39
Operators with >3 years of experience in obstetrical ultrasound, n	10 (25.6%)

Table 3. Fetal weight estimation according to 36 commonly used weight estimation formulae

Formula	MPE, %	CI	MAPE, %
Hart	0.3 ± 4.8	-0.2; 0.8	3.9 ± 2.8
Schillinger	-3.7 ± 6.6	-4.4; -3.0	6.1 ± 4.5
Hansmann	-6.5 ± 5.8	-7.1; -5.9	7.2 ± 4.9
Merz	-6.0 ± 7.2	-6.8; -5.3	7.5 ± 5.7
Ferrero	-5.4 ± 8.3	-6.3; -4.5	7.6 ± 6.3
Shinozuka	-6.3 ± 8.1	-7.2; -5.5	8.3 ± 6.0
Shepard	-4.8 ± 9.4	-5.8; -3.8	8.6 ± 6.2
Hadlock V	-6.7 ± 8.7	-7.6; -5.8	8.7 ± 6.7
Rose	-1.6 ± 10.6	-2.7; -0.5	8.8 ± 6.1
Hadlock III	-7.3 ± 8.5	-8.2; -6.4	9.1 ± 6.6
Birnholz	5.5 ± 11	4.4; 6.7	9.9 ± 7.2
Hadlock I	-9.0 ± 8.3	-9.9; -8.2	10.0 ± 7.0
Warsof	-9.3 ± 9.1	-10.3; -8.4	10.6 ± 7.5
Hadlock II	-10.0 ± 9.0	-10.9; -9.1	11.1 ± 7.6
Vintzeleos	4.4 ± 13.2	3.0; 5.8	11.1 ± 8.4
Schild sex-specific	-11.5 ± 6.8	-12.2; -10.8	11.7 ± 6.4
Ott	-11.8 ± 7.6	-12.6; -11.0	12.1 ± 7.1
Jordaan	-10.2 ± 10.9	-11.3; -9.1	12.3 ± 8.5
Persson	-12.3 ± 8.4	-13.2; -11.4	12.7 ± 7.8
Hadlock VI	-12.6 ± 8.1	-13.5; -11.8	12.9 ± 7.6
Sabbagha	-13.0 ± 6.5	-13.7; -12.3	13.1 ± 6.3
Higginbottom	-10.5 ± 13.1	-11.9; -9.1	13.5 ± 10.0
Halaska	-13.7 ± 6.3	-14.4; -13.0	13.8 ± 6.2
Combs	-14.1 ± 7.1	-14.8; -13.4	14.1 ± 7.0
Hadlock IV	-0.6 ± 18.2	-2.5; 1.3	14.3 ± 11.1
Campbell	-14.9 ± 7.1	-15.6; -14.2	14.9 ± 7.1
Merz II	9.6 ± 16.1	7.9; 11.3	15.3 ± 10.8
Weiner I	-17.1 ± 8.8	-18.0; -16.2	17.2 ± 8.6
Woo	-25.4 ± 5.9	-26.0; -24.8	25.4 ± 5.9
Weiner II	-25.5 ± 9.6	-26.5; -24.5	25.6 ± 9.2
Scott	-26.2 ± 5.6	-26.8; -25.6	26.2 ± 5.6
Thurnau	-27.4 ± 5.0	-27.9; -26.9	27.4 ± 5.0
Siemer	-28.6 ± 4.1	-29.0; -28.2	28.6 ± 4.1
Schild	-30.7 ± 5.3	-31.3; -30.1	30.7 ± 5.3
Mielke II	-39.8 ± 10.7	-40.9; -38.7	39.8 ± 10.7
Mielke I	-62.2 ± 4.3	-62.7; -61.8	62.2 ± 4.3

For each of the 36 formulae, MPE (EFW – BW)/BW × 100 and MAPE (| EFW – BW | / BW × 100) and their standard deviation (SD) are demonstrated. In addition, the confidence interval is shown for the PE. The results are sorted according to the APE. Median BW was 4,200.0 g.

Hadlock IV approach, the CI included 0, indicating a non-significant systematic error. Consistently, MAPE was smallest with the Hart approach (3.9%) and biggest with the Mielke I formula (62.2%). MPEs according to 95% limits of agreement and MAPEs are also demonstrated in figure 1.

Table 4. Frequency distribution of differences between EFW and BW

Formula	Within			
	5%	10%	20%	30%
Hart	69.5	95.6	100.0	100.0
Schillinger	48.6	81.4	99.1	100.0
Hansmann	4.6	69.4	24.6	1.4
Merz I	5.7	65.4	25.1	3.4
Ferrero	42.3	68.6	95.4	99.7
Shinozuka	5.1	60.6	29.4	4.6
Shepard	4.3	61.4	28.6	5.4
Hadlock V	4.3	58.6	30.0	6.9
Rose	2.0	60.9	30.3	6.3
Hadlock III	2.9	58.0	32.0	6.9
Birnholz	3.1	52.0	36.0	7.7
Hadlock I	4.0	48.6	37.4	9.7
Warsof	3.7	46.6	37.4	11.7
Hadlock II	1.7	48.9	36.0	12.0
Vintzeleos	26.9	50.9	85.4	98.0
Schild I	1.7	39.4	47.7	10.9
Ott	22.0	42.0	83.7	100.0
Jordaan	25.4	45.4	79.7	96.3
Persson	2.0	37.4	42.9	16.0
Hadlock VI	2.3	36.6	41.1	18.3
Sabbagha	10.9	33.7	84.9	100.0
Higginbottom	3.1	39.1	32.3	17.7
Halaska	0.0	27.7	56.0	15.7
Combs	9.1	29.1	77.7	99.1
Hadlock IV	2.6	40.3	29.7	16.6
Campbell	5.1	26.9	78.0	96.6
Merz II	18.9	38.3	70.0	89.7
Weiner I	0.0	21.7	39.7	31.1
Woo	0.0	0.3	20.3	77.1
Weiner II	0.6	3.7	23.1	38.0
Scott	0.0	0.0	14.6	58.9
Thurnau	0.0	0.0	6.3	64.6
Siemer	0.0	0.0	0.9	61.7
Schild II	0.0	0.0	2.0	41.7
Mielke II	0.6	0.9	3.7	18.6
Mielke I	0.0	0.0	0.0	0.0

Differences were demonstrated as proportion of cases with a discrepancy within ±5%, ±10%, ±20% and ±30%. The results are sorted according to the APE listed in table 3.

Frequency Distribution of Differences between EFW and BW

Table 4 shows the frequency distribution of the differences between EFW and BW for each formula. At all discrepancy levels between ±5 and ±30%, the Hart formula was most accurate. In 95.6% of the cases, the dis-

Table 5. Detection and false positive rates in screening for fetuses with a fetal BW of 4,000, 4,300 and 4,500 g or more by 36 commonly used weight estimation formulae

Formula	≥4,000 g, %	≥4,300 g, %		≥4,500 g, %	
	DR	DR	FPR	DR	FPR
Hart	100 (203)	42.6 (29)	17.8 (24)	0 (0)	0 (0)
Schillinger	64.3 (225)	45 (54)	13.5 (31)	38.3 (18)	3 (9)
Hansmann	48 (168)	15.8 (19)	3 (7)	10.6 (5)	0.3 (1)
Merz I	52.6 (184)	33.3 (40)	8.3 (19)	25.5 (12)	1.7 (5)
Ferrero	56.6 (198)	45.8 (55)	10 (23)	40.4 (19)	3 (9)
Shinozuka	46.6 (163)	34.2 (41)	12.2 (28)	27.7 (13)	3.6 (11)
Shepard	56 (196)	41.7 (50)	20 (46)	40.4 (19)	9.6 (29)
Hadlock V	51.1 (179)	35.8 (43)	11.7 (27)	31.9 (15)	5 (15)
Rose	61.7 (216)	54.2 (65)	31.7 (73)	55.3 (26)	22.4 (68)
Hadlock III	43.4 (152)	31.7 (38)	10 (23)	29.8 (14)	3.3 (10)
Birnholtz	80.6 (282)	80.8 (97)	57.4 (132)	83 (39)	45.9 (139)
Hadlock I	38.3 (134)	24.2 (29)	6.5 (15)	27.7 (13)	2 (6)
Warsof	39.1 (137)	26.7 (32)	6.5 (15)	27.7 (13)	3 (9)
Hadlock II	34 (119)	22.5 (27)	6.5 (15)	19.1 (9)	2.3 (7)
Vintzileos	73.4 (257)	50.8 (61)	63 (145)	51.1 (24)	46.5 (141)
Schild I	21.4 (75)	8.3 (10)	0.9 (2)	2.1 (1)	0.7 (2)
Ott	23.7 (83)	17.5 (21)	0 (0)	17 (8)	0 (0)
Jordaan	36.6 (128)	39.2 (47)	7.4 (17)	46.8 (22)	4.6 (14)
Persson	24.6 (86)	15.8 (19)	1.3 (3)	19.1 (9)	1 (3)
Hadlock VI	22.3 (78)	16.7 (20)	0.9 (2)	12.8 (6)	0 (0)
Sabbagha	15.4 (54)	6.7 (8)	0 (0)	2.1 (1)	0 (0)
Higginbottom	40.3 (141)	40.8 (49)	11.3 (26)	40.4 (19)	8.9 (27)
Halaska	9.4 (33)	2.5 (3)	0.4 (1)	2.1 (1)	0 (0)
Combs	13.7 (48)	8.3 (10)	0 (0)	2.1 (1)	0 (0)
Hadlock IV	58.6 (205)	64.2 (77)	36.5 (84)	74.5 (35)	31 (94)
Campbell	8 (28)	0 (0)	0 (0)	0 (0)	0 (0)
Merz II	80.3 (281)	50.8 (61)	78.3 (180)	51.1 (24)	59.4 (180)
Weiner I	12.6 (44)	10 (12)	0.4 (1)	8.5 (4)	0.3 (1)
Woo	0.3 (1)	0 (0)	0 (0)	0 (0)	0 (0)
Weiner II	4.9 (17)	3.3 (4)	0.4 (1)	4.3 (2)	0.3 (1)
Scott	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Thurnau	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Siemer	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Schild II	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Mielke II	0.6 (2)	0 (0)	0 (0)	0 (0)	0 (0)
Mielke I	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

The results are sorted according to the MAPE listed in table 3.

crepancy between EFW and BW was within 10%. For comparison, only with 12 of the 36 formulae the discrepancy was within 10% in more than half of the cases.

Screening for Fetuses with a BW of 4,000, 4,300 and 4,500 g or More

Table 5 shows the detection and false positive rates in screening for fetuses with a fetal BW of 4,000, 4,300 and

4,500 g or more. The mean detection rates for fetuses with a BW ≥4,000, ≥4,300 and ≥4,500 g were 29, 24 and 22%, respectively, and false positive rates were 12% (for ≥4,300 g) and 7% (for ≥4,500 g). Only 11 formulae detected more than half of the fetuses with 4,000 g and more and only 5 formulae correctly identified more than half of the fetuses with a BW of 4,500 g or more. The Hart formula correctly identified all fetuses with a BW

$\geq 4,000$ g but none of the fetuses with a BW $\geq 4,500$ g. The highest detection rate for fetuses with a BW $\geq 4,500$ g was achieved with the Hadlock IV formula (74.5%) but for a false positive rate of 31.5%.

Discussion

In the present study we compared 36 weight estimation formulae in a population of 350 fetuses weighing $\geq 4,000$ g. Only with 2 formulae (Hard and Hadlock IV) the systematic error was not significantly different from 0. However, only the Hart approach combined a small MPE (or systematic error) with a small standard deviation and a small MAPE. Interestingly, the detection rate for fetuses with a BW $\geq 4,000$ and $\geq 4,500$ g was 100 and 0% with the Hart formula. MPE and MAPE were smallest with the Hart formula (MPE 0.3%, MAPE 3.9%). Among all formulae the mean detection rates for fetuses with a BW $\geq 4,000$, $\geq 4,300$ and $\geq 4,500$ g were low (29, 24 and 22%, respectively) for impressively high false positive rates (12 and 7%).

The advantages of certain ultrasound-based formulae have been critically analyzed. Most studies have found that, regardless of the applied formula, accuracy of the EFW decreases at the extremes of FW of $>4,000$ and $<1,500$ g [11, 12, 43, 44]. However, these two groups of neonates require a higher accuracy of weight estimation for the obstetrical management. Siemer et al. [45] evaluated 11 weight estimation formulae in a population of 1,941 pregnancies. Among 211 newborns $\geq 4,000$ g, MPE and MAPE ranged from 5.2 and 7.5% with the Merz formula to 14.5 and 14.9% with the Campbell formula, respectively. These results are consistent with our study where the Merz formula achieved a MPE of 6.0% and a MAPE of 7.5%.

Combs et al. [46] compared the accuracy of 31 formulae in predicting fetal macrosomia in women with diabetes. In this study, the Ott formula was superior with a MPE and MAPE of -2.9 and 8.2%. The detection rate was 45% for fetuses with a BW $\geq 4,000$ g. Nevertheless, none of the formulae proved significant advantage over others in assessing weight in fetal macrosomia. In our study the Ott formula showed a substantially higher MPE (11.8%), MAPE (12.1%) and a much lower detection rate for fetuses $\geq 4,000$ g (23.7%). There are methodological differences between these two studies. Combs et al. included intervals between sonogram and delivery of up to 14 days with a mean difference of almost 6 days and applied a correction factor in each case according to the temporal dif-

ference. In our study the median temporal difference was only 1 day which was shown to be irrelevant for the accuracy of FW estimation [47]. The MAPEs in the study of Combs et al. were much higher than in our study, which questions the reliability of these correction factors. In addition, one can speculate that this discrepancy is caused by the preselection of diabetic pregnancies in the study of Combs et al.

In the present study, the formulae of Siemer, Scott, Thurnau, Weiner and Mielke showed the highest MPE and MAPE. This observation is not surprising because these formulae were exclusively developed on and dedicated to small fetuses, however, the dimension of the demonstrated error is remarkable. This should draw clinicians' attention to the purpose of the used formula to prevent avoidable errors.

Several workgroups have focused on the improvement of FW estimation in macrosomic fetuses. The recently published Hart formula was especially developed for large fetuses. The authors restricted the use to fetuses with an AC ≥ 35.1 cm. Indeed, in our study the MPE (-0.3%) and MAPE (3.9%) were lowest with the Hart formula which was consistent to their results (MPE -1.8 and MAPE 3.6%) [42]. In our study, the Hart formula detected all fetuses $\geq 4,000$ g. Surprisingly, the detection rate fell to 0% for fetuses $\geq 4,500$ g indicating a low reliability of the Hart formula above this threshold. This observation demonstrates the general problems of logistic regression models to predict FW: the evaluated equations were designed on the basis of data collected in small samples from a limited number of centres using a non-standardised retrospective data collection. The best-fit formula could only be as accurate and representative as it was in the formula finding population.

Melamed et al. [12] compared 26 weight estimation formulae and found that formulae based on three and more biometric indices were more accurate. In our study, this could not be confirmed. Four of the 5 formulae (Schillinger, Ferrero, Hansmann and Merz) with the lowest MAPE (3.9–7.6%) were based on the measurement of only two biometric measurements. Some authors even argue that the isolated measurement of the fetal AC is as good as using the weight estimation formulae in predicting macrosomia [3, 48]. However, it is the measurement of the AC that accounts for the biggest proportion of the systematic and the random error [49, 50]. The observer variability of the AC, which can be considered as a marker for the reproducibility of a measurement, is estimated to produce a random error of 3.5% of the EFW [51, 52]. The measurement of the fetal head size at term or during

labour is also associated with a substantial error, as it is particularly difficult to correctly assess the dimensions of the engaged fetal head [53]. The Ferrero formula is only based on AC and FL and accounts to the 5 formulae with smallest MPE (5.4%) and MAPE (7.6%) in our study [39].

Nahum and Stanislaw [54] and similarly Mazouni et al. [55] combined sonographic data with maternal and pregnancy-specific variables such as gestational age, parity, fetal sex, maternal height and weight to increase the detection rate of macrosomic fetuses. Both studies showed some improvement but in a recent independent study these results were not confirmed [56].

A recent discussion concentrates on the value of three-dimensional (3D) ultrasound in evaluating fetal body composition and consecutively in estimating FW. Lee et al. [57, 58] recently showed that in late stage pregnancies the fetal percentage of body fat is most highly correlated with the fractional thigh volume assessed by 3D ultrasound. However, Hasenoehrl et al. [59] compared different formulae using 2D (Hansmann, Merz, Hadlock) and 3D ultrasound (Schild, Liang, Chang). The 3D Schild formula showed a moderate improvement of accuracy but the other 3D formulae demonstrated poor results. Especially in fetuses of diabetic mothers the disproportionate contribution of fat to fetal body weight applying conventional weight estimation formulae may, in theory, lead to an overestimation of their weights [60]. 2D measurements of fatty tissue failed to demonstrate an improvement of the diagnosis

of fetal macrosomia [61, 62]. In addition, Alsulyman et al. [63] could not find significant differences in MAPE between infants of women with diabetes and those born of women without diabetes.

On clinical grounds, the most important question remains whether it is applicable to use FW estimation as a screening test for fetuses with an increased risk for shoulder dystocia. In spite of some controversies about the relationship between fetal size and shoulder dystocia [43, 64, 65], most guidelines refer in their recommendations for risk groups like diabetic mothers to a threshold of EFW $\geq 4,500$ g [66, 67]. In our study, none of the formulae detected all cases with a BW $\geq 4,500$ g. Among all tested formulae, the mean detection rate was only 22%. The highest detected rate of 83% was achieved with the Birnholz formula but for a false positive rate of 46%. The only other formula that identified at least 70% of the affected fetuses was the Hadlock IV formula (74.5%) but also for a clinically not applicable false positive rate of 31%. It gets obvious how questionable it is to rely solely on FW estimation in predicting macrosomia and how important it is to search for new approaches to increase the accuracy of FW estimation.

In summary, the prediction of macrosomia is a clinically important but unsolved problem. Some formulae were better than others but none reached an acceptable detection and false positive rate in screening for fetuses $\geq 4,500$ g that could lead to clinical recommendation.

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