Finding the best formulas to estimate fetal weight based on ultrasound for the Turkish population: a comparison of 24 formulas

Özgür Koçak1,*, Cem Koçak2

1 Department of Obstetrics and Gynecology, Hitit University, 19040 Corum, Turkey
2 Faculty of Health Sciences, Hitit University, 19040 Corum, Turkey
*Correspondence: drozgur@hotmail.com (Özgür Koçak)

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Background: Although prenatal diagnosis of fetal weight is a very important parameter that guides the clinician, the margin of error in fetal weight is still very high. Aims: The aim of this study is to identify the most accurate sonographic formulas for fetal weight estimation in general and specific gender subgroups of the Turkish population. Method: This study is a prospective study conducted with the term 160 pregnant women who had cesarean indication and hospitalized to give birth by a cesarean section. The actual birth weight of newborn babies and the estimated fetal weights obtained with 24 formulas were compared. Additionally, the data obtained were separated according to the gender of the newborns and the most appropriate formulas for fetal gender were tried to be determined separately. Results: The lowest Root Mean Square Error (RMSE) values which are the best indicator of success to predict were obtained as 301.8 gr, 284.9 gr and 304.4 gr with the formula of Schild et al. Female for male fetuses and the formula of Campbell and Wilkin for female fetuses, respectively. Male for all, the formula of Schild et al. Male, Schild et al. Female, and Campbell and Wilkin were selected as the best formulas for all fetuses, male fetuses and female fetuses, respectively, for estimating fetal weights in Turkish population. Conclusion: The formulas of Schild et al. Male, Schild et al. Female, and Campbell and Wilkin for male fetuses and female fetuses, respectively, for estimating fetal weights in Turkish population.

Keywords
Fetal weight estimation, Birth weight, Fetal weight formulas, Foetal weight, Prenatal ultrasonography, Obstetric ultrasound

1. Introduction

The accurate estimating of fetal weight at the prenatal period is very important because of the fact that the fetal weight can indicate the level of intrauterine well-being and the probability of survival of the fetus. Detection of small for gestational age (SGA) or large for gestational age (LGA) fetuses in the prenatal period helps obstetricians to decide about the patient. In this way, mortality and morbidity can be reduced [1–5].

From this viewpoint, the fetal weight estimation that is closest to the real is a very crucial subject in order that physicians can make the right decisions and select the right management option. Therefore, researchers have proposed numerous formulas based on the ultrasonography parameters in the literature from the 1970s to the present. The most part of these Fetal Weight Estimation Formulas in the literature generally depends on one, a few or all of the ultrasonographic parameters that are named as abdominal circumference (AC), biparietal diameter (BPD), femur length (FL), head circumference (HC) and transverse abdominal diameter (TAD). Some formulas developed between the years of 1975 and 1993 can be given as Campbell and Wilkin [6], Warsof et al. [7], Higginbottom et al. [8], Shepard et al. [9], Thurnau et al. [10], Hadlock V [11], Hadlock VI [11], Hadlock I [12], Hadlock II [12], Hadlock III [12], Hadlock IV [12], Weiner I [13], Weiner II [13], Woo et al. [14], Ott et al. [15], Rose and McCallum [16], Vintzileos et al. [17], Merz I [18], Merz II [18] and Combs [19]. Also, some formulas proposed between the years of 2004 and 2019 can be given as Schild et al.—Female [20], Schild et al.—Male [20], Hart et al. [21], Munim et al. [22], Esinler et al. [23], Chen et al. [24], Lima et al. [25] and Hiwale et al. [26].

Furthermore, there are also many studies that aim to find the best formula for any country or region by comparing different formulas in the literature. Some of these studies are Siemer et al. [27], Hasenoehrl et al. [4], Hoopmann et al. [28], Campbell et al. [6], Esinler et al. [29], Hiwale et al. [3].

Siemer et al. [27], Hasenoehrl et al. [4], and Esinler et al. [29] were compared some formulas for both fetuses with birth weight (BW) less than 2500 and more than 4000 gr. Hoopmann [28] compared the formulas of macrosomic fetuses. Some of the studies are population-based.

Siemer et al. [27], Hasenoehrl et al. [4] and Hoopmann et al. [28] studied at Germany population, Campbell et al. [6] for the Australian population, Esinler et al. [29] for Turkish population, Hiwale et al. [3] for the Indian population, etc.

The aim of this study is to find the most accurate formula for the Turkish population based on gender. We compared the 24 formulas for this purpose. 24 compared formulas are given in Table 1 (Ref. [6–13, 15–21, 23, 26]).
Table 1. 24 FEW formulas compared in this study.

| Articles                      | Parameters | Formulas |
|-------------------------------|------------|----------|
| Schild et al.—Male [20]       | AC, BPD, FL, HC | 43576.579 + 1913.853×log_{10}(0.1 × BPD) + 0.00001323 × HC^3 + 0.55352×AC^2 + 13602.664 × √0.1 × AC - 0.000721 × AC^3 + 0.00231 × FL^3 (gr, mm) |
| Campbell and Wilkin [6]       | AC         | 1000 × e^{-4.564+0.00282×AC-0.0000331×AC^2} (gr, mm) |
| Schild et al.—Female [20]     | AC, BPD, FL | −4035.275 + 0.001143 × BPD^3 + 1159.878 × √0.1 × AC + 0.010079 × FL^3 − 0.81277 × FL^2 (gr, mm) |
| Estinier et al. [23]          | AC, FL     | −1073.4 + 0.016 × AC^2 + 0.371 × FL + 20.187 × (AC/FL)^2 |
| Hadlock III [12]              | AC, BPD, FL| 10^1 - 3.356-0.000334 × AC + FL + 0.0016 × BPD + 0.0457 × AC + 0.0163 × FL (gr, mm) |
| Hadlock II [12]               | AC, FL     | 10^1 - 3.304+0.000094 × AC + FL + 0.005281 × AC + 0.1938 × FL (mm) |
| Hadlock I [12]                | AC, BPD, FL| 10^1 - 3.596+0.00062 × HC + 0.00424 × AC + 0.0174 × FL + 0.000061 × BPD + 0.0000386 × AC + 0.0 × FL (gr, mm) |
| Hadlock VI [11]               | AC         | e^2.695 + 0.0253 × AC - 0.000275 × AC^2 (gr, mm) |
| Hadlock IV [11]               | AC, FL, HC | 10^1 - 0.326 - 0.0003326 × AC + FL + 0.00107 × HC + 0.0438 × AC + 0.0158 × FL (gr, mm) |
| Ott et al. [15]               | AC, FL, HC | 10^0 - 0.9337 + 1.2594 × 2.00004355 × AC + 0.005394 × AC - 0.000008582 × HC + AC (gr, mm) |
| Combs et al. [19]             |            | 0.00023718 × AC^2 × FL + 0.0000312 × HC^3 (gr, mm) |
| Merz II [18]                  | AC, BPD    | −3200.40479 + 15.707186 × AC + 0.1590391 × BPD (gr, mm) |
| Rose and McCallum [16]        | TAD, BPD, FL| 0.041 + 0.0144 × (BPD + TAD + FL) (gr, mm) |
| Warsof et al. [7]             | AC, BPD    | 0.0000816 × AC^3 (gr, mm) |
| Higginsbottom [8]             | AC         | 1000 × (1.5622 - 0.00108 × HC + 0.00468 × AC + 0.0171 × FL + 0.00000 × HC^2 - 0.000003685 × AC × FL) (gr, mm) |
| Hadlock V [12]                | HC, AC, FL | 10^1 - 1.7492 + 0.0166 × BPD + 0.0046 × AC - 0.0002546 × AC × BPD (gr, mm) |
| Shepard et al. [9]            | AC, BPD    | 10^1 - 0.879+0.0084 × BPD + 0.0026 × AC (gr, mm) |
| Vintzileos et al. [17]        | AC, BPD    | 10^1 - 0.78437 + 0.00004197 × HC + AC + 0.00008545 × AC × FL (gr, mm) |
| Hivale et al. [26]            | AC, FL, HC | 10^1 - 0.6961 + 0.002253 × HC + 0.001645 × AC + 0.006439 × FL (gr, mm) |
| Weiner II [13]                | AC, FL, HC | −229.076 + 0.09337 × AC × BPD (gr, mm) |
| Thurnau et al. [10]           | AC, BPD    | 10^1 - 0.6575 + 0.004035 × HC + 0.001285 × AC (gr, mm) |
| Merz I [18]                   | AC         | 0.0001 × AC^3 (gr, mm) |
| Hart et al. [21]              | MW, HC, AC, FL | 0.07638 + 0.000295 × MW (kg) + 0.00000395 × HC + 0.0000524 × AC + 0.000487 × FL (gr, mm) |

AC, Abdominal circumference; BPD, Biparietal diameter; FL, Femur length; HC, Head circumference (HC); TAD, Transverse abdominal diameter.

2. Materials and methods

This study was planned prospectively in a tertiary hospital between 1 April 2019 and 1 October 2019. 160 pregnant women who were term pregnant and had a cesarean indication hospitalized to give birth by cesarean included in the study. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Hitit University (approval number: 069). This study included pregnant women with a single pregnancy, between 38 and 40 weeks, without a known fetal anomaly, without communication problems, and who wanted to participate in the study. After obtaining informed consent from the pregnant women, the sociodemographic information was recorded on the prepared form. Afterward, Hitachi HI Vision Preirus ultrasound system with Convex probe (8–4 MHz) was performed using ultrasound and AC (Abdominal circumference), BPD (Biparietal diameter), FL (Femur length), HC (Head circumference) and TAD (Transverse abdominal diameter) measurements were taken. In addition, the location of the placenta, placental dimensions in 3 planes, and umbilical cord thickness were recorded. BPD was measured at the section of cavum septum pellucidum and falx cerebri plane and the cursors were placed outside to inside. HC was measured from the outside of the cranial bones in the same plane as the BPD. AC and TAD were measured at the level of where the umbilical vein passed through the liver and symmetrical rib images seen. FL was measured vertically from metaphysis to metaphysis.

All of the patients gave birth by cesarean on the day of the ultrasound examination. The newborns were weighted with an electronic machine immediately after the delivery. The baby's birth weight is recorded in the patient file.

In this study, the main accuracy measurement was determined as the root mean square error (RMSE). Therefore, the formulas that could calculate fetal weight estimations with the lowest RMSE values were selected as the best FWE (fetal weight estimation) formulas. In addition, the lowest mean error (ME), the lowest mean percentage error (MPE), the lowest average percentage error (MPE), the highest Pearson correlation (r), and deviations from ABW (Actual birth weight) ±5%, ±10%, and ±15% were used to find the best formulas. Calculations were made by Using Matlab, SPSS, and Excel. Formulations of RMSE, ME, MPE, and MAPE.
are given below, respectively.

\[
\text{RMSE} = \frac{1}{n} \sum_{i=1}^{n} (\text{FWE}_i - \text{ABW}_i)^2
\]  

(1)

\[
\text{ME} = \frac{1}{n} \sum_{i=1}^{n} (\text{FWE}_i - \text{ABW}_i)
\]  

(2)

\[
\text{MPE} = \sum_{i=1}^{n} \left( \frac{\text{FWE}_i - \text{ABW}_i}{\text{ABW}_i} \right) \times 100
\]  

(3)

\[
\text{MAPE} = \sum_{i=1}^{n} \left| \frac{\text{FWE}_i - \text{ABW}_i}{\text{ABW}_i} \right| \times 100
\]  

(4)

Eqns. 1, 2, 3, 4, FWE\(_i\), ABW\(_i\), and \(|.|\) indicate fetal weight estimation of \(i\)th baby, actual birth weight of \(i\)th baby and the absolute value, respectively.

3. Results

Some of the demographic information of patients and some values of ultrasound parameters are given in Table 2.

For all fetuses in this study, statistics of RMSE, MAPE, MPE, and Pearson’s r are given in Table 3 (Ref. [6–13, 15–21, 23, 26]) and the 5%, 10%, and 15% deviations from actual birth weight are given in Table 4 (Ref. [6–13, 15–21, 23, 26]) respectively. In Table 3, the formula of Schild et al.—Male [20] was the best formula in estimating fetal weight for all fetuses based on having the lowest RMSE. Furthermore, estimations obtained from the formula of Schild et al.—Male [20] had the lowest RMSE with the value of 301.8 gr, the lowest MAPE with the value of 7.2% ± 5.8% and the highest percentages of estimations within the 5% and the 10% ranges of ABW with the values of 43.1% and 76.9%, respectively, as shown in Table 3 and Table 4. Furthermore, estimations obtained from the formula of Schild et al.—Male [20] had a great percentage of estimations within the 15% range of ABW and pretty small values for each of MPE% and ME. The charts of FWE calculated by using the formula of Schild et al.—Male [20] and ABW were comparatively given in Fig. 1 for all fetuses. It can be shown in Fig. 1 that estimations obtained by using the formula of Schild et al.—Male [20] were quite close to ABW values.

In Table 3 and Table 4, formulas of Campel and Wilkin [6], Schild et al.—Female [20], Esinler et al. [23], Hadlock III [12], Hadlock II [12], Hadlock I [12], Hadlock VI [11], Hadlock IV [11], Ott et al. [15] and Combs et al. [19] were ranked as the sufficient formulas in estimating fetal weight based on having the low RMSE. Among these formulas, the formula of Esinler et al. [23] had the lowest MAPE with the value of 7.2% ± 5.6%, the formula of Hadlock I [12] had the lowest MPE with the value of 0.3% ± 9.8% and the lowest ME with the value of -4.5 gr ± 320.7 gr, the formula of Schild et al.—Female [20] had the highest percentage of estimations within the 15% range of ABW with the value of 91.9% and Pearson’s r value between estimations obtained from the formula of Hadlock III [12] and ABW had the highest correlation with the value of 0.701.

Additionally, insufficient formulas in estimating fetal weight could be seen in Table 3 and Table 4. The formulas of Thurnau et al. [10], Weiner I [13], Merz I [18], and Hart et al. [21] were classified as very insufficient formulas in estimating fetal weight for Turkish population.

For male fetuses in this study, statistics of RMSE, MAPE, MPE, and Pearson’s r are given in Table 5 (Ref. [6–13, 15–21, 23, 26]) and the deviations 5%, 10%, and 15% deviations from actual birth weight are given in Table 6 (Ref. [6–13, 15–21, 23, 26]), respectively. In Table 5, the formula of

| Variable                      | Mean ± SD     |
|-------------------------------|---------------|
| Maternal age (yr)             | 29.96 ± 4.87  |
| Gestational age (wk)          | 38.56 ± 1.23  |
| Biparietal diameter (cm)      | 9.29 ± 0.36   |
| Abdominal circumference (cm)  | 33.98 ± 1.82  |
| Head circumference (cm)       | 33.04 ± 1.28  |
| Femur length (cm)             | 7.35 ± 0.30   |
| Actual birth weight (gr)      | 3327.13 ± 401.62 |
| Interval between ultrasound scan and delivery (dy) | 0.00 ± 0.00 |
Schild et al.—Female [20] was the best formula in estimating fetal weight for male fetuses based on having the lowest RMSE. Estimations obtained from the formula of Schild et al.—Female [20] had the lowest RMSE with the value of 284.8 gr, the lowest MAPE with the value of 6.6%, the highest percentages of estimations within the 5%, 10%, and 15% ranges of the actual birth weight with the values 5.0%, 79.0%, 96.3%, respectively, as shown in Tables 5 and 6. Furthermore, estimations obtained from the formula of Schild et al. Female [20] had pretty small values for each of MPE% and ME. The charts of FWE calculated by using the formula of Schild et al. Female [20] and ABW were comparatively given in Fig. 2 for male fetuses. It can be shown in Fig. 2 that estimations obtained by using the formula of Schild et al. Female [20] are quite close values to ABW values for male fetuses.

In Table 5 and Table 6, the formulas of Schild et al.—Male [20], Hadlock III [12], Hadlock I [12], Ott et al. [15], Campel and Wilkin [6], Exsimler et al. [23], Hadlock IV [11], Hadlock II [12], Combs et al. [19], Hadlock VI [11], Rose and McCallum [16], Warsof et al. [7] and Merz II were ranked as the sufficient formulas in estimating fetal weight for male fetuses based on having the low RMSE. Among these formulas, the formula of Hadlock I [12] had the lowest MPE with the value of 0.2% ± 9.0% and the lowest ME with the value of -5.6 ± 305.9 and Pearson’s r value between estimations obtained from the formula of Rose and McCallum [16] and ABW had the highest correlation with the value of 0.663.

Additionally, insufficient formulas in estimating fetal weight could be seen in Table 5 and Table 6. Also, the formulas of Thurnau et al. [10], Weiner I [13], Merz I [18], and Hart et al. [21] were classified as very insufficient formulas in estimating the fetal weight of male fetuses for the Turkish population.

For female fetuses in this study, statistics of RMSE, MAPE, MPE, and Pearson’s r are given in Table 7 (Ref. [6–13, 15–21, 23, 26]) and the deviations 5%, 10%, and 15% deviations from actual birth weight are given in Table 8 (Ref.

![Fig. 2. The graphs of FWE of Schild et al.—Female [20] and ABW for boy fetuses.](image-url)
Table 4. Frequency distributions of EFW within a certain range of ABW for all fetuses (n = 160).

| Formulas                  | ±5% deviation from ABW | ±10% deviation from ABW | ±15% deviation from ABW |
|---------------------------|------------------------|-------------------------|-------------------------|
|                           | Frequency | Percent | Frequency | Percent | Frequency | Percent |
| Schild et al.—Male [20]   | 69        | 43.1    | 123       | 76.9    | 142       | 88.8    |
| Campbell and Wilkin [6]   | 67        | 41.9    | 118       | 73.8    | 146       | 91.3    |
| Schild et al.—Female [20] | 67        | 41.9    | 119       | 74.4    | 147       | 91.9    |
| Esinler et al. [23]       | 67        | 41.9    | 117       | 73.1    | 146       | 91.3    |
| Hadlock III [12]          | 59        | 36.9    | 114       | 70.6    | 142       | 88.8    |
| Hadlock II [12]           | 61        | 38.1    | 113       | 70.6    | 142       | 88.8    |
| Hadlock VI [11]           | 64        | 40.0    | 115       | 71.9    | 143       | 89.4    |
| Hadlock IV [11]           | 62        | 38.8    | 110       | 68.8    | 142       | 88.8    |
| Ott et al. [15]           | 57        | 35.6    | 111       | 69.4    | 142       | 88.8    |
| Combs et al. [19]         | 63        | 39.4    | 107       | 66.9    | 140       | 87.5    |
| Merz II [18]              | 59        | 36.9    | 105       | 65.6    | 131       | 81.9    |
| Rose and McCallum [16]    | 50        | 31.3    | 104       | 65.0    | 132       | 82.5    |
| Warnof et al. [7]         | 57        | 35.6    | 104       | 65.0    | 133       | 83.1    |
| Higginbottom [8]          | 55        | 34.4    | 92        | 57.5    | 127       | 79.4    |
| Hadlock V [12]            | 50        | 31.3    | 99        | 61.9    | 122       | 76.3    |
| Shepard et al. [9]        | 40        | 25.0    | 82        | 51.3    | 114       | 71.3    |
| Vintzileos et al. [17]    | 47        | 29.4    | 88        | 55.0    | 115       | 71.9    |
| Hivale et. al. [26]       | 36        | 22.5    | 69        | 43.1    | 103       | 64.4    |
| Weiner II [13]            | 41        | 25.6    | 78        | 48.8    | 100       | 62.5    |
| Thurnau et al. [10]       | 8         | 5.0     | 26        | 16.3    | 54        | 33.8    |
| Weiner I [13]             | 11        | 6.9     | 35        | 21.9    | 58        | 36.3    |
| Merz I [18]               | 20        | 12.5    | 43        | 26.9    | 59        | 36.9    |
| Hart et al. [21]          | 2         | 0.0     | 2         | 1.3     | 8         | 5.0     |

EFW, Estimated Fetal Weight; ABW, Actual Birth Weight.

[6–13, 15–21, 23, 26]), respectively. The formula of Campbell and Wilkin [6] was the best formula in estimating fetal weight for female fetuses based on having the lowest RMSE. Estimations obtained from the formula of Campbell and Wilkin [6] had the lowest RMSE with the value of 304.4 gr, the lowest MAPE with the value of 7.3% ± 5.5%, the lowest MPE with the value of -0.3% ± 9.3% and the highest percentage of estimations within the 15% range of ABW with the value of 89.9% as shown in Table 7 and Table 8. Estimations obtained from the formula of Campbell and Wilkin [6] had quite small values for each of MPE% and ME. The charts of FWE calculated by using the formula of Campbell and Wilkin [6] and ABW were comparatively given in Fig. 3 for male fetuses. It can be seen in Fig. 3 that estimations obtained by using the formula of Campbell and Wilkin [6] are quite close values to ABW values for female fetuses.

The formulas of Campbell and Wilkin [6], Esinler et al. [23], Schild et al.—Male [20], Hadlock VI [11], Hadlock II [12], Schild et al.—Female [20], Hadlock III [12], Hadlock I [12], Hadlock IV [11] and Ott et al. [15] were ranked as the sufficient formulas in estimating fetal weight for female fetuses based on having the low RMSE. Among these formulas, the formula of Schild et al. Male [20] had the lowest ME with the value of 0.8 ± 320.0, the formula of Hadlock II [12] had the highest percentages of estimations within the 5% and 15% ranges of ABW with the values of 41.8% and 89.9%, respectively, the formula of Hadlock VI [11] the highest percentage of estimations within the 10% range of ABW with the value of 77.2% and Pearson’s r value between estimations obtained from the formula of Hadlock II [12] and ABW had the highest correlation with the value of 0.740.

Insufficient formulas in estimating fetal weight could be seen in Table 7 and Table 8. The formulas of Weiner II [13], Thurnau et al. [10], Weiner I [13], Merz [18], and Hart et al. [21] were classified as very insufficient formulas in estimating the fetal weight of girl fetuses for the Turkish population.
Table 5. The values of RMSE, MAPE, MPE, ME and Pearson’s r of the formulas for male fetuses (n = 81).

| FORMULAS      | RMSE (%) | MAPE (%) | MPE (%) | ME (CI) | r         |
|---------------|----------|----------|---------|---------|-----------|
| The Best      | 284.9 ± 5.0 | 6.6 ± 5.0 | 53–7.7 | -1.3 ± 8.2 | (-3.2–0.5) | 0.653 |
| Schild et al. | 285.2 ± 5.2 | 5.7–7.8 | 0.9 ± 8.6 | (-1.0–2.8) | -12.3 ± 286.8 | (-51.1–75.7) |
| Hadlock III   | 303.1 ± 5.4 | 6.1–8.5 | 1.5 ± 9.0 | (-0.5–3.5) | 36.8 ± 302.7 | (-30.2–103.7) |
| Hadlock I     | 304.1 ± 5.4 | 6.0–8.4 | 0.2 ± 9.0 | (-1.8–2.2) | -5.6 ± 305.9 | (-73.3–62.0) |
| Ott et al.    | 307.7 ± 5.6 | 5.9–8.4 | -0.8 ± 9.1 | (-2.8–1.2) | -40.6 ± 306.9 | (-108.4–27.3) |
| Campbell & Wilkin [6] | 308.6 ± 5.7 | 5.9–8.5 | 0.0 ± 9.2 | (-2.7–1.3) | -42.6 ± 307.6 | (-110.6–25.4) |
| Eisiner et al. [23] | 308.8 ± 5.4 | 5.8–8.2 | 0.0 ± 9.3 | (-2.1–1.2) | 30.7 ± 314.9 | (-53.5–85.4) |
| Hadlock IV    | 312.2 ± 5.3 | 6.0–8.5 | 0.0 ± 9.3 | (-2.1–1.2) | 30.7 ± 314.9 | (-53.5–85.4) |
| Hadlock II    | 312.5 ± 5.3 | 6.0–8.6 | 0.0 ± 9.3 | (-2.1–1.2) | 30.7 ± 314.9 | (-53.5–85.4) |
| Combs et al.  | 315.8 ± 5.2 | 5.9–8.4 | 0.0 ± 9.3 | (-2.1–1.2) | 30.7 ± 314.9 | (-53.5–85.4) |
| Hadlock VI    | 325.0 ± 5.7 | 6.3–9.0 | 0.9 ± 9.8 | (-1.4–2.9) | 8.8 ± 326.9 | (-63.5–81.1) |
| Rose & McCallum [16] | 346.6 ± 5.7 | 7.3–9.8 | 2.7 ± 9.9 | 0.5–4.9 | 84.1 ± 338.4 | 9.3–158.9* |
| Insufficient  |          |          |         |         |           |          |
| Higginbottom  | 340.7 ± 5.6 | 7.4–10.3 | 6.2 ± 9.2 | 4.1–8.2 | 186.2 ± 297.5 | 120.4–252.0* |
| Merz II       | 349.4 ± 5.6 | 7.4–10.3 | 6.2 ± 9.2 | 4.1–8.2 | 186.2 ± 297.5 | 120.4–252.0* |
| Vintzileos et al. [17] | 442.6 ± 7.0 | 9.2–12.6 | 6.7 ± 11.5 | 3.2–14.2 | 215.9 ± 388.8 | 130.0–301.9** |
| Shepard et al. | 452.6 ± 7.7 | 9.7–13.2 | 8.7 ± 10.8 | 6.3–11.1 | 279.3 ± 358.3 | 200.1–358.6** |
| Weiner II     | 463.7 ± 7.9 | 9.2–12.6 | 9.5 ± 11.6 | 7.5–12.8 | 324.5 ± 333.3 | 309–(−258.8)** |
| Hivale et al. | 468.1 ± 7.4 | 9.5–12.8 | 10.8 ± 12.4 | 9.1–15.0 | 393.9 ± 330.1 | 399–(−295.2)** |
| Very Insufficient | 576.1 ± 7.7 | 17.6±7.3 | 17.9±11.8 | 16.1–18.0 | 604.7 ± 279.9 | 666.5–(−545.2)** |
| Thurnau et al. [10] | 655.5 ± 7.7 | 26.0–19.1 | 17.8–20.9 | 16.0–17.0 | 604.7 ± 279.9 | 666.5–(−545.2)** |
| Weiner I      | 705.2 ± 8.5 | 18.3±9.0 | 17.9±11.8 | 16.0–17.0 | 604.7 ± 279.9 | 666.5–(−545.2)** |
| Merz et al.   | 769.0 ± 9.2 | 22.7–22.6 | 18.3±11.8 | 16.0–17.0 | 616.6 ± 426.2 | 514–718.9** |
| Hart et al.   | 1125.4 ± 10.4 | 29.6–32.9 | 31.3±12.0 | 29.0–31.9 | 1070.7±350.9 | 1147.6–(−992.4)** |

CI, Confidence interval; MAPE, mean absolute percentage error; MPE, mean percentage error; ME, Mean error.

** significant at 0.01 significance level (Null Hypothesis is ME = 0 and Alternative Hypothesis is ME ≠ 0); * significant at 0.05 significance level (Null Hypothesis is ME = 0 and Alternative Hypothesis is ME ≠ 0).

4. Discussion

In this study, the accuracy performances of formulas in the literature were compared, and then the best formulas were found for the Turkish population. As a result of comparisons, Formulas in the literature were classified as the best, sufficient, insufficient, and very insufficient for each gender not specific, male fetuses and female fetuses in Table 4, Table 6, and Table 8, respectively. The main accuracy criteria of this study were the lowest RMSE value. In accordance with this main criteria, the formulas of Schild et al. Male [20], Schild et al. Female [20] and Campbell & Wilkin [6] were found as the best formulas for all fetuses, male fetuses, and female fetuses, respectively, in estimating the fetal weights for Turkish population. Also, as a result of all applications in this study, each formulas of Schild et al. Male [20], Schild et al. Female [20], Campbell & Wilkin [6], Hadlock I [12], Hadlock II [12], Hadlock III [12], Hadlock VI [11], Eisiner et al. [23] and Rose & McCallum [16] had the best accuracy performance depending on at least one criteria that is one of minimum RMSE, minimum MAPE, minimum MPE, minimum ME, maximum r, maximum percents of ±5%, ±10% and ±15% deviations from ABW. On the other hand, the formulas of Higginbottom [8], Shepard et al. [9], Hadlock V [12], Vintzileos et al. [17] and Hivale et al. [26] were insufficient formulas and the formulas Thurnau et al. [10], Weiner et al. [13], Merz et al. [18] and Hart et al. [21] were the worst formulas in estimating all fetuses, male fetuses and female fetuses for Turkish population.

The idea of developing different formulas for both male and female fetuses was proposed by Schild et al. [20] in the literature. In the article of Schild et al. [20], MAPE value, the percent of ±10% deviation from ABW, and the percent of ±15% deviation from ABW had been calculated as 6.9%, 79.3%, and 90.5%, respectively, by using the formula Schild et al. —Female [20] for female fetuses. These values in this study were found as 7.3%, 75.9%, and 89.9%, respectively, by using the formula of Campbell and Wilkin [6] for female fetuses. According to these results, accuracy performances in the article of Schild et al. [20] were a little better than the accuracy performances of this study in estimating weight for female fetuses. However, in the article by Schild et al. [20], MAPE value, the percent of ±10% deviation from ABW, and the percent of ±15% deviation from ABW had been calculated as 7.0%, 73.3%, and 91.1%, respectively, by using the formula Schild et al.—Male [20] for male fetuses. These values in this study were found as 6.6%, 79.0%, and 96.3%, respectively, by using the formula of Schild et al.—Female [20]. According to these results, the accuracy performances of this study were a little better than the accuracy performances of this study in estimating weight for male fetuses. For this reason, it could be said that the values of accuracy per-
Performances in this study are similar to the values of accuracy performances in the article of Schild et al. [20] for both male and female fetuses. And so, it could be thought that selecting different formulas is a logical way of estimating fetal weights.

Esinler et al. [29] found that the best formulas are Hadlock I [12], Ott et al. [15], and Comps et al. [19] in all fetuses, in fetuses >4000 gr and in fetuses <2500 gr, respectively, for Turkish population. Indeed, the formulas of Hadlock I [12], Ott et al. [15], and Comps et al. [19] were generally sufficient formulas in our study. However, in this study, Schild et al.—Male [20], Schild et al.—Female [20], and Campel and Wilkin [6] were the best formulas in estimating fetal weights for the Turkish population. Further, accuracy performances in our study were better than the accuracy performances in Esinler et al. [29]. For example, 7.2%, 6.6%, and 7.4 that are MAPE values calculated in our study were lower than 7.7%, 7.3%, and 10.3 in the article of Esinler et al. [29]. So, the reason why different formulas can be chosen as the best formulas for Turkish populations might be because of the fact that the interval range between ultrasound scan and delivery day. It was zero in our study while the interval range between ultrasound scan and delivery was <7 days in the study of Esinler et al. [29].

Hiwale et al. [26] developed a new formula for an Indian population. But, the formula of Hiwale et al. [26] was insufficient FWE formula with the RMSE value of 478.0 gr. Similarly, Hiwale et al. [3] found that the Woo et al. [30] formula’s is the best formula for the Indian population. However, the formula of Campbell and Wilkin [6] was found as insufficient for the Indian population in the study of Hiwale et al. [3]. Despite the formula of Campbell and Wilkin [6] was a considerable sufficient formula in this study. As another comparison, the formula of Hart et al. [21] was the best formula for the Germany population despite the formula of Hart et al. [21] was the worst formula for the Turkish population in this study. For another example, the formula of Hadlock IV [11] was the best formula in estimation fetal weights for the Mexican population in the study of Blue et al. [31] despite the formula of Hadlock IV [11] was a little sufficient formula in our study. These findings show that the efficacy of the formulas for countries might differ from each other. Therefore, in this study, it could be thought that finding the best formulas for a Turkish population will contribute to researchers that will plan to study interested in FWE in the future.

The advantages of this study can be given as follows.

Comparisons were made for a gender non-specific and gender-specific. All fetuses (n = 160), male fetuses (n = 81) and female fetuses (n = 79) in Turkish people included randomly. The approach in this study is similar to the approach of Schild et al. [20] that proposed 2 different formulas for

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Table 6. Frequency distributions of EFW within a certain range of ABW for male fetuses (n = 81).

| Formulas                         | 5% deviation from ABW | 10% deviation from ABW | 15% deviation from ABW |
|----------------------------------|------------------------|-------------------------|-------------------------|
|                                 | Frequency | Percent | Frequency | Percent | Frequency | Percent |
| Schild et al.—Female [20]        | 40       | 50.6    | 64        | 79.0    | 78        | 96.3    |
| Schild et al.—Male [20]          | 37       | 45.7    | 63        | 77.8    | 72        | 88.9    |
| Hadlock III [12]                 | 32       | 39.5    | 59        | 72.8    | 74        | 91.4    |
| Hadlock I [12]                   | 32       | 39.5    | 59        | 72.8    | 73        | 90.1    |
| Ott et al. [15]                  | 32       | 39.5    | 69        | 85.2    | 73        | 90.1    |
| Campbell and Wilkin [6]          | 35       | 43.2    | 58        | 71.6    | 75        | 92.6    |
| Esinler et al. [23]              | 35       | 43.2    | 59        | 72.8    | 75        | 93.8    |
| Hadlock IV [11]                  | 34       | 42.0    | 60        | 74.1    | 73        | 90.1    |
| Hadlock II [12]                  | 33       | 40.7    | 57        | 70.4    | 73        | 90.1    |
| Combs et al. [19]                | 38       | 46.9    | 57        | 70.4    | 72        | 88.9    |
| Hadlock VI [11]                  | 33       | 40.7    | 54        | 66.7    | 73        | 90.1    |
| Rose and McCallum [16]           | 26       | 32.1    | 54        | 66.7    | 71        | 87.7    |
| Warsof et al. [7]                | 31       | 38.3    | 57        | 70.4    | 73        | 90.1    |
| Merz II [18]                     | 28       | 34.6    | 50        | 61.7    | 66        | 81.5    |
| Hadlock V [12]                   | 25       | 30.9    | 49        | 60.5    | 64        | 79.0    |
| Higginbottom [8]                 | 27       | 33.3    | 50        | 61.7    | 64        | 79.0    |
| Vintzileos et al. [17]           | 25       | 30.9    | 41        | 50.6    | 57        | 70.4    |
| Shepard et al. [9]               | 21       | 25.9    | 38        | 46.9    | 55        | 67.9    |
| Weiner II [13]                   | 24       | 29.6    | 47        | 58.0    | 57        | 70.4    |
| Hiwale et al. [26]               | 17       | 21.0    | 39        | 48.1    | 56        | 69.1    |
| Thurman et al. [10]              | 2        | 2.5     | 13        | 16.0    | 31        | 38.3    |
| Weiner I [11]                    | 9        | 11.1    | 17        | 21.0    | 31        | 38.3    |
| Merz I [18]                      | 10       | 12.3    | 19        | 23.5    | 28        | 34.6    |
| Hart et al. [21]                 | 0        | 0.0     | 1         | 1.2     | 2         | 2.5     |
each male and female. The best formulas have been determined for all fetuses, fetuses with BW less than 2500 gr and fetuses with BW bigger than 4000 in the literature. To the best of our knowledge, there is no study to compare males and females in the literature. For this reason, this study is the first one comparing these two.

- In the literature, most of the studies of the fetal weight estimation (FWE) are the retrospective studies, that interval range between ultrasound scan and delivery is <14 days. This situation may cause a measurement error. However, the interval range between ultrasound scan and delivery was zero in this study.

- In the literature, many different doctors have scanned fetuses to estimate the fetal weight. It is known that interobserver variability is high in ultrasonographic evaluation. In this study, one senior doctor scanned all fetuses. Therefore, interobserver variability completely eliminated.

- In the literature, many different ultrasound devices may be used during scanning. This situation may cause to make measurement errors since measurement sensitivities of ultrasound devices may differ from each other. In this study, one ultrasound device was used to be scan for all fetuses.

Author contributions

ÖK designed the research study. ÖK performed the research. CK analyzed the data. ÖK and CK wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Hittit University (approval number: 069).

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Conflict of interest

The authors declare no conflict of interest.

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**Table 7. The values of RMSE, MAPE, MPE, ME and Pearson’s r of the formulas for female fetuses (n = 79).**

| FORMULAS | RMSE | MAPE (%) | MAPE (CI %) | MPE (%) | MPE (CI %) | ME | ME (CI) | r    |
|----------|------|----------|-------------|---------|------------|----|---------|------|
| The Best | 304.4| 7.3 ± 5.7| 6.0–8.6     | −0.3 ± 9.3| (−2.4)–1.81| −32.5| 304.6   | 0.735|
| Sufficient | 317.0| 7.4 ± 5.8| 6.1–8.7     | −2.2 ± 9.1| (−4.2)–(−0.1)| −97.1| 303.1   | 0.735|
| Esler et al. – Male [20] | 317.9| 7.7 ± 6.2| 6.3–9.1     | 0.9 ± 9.9 | (−1.3)–3.1 | 0.8 | 320.0   | 0.698|
| Schild et al. – Male [20] | 319.1| 7.5 ± 6.6| 6.0–9.0     | 1.2 ± 9.9 | (−1.0)–3.4 | 22.7 | 320.4   | 0.735|
| Hadlock VI [11] | 319.8| 7.6 ± 6.5| 6.1–9.0     | 1.8 ± 9.9 | (−0.4)–4.0 | 42.3 | 319.0   | 0.740|
| HDI [13] | 327.3| 8.0 ± 6.2| 6.6–9.3     | −1.2 ± 10.1| (−3.4)–1.1 | −65.1| 322.8   | 0.700|
| Hadlock III [12] | 328.8| 8.0 ± 6.6| 6.6–9.5     | 1.8 ± 10.3| (−0.5)–4.1 | 42.5 | 328.1   | 0.732|
| Hadlock I [11] | 335.1| 8.2 ± 6.5| 6.8–9.7     | 0.4 ± 10.5| (−1.9)–2.8 | −3.3 | 337.2   | 0.718|
| Hadlock IV [11] | 338.8| 8.4 ± 6.3| 7.0–9.8     | −0.5 ± 10.5| (−2.8)–1.9 | −33.2| 339.3   | 0.709|
| Ott et al. [15] | 343.0| 8.6 ± 6.5| 7.1–10.0    | −0.6 ± 10.8| (−3.0)–1.8 | −40.3| 342.8   | 0.690|
| Insufficient | 351.5| 8.8 ± 6.2| 7.4–10.2    | −2.5 ± 10.5| (−4.9)–(−0.2) | −106.6| 337.1   | 0.686|
| Combs et al. [19] | 361.6| 8.9 ± 8.4| 7.1–10.8    | 6.2 ± 10.6 | 3.9–8.6 | 179.7| 315.8   | 0.723|
| Merz II [18] | 396.2| 9.6 ± 7.6| 7.9–11.3    | 2.5 ± 12.0 | (−0.2)–5.2 | 72.4 | 392.0   | 0.707|
| Rose and McCallum [16] | 396.2| 9.7 ± 7.3| 8.1–11.3    | −4.2 ± 11.4| (−6.8)–(−1.7) | −153.4| 367.7   | 0.695|
| Higginbottom [8] | 405.0| 9.7 ± 7.5| 8.0–11.4    | −2.5 ± 12.1| (−5.2)–0.2 | −84.9| 398.6   | 0.730|
| Hadlock V [12] | 445.5| 11.2 ± 11.2| 8.7–13.7   | 7.4 ± 14.0 | 4.3–10.6 | 187.6| 406.7   | 0.711|
| Shepard et al. [9] | 479.4| 11.6 ± 9.9| 9.4–13.9    | 8.0 ± 13.1 | 5.0–10.9 | 249.0| 412.3   | 0.693|
| Hulst et al. [26] | 487.9| 11.0 ± 6.8| 11.0–14.0   | −10.2 ± 10.0| (−12.4)–(−7.9) | −352.4| 339.6   | 0.694|
| Vintzileos et al. [17] | 496.1| 11.4 ± 10.1| 9.2–13.7   | 6.0 ± 4.0  | 2.8–9.1 | 190.8| 460.9   | 0.699|
| Very Insufficient | 511.3| 13.0 ± 7.6| 11.3–14.7   | −9.6 ± 11.7| (−12.2)–(−7.0) | −331.3| 391.9   | 0.650|
| Weiner II [13] | 689.5| 18.1 ± 7.6| 16.4–19.9   | −17.6 ± 18.7| (−19.6)–(−15.7) | −609.4| 324.7   | 0.692|
| Thurnau et al. [10] | 808.7| 19.8 ± 14.4| 16.6–23.0  | 19.5 ± 14.8| 16.2–22.8 | 643.1| 493.4   | 0.730|
| Merz I [18] | 769.0| 20.2 ± 10.2| 17.9–22.4  | −18.6 ± 12.8| (−21.5)–(−15.8) | −633.1| 459.4   | 0.553|
| Weiner I [13] | 1130.9| 30.6 ± 8.5| 28.7–32.5   | −30.2 ± 9.8| (−32.4)–(−28.0) | −1042.8| 440.5   | 0.496|

CI, Confidence interval; MAPE, mean absolute percentage error; MPE, mean percentage error; ME, Mean error.

** significant at 0.01 significance level (Null Hypothesis is ME = 0 and Alternative Hypothesis is ME ≠ 0).
Table 8. Frequency distributions of EFW within a certain range of ABW for female fetuses (n = 79).

| Deviations of EFW from ABW | ±5% deviation from ABW | ±10% deviation from ABW | ±15% deviation from ABW |
|----------------------------|------------------------|-------------------------|------------------------|
| Formulas                   | Frequency | Percent | Frequency | Percent | Frequency | Percent |
| Campbell and Wilkin [6]    | 32        | 40.5    | 60        | 75.9    | 71        | 89.9    |
| Esinier et al. [21]        | 32        | 40.5    | 58        | 73.4    | 70        | 88.6    |
| Schild et al.—Male [20]    | 32        | 40.5    | 60        | 75.9    | 70        | 88.6    |
| Hadlock VI [11]            | 31        | 39.2    | 61        | 77.2    | 70        | 88.6    |
| Hadlock II [12]            | 33        | 41.8    | 56        | 70.9    | 71        | 89.9    |
| Schild et al.—Female [20]  | 27        | 34.2    | 55        | 69.6    | 69        | 87.3    |
| Hadlock III [12]           | 27        | 34.2    | 55        | 69.6    | 71        | 89.9    |
| Hadlock I [12]             | 29        | 36.7    | 54        | 68.4    | 69        | 87.3    |
| Hadlock IV [11]            | 28        | 35.4    | 50        | 63.3    | 69        | 87.3    |
| Ott et al. [15]            | 25        | 31.6    | 53        | 67.1    | 69        | 87.3    |
| Combs et al. [19]          | 25        | 31.6    | 50        | 63.3    | 68        | 86.1    |
| Merz II [18]               | 31        | 39.2    | 55        | 69.6    | 65        | 82.3    |
| Rose and McCallum [16]     | 24        | 30.4    | 50        | 63.3    | 61        | 77.2    |
| Warsof et al. [7]          | 26        | 32.9    | 47        | 59.5    | 60        | 75.9    |
| Higginbottom [8]           | 28        | 35.4    | 42        | 53.2    | 63        | 79.7    |
| Hadlock V [12]             | 25        | 31.6    | 50        | 63.3    | 58        | 73.4    |
| Shepard et al. [9]         | 19        | 24.1    | 44        | 55.7    | 59        | 74.7    |
| Hivale et al. [26]         | 19        | 24.1    | 30        | 38.0    | 47        | 59.5    |
| Vintzileos et al. [17]     | 22        | 27.8    | 47        | 59.5    | 58        | 73.4    |
| Weiner II [13]             | 17        | 21.2    | 31        | 39.2    | 43        | 54.4    |
| Thurman et al. [10]        | 6         | 7.6     | 13        | 16.5    | 23        | 29.1    |
| Merz I [18]                | 10        | 12.7    | 24        | 30.4    | 31        | 39.2    |
| Weiner I [13]              | 8         | 10.1    | 18        | 22.8    | 27        | 34.2    |
| Hart et al. [21]           | 0         | 0.0     | 1         | 1.3     | 6         | 7.6     |

EFW, Estimated Fetal Weight; ABW, Actual Birth Weight.

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