

# Validation of Sonographic Fetal Weight Estimators Among Term Parturients in Uganda

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## Research article

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# Abstract

## Background

Accuracy of fetal weight estimation by ultrasound is essential in making decisions on the time and mode of delivery. There are many proposed formulas for fetal weight estimation such as Hadlock 1, Hadlock 2, Hadlock 3, Hadlock 4 and Shepard. What best applies to the Ugandan population isn't known since no validation of any of the formulas has been done before. The primary aim of this study was to determine the accuracy of sonographic estimation of fetal weight using five most commonly used formulas, and analyze formula variations for different weight ranges.

## Methods

This was a hospital based prospective cohort study at Mulago National Referral Hospital, Kampala, Uganda. A total of 356 pregnant women who consented and were within three days of birth, prenatal ultrasound fetal weight determined by measuring the biparietal diameter, head circumference, abdominal circumference, femoral length, and then was compared with actual birth weight.

## Results

The overall accuracy of Hadlock 1, Hadlock 2, Hadlock 3, Hadlock 4 and Shepard formula were 66.9%, 73.3%, 77.3%, 78.4% and 69.7% respectively. All Hadlocks showed significant mean difference between weight estimates and actual birth weight ( $p < 0.01$ ) whereas Shepard formula did not [ $p = 0.2$ ], when no stratification of fetal weights was done. However, all Hadlocks showed a none significant ( $p$ -values  $> 0.05$ ) mean difference between weight estimates and actual birth weight when the actual birth weight was  $\geq 4000.0$ gms. Shepard weight estimates showed a none significant mean difference when actual birth weight was  $< 4000$ gms. Bland-Altman graphs also showed a better agreement of weight estimated by Shepard formula and actual birth weights.

## Conclusion

All the five formulas were accurate at estimating actual birth weights within 10% accuracy. However, this accuracy varied with the fetal birth weight. Shepard was more accurate in estimating actual birth weights  $< 4000$ grams whereas all Hadlocks were more accurate when the actual birthweight was  $\geq 4000$ grams.

## Background

Maternal and infant mortality is a major public health issue globally and in Uganda. In 2017, an estimated 295,000 women died during and following pregnancy and child birth, as a vast majority of these deaths (94%) occurred in low resource setting. Sub-Saharan Africa alone accounted for approximately two-third (196,000) of maternal deaths and 6,000 of these cases were from Uganda (1).

Antenatal care reduces both maternal and infant morbidity and mortality and prenatal fetal weight estimation is known to be an important component of standard antenatal care. Fetal weight is one of the determinants of outcome of pregnancies and is also the major determinant of infants' wellbeing in the first year of life(2).

Maternal risks associated with the delivery of an excessively big fetus include birth canal and pelvic floor injuries, as well as postpartum hemorrhage(3).

Accurate prediction of fetal weight is useful in the management of labor and reduces complications associated with macrosomia, thereby reduces maternal and peri-natal morbidity and mortality(4). Ultrasound is widely used preferentially over the clinical models of fetal weight estimation prenatally and excludes fetal anomalies among preterm fetuses(5). Although sonographic fetal weight could be predicted on single fetal parameter such as, the Biparietal Diameter (BPD), Abdominal Circumference (AC), Femur Length (FL), Head Circumference (HC) and Gestational age, a combination of several fetal parameters yields more accurate estimates of fetal weights(6, 7).

Fetal weight is influenced by several factors including maternal characteristics (age and weight), fetus related (anteriorly located placentae, oligohydramnios) and racial factors. Racial variation is an important factor to consider when sonographic fetal weight prediction models derived from one ethnic population are being used. All ultrasound scanners in Africa are imported from countries like America, Europe and Asia whose weight models are based on their population(8, 9). Most fetal weight formulae are based on the normal fetal growth curves and do not take into consideration the factors attributing to either a growth restricted or macrosomic (> 4000 g) fetus. Thus, the accuracy of fetal weight estimations, in predicting microsomic and macrosomic fetuses using fetal growth curves has been questioned(10, 11).

Obstetric sonographic assessment for the purpose of obtaining fetal biometric measurement to predict fetal weight has been integrated into the main stream of obstetric practice during the past four decades(12). Using sonography to estimate fetal weight has limitation including but not limited to the following: maternal obesity, oligohydramnios, anterior placentation, reduced visualization of fetal body structure and inadequate trained personnel(12, 13).

In one large cohort study in Israel, to assess and compare the accuracy of twenty-three models of sonographic fetal weight estimation, they found greater accuracy for models that used 3 or more fetal biometrics. These biometric are FL, AC, BPD, and HC(14). In contrary to this, another large cohort study, twenty-six models of sonographic fetal weight estimation were used and showed that fetal weight estimations based on AC alone were more accurate than models based on FL, AC + FL, or AC + BPD(15).

Almost all the currently used formulas for estimating fetal weight have significant degree of disparity, and various studies have been done to compare the accuracy of different methods of estimation. However, significantly reducing potential perinatal complications associated with labor of both small and excessively large fetuses requires, accurate estimation of fetal weight occurs before deliveries(12).

In Uganda, there is no formula that has been recommended for use across entire birth weight ranges due to lack of validation information. And data on the weight of Ugandan fetuses are scarce.

This study was, therefore, carried out to sonographically estimate fetal weights, in a population of Ugandan pregnant women, in a tertiary hospital in Kampala. Accuracy of fetal weight estimation using five most commonly used formulas (Hadlock 1, Hadlock 2, Hadlock 3, Hadlock 4, and SHEPARD) in the three strata of birth weights was determined and comparison of all the five formulas for weight estimation differences was done.

## Methods

### ***Study design and setting***

This was a hospital based prospective cohort study conducted at the labor ward of Mulago National Referral and Teaching Hospital, Kampala, Uganda between January and June 2019. Mulago National Referral Hospital (Maternity Unit) is located in Kawempe 5km from Kampala city center. The labor suite is managed by consultants, specialists, residents, intern doctors and midwives. There are minimum of seven midwives and eight doctors working in three and two shifts respectively daily. The unit admits on average 65 mothers for labor and conducts on average 17 Caesarian sections daily (Mulago labor suite register 2018).

### ***Study population***

All consenting parturient mothers with singleton fetus at term pregnancy (37-42 weeks) and who delivered within 72 hours from the onset of true labor were consecutively recruited. Deliveries resulting into still births, intrauterine fetal death, detectable congenital anomalies, severe oligo- or polyhydramnios and maternal diabetes or pre-eclampsia were excluded.

### ***Sample Size***

The sample size was determined using the Computer Programme for Epidemiologist (PEPI), version 3.01, described by Armitage and Berry, and 365 participants were determined as the sample size of the study. The following assumptions were used in determining the sample size,

P = Taking the accuracy of Hadlock 4 formula for estimation of fetal weight to be on average 68%, Hadlock 3 formula 63.3%, Hadlock 2 formula 60.9% and Hadlock 1 formula 67.3%. Z = Z value (e.g. 1.96 for 95% confidence level). c = confidence interval, expressed as decimal/ the margin of sampling error tolerated=5%

### ***Study procedure***

Maternal data were gathered using pre-tested semi-structured questionnaire after the labor ward obstetrician confirmed active phase of labor and the parturient consented. The questionnaire used was developed for this study (Annex). Ultrasound examination of the fetus was performed by the principle investigator under the supervision of a qualified radiologist. A targeted ultrasound scan for biometry was performed using 3.5-5 MHz transducer on the SIEMENS ultrasound machine (ACUSON X600), model 10789636, manufactured June, 2016. Estimation of fetal weights was determined using measurements of fetal BPD, HC, AC and FL using standard recommended protocols(16, 17) (Figure 1). AC and FL were used to calculate Hadlock 1; Hadlock 2 was calculated using BPD, AC and FL, Hadlock 3 using HC, AC and FL; Hadlock 4 BPD, HC, AC and FL; and Shepard BPD and AC. The estimated fetal weights in all the five formulas as well as the mean of each fetal parameter were stored in the ultrasound machine's computer memory and immediately recorded in the datasheet.

After delivery, weights were taken using a standard analogue Way master (England) scale corrected for zero error within 30 minutes of delivery. The weights were rounded to the nearest 50g.

### ***Statistical analysis***

Normality test was applied first by visually comparing the respective histograms to a normal bell shaped graphs and then statistically tested for normality using Shapiro-Wilk Test. Absolute value of the difference between the

sonographic estimated fetal weight by Hadlock 1, Hadlock 2, Hadlock 3, Hadlock 4, and Shepard formulas and the actual birth weight were calculated for each case and from this the mean weight difference and the percentage error were calculated. Mean percentage (relative) error was defined as: Estimated fetal weight (EFW) - actual birth weight (ABW)  $\times$  100/ABW, and absolute percentage error as (absolute value (EFW - ABW))  $\times$  100/ABW. Percentage errors were grouped as being within 10%, 20%, 30% or more than 30% of the birth weight. Percentage error within 10 % of the birth weight was considered accurate. The mean percentage error represented the sum of the positive (overestimation) and negative (underestimation) estimation from actual birth weight, and the mean absolute percentage error was the sum of the absolute deviation (regardless of their direction) reflecting the size of the overall predictive error in terms of actual birth weight. To compare sonographic fetal weight estimators and the actual birth weight, paired t-test was used. For significance in mean difference between sonographic weight estimators and the actual birth weight, a p-value of <0.05 was considered. Comparison was also made at different categories of actual birth weight i.e <2,500 g, 2,500-3999 g, and  $\geq$ 4,000 g and placenta location.

Altman and Bland (B&A) analysis, was used to study the mean difference and construct limits of agreement. The B&A plot analysis was used to evaluate a bias between the mean differences, and to estimate an agreement interval, within which 95% of the differences of the Hadlock1, Hadlock 2, Hadlock 3, Hadlock 4 and Shepard formulas compared to actual weight points.

## Results

A total of 365 parturients were recruited in the study, 3 fetuses had congenital anomalies and 6 of the fetuses had a BPD  $\geq$ 10 cm, and Shepard failed to calculate the fetal weight estimation and consequently was removed from this study, remaining 356 leading to a completion rate of 99.2%. The median age of the parturients was 24years (IQR 21-29). The majority of the parturients were multiparous (49%). The maternal body mass index (BMI) in majority of the parturients were within the normal range (57.3%). The mean actual birth weight was 3.3 $\pm$ 0.42 kg (Range 1.6-4.35 kg). The median gestational age was 38weeks 5days (Range 38-42 weeks). Majority (91%) of the newborns were in the normal birth weight (2,500-3999 g) (**Table 1**).

The maximum birth weight (4789 g) estimation was done by Shepard formula and the minimum birth weight (1634 g) estimated was by Hadlock 2. Hadlock 1 had the highest percentage (73%) of overestimation and Shepard had the highest percentage (52.8%) of underestimation of fetal birth weights (**Table 2**).

All the five formulas were able to estimate the actual birth weight with an accuracy of the difference being within 10%. The number of neonates with the difference between their actual birth weight and the formula lying within 10% accuracy for; Hadlock 1 was 238(66.9%), Hadlock 2 was 261 (73.3%), Hadlock 3 was 275(77.3%), Hadlock 4 was 279(78.4%) and Shepard was 248(69.7%). The mean difference between formulas and the actual birth weight was statistically significant for all the Hadlock formulas but for Shepard formula the difference wasn't statistically significant (p=0.200) (**Table 3**) (**Table 4**).

The mean percentage errors of the microsomic babies (<2500g) and normal birth weight babies (2500-3999g) showed a steady decrement from Hadlock 1 to Hadlock 2 to Hadlock 3 to Hadlock 4 and to Shepard. And the mean percentage errors for macrosomic babies ( $\geq$ 4000g) showed the reverse (**Table 5**) (**Table 8**). This implied, the Shepard formula followed by Hadlock 4 and Hadlock 3 are better estimators when the birth weight was in the

range of microsomic to normal birth weight. Whereas Hadlock 1 followed by Hadlock 2 are better estimators if the estimated birth weights are in the macrosomic range. However, this couldn't be conclusive because the different strata of birth weights were not fairly distributed (**Table 8**).

The mean difference between all formulas (except SHEPARD) and actual birth weight was not statistically significant if the neonate weighed more than or equal to 4000g. For neonates whose actual birth weight was less than 2500g and between 2500 to 3999g, the mean difference between the formulas and actual birth weight was statistically significant except for SHEPARD formula (**Table 8**).

In Bland and Altman plot, Hadlock 1, Hadlock 2, Hadlock 3 and Hadlock 4 were poor estimators of actual birth weight as shown in the plots. However, Shepard was a good estimator of actual birth weight (Figure 2-6).

## Discussion

Prenatal evaluation of fetal weight has a paramount importance in decision making in the management of ongoing pregnancies and the timing and mode of delivery. This study aimed at determining the most accurate fetal weight estimator for our population. We found that the mean actual birth weight was  $3.3 \pm 0.42$  kg, the most accurate estimator (formula) of fetal weight was Shepard followed by Hadlock 4.

The maternal body mass index distribution was more than half in normal and one third in overweight. One study showed that fetal weight gain had linear increment with minimally dependency on maternal obesity(18).

The parity had equal distribution between primiparous and multiparous, but very few with grand multiparous mothers. Increased parity was associated with underestimation of fetal weights when Combs(19) and Sabbagha(20) formulas were used but showed improvement with Hadlocks(21).

The mean actual birth weight was  $3.3 \pm 0.42$  kg. This was similar to the southeast Nigerian study ( $3.3 \pm 0.55$  kg) (22), southwest Nigerian study ( $3.25 \pm 0.66$  kg)(12), Jordanian study ( $3.13 \pm 0.5$  kg)(23), Israeli study ( $3.32 \pm 0.5$  kg) (21) but slightly lower than Australian study ( $3.6 \pm 0.3$  Kg)(11).

In our study we used the numbering of the Hadlocks which is most commonly used. However, other authors used different labelling (alphabets) of Hadlock formula as in the study done by Campbell Westerway(11).

All formulas differed significantly in terms of the mean systematic percent error ( $P < 0.05$ ). However, all the formulas estimated fetal birth weight with high accuracy within 10% of actual birth weight. Hadlock 4 being the highest (78.5%) and Hadlock 1 (66.9%) being the least which is comparable with the study done by Oshri et al., except the difference in percentages. Hadlock 1 was the least accurate (57.8%) and Hadlock 4 was the highest accurate (72.3%), Hadlock 2 (63.3%) and Hadlock 3 (68%) lied between those percentages(14). Shepard formula wasn't included in Oshri et al. study. Comparisons of accuracy with 10% of actual birth weight in different study is done (**Table 6**).

As much as all the formula showed high accuracy of estimation of fetal weight within 10% of actual birth weight, Shepard formula showed the best estimation of fetal weights with highest percentage of agreement with actual birth weights and smallest magnitude of mean difference (0.07) and the least percentage of error, followed by Hadlock 4 and Hadlock 3. The least percentage of agreement was demonstrated by Hadlock 1 (0.61).

The mean difference between all formulas (except SHEPARD) and actual birth weight was not statistically significant if the neonate weighed greater or equal to 4000 grams. For neonates whose actual birth weight was less than 2500grams and between 2500 to 3900 grams, the mean difference between the formulas and actually birth weight was statistically different except for SHEPARD. This is in consonance with the southeastern Nigeria study demonstrated with Hadlock 2. As the weight increased from normal birth weight to macrosomia, the accuracy of Hadlock 2 in estimation fetal weight increased significantly(12, 22). Similarly, in 282 women in tertiary hospital of Logos Nigeria(24), Hadlock 3 demonstrated incremental percentage of accuracy within 10% of ABW as the weight increased from normal birthweight to macrosomia. Same result was also obtained from southwestern Nigeria(12).

Different studies showed different values of MPEs and APEs of the different formulas. Our study in contrast to the comparative studies done showed varying results in the MPEs of all the formulas. In contrary to our findings, German study(25) demonstrated that the Shepard was having better estimation of fetal weight in the macrosomic babies than the Hadlock 1 and Hadlock 2, as demonstrated by the least mean percentage error (-1.8). The Israeli study on the other hand showed similar findings to this study that Hadlock 4 followed by Hadlock 3 showed better estimation of fetal weight though Shepard was not evaluated in the study. The comparisons of mean percentage errors for the different formulas from different studies are done (**Table 7**).

The mean percentage errors in different strata of birth weight compared with MPE done on Australia by Westerway showed that Shepard better estimated macrosomic babies when compared to this study. On the other hand, Hadlock 4 better estimated fetal weights in the normal birth weight category than the macrosomic babies. The MPEs of different strata (Category) of birth weights are compared with other studies.

### **Study limitation**

Our study isn't without limitations. A major limitation of this study is the lack of generalizability of the study findings since the study was conducted in one study site and due to none probability sampling method (consecutive sampling) used. However, this lack of generalizability could be minimal because of the referral nature of the Hospital where the study was conducted. Furthermore, Shepard formula can't estimate fetal weight if the BPD is  $\geq 10$ cm. This resulted in to lack of estimation of six fetuses and consequently exclusion from the study. This exclusion could have introduced selection bias however this was minimal since the number excluded was less than 10%. Information bias in this study was minimal because the weighing scale used to measure actual birth weight was calibrated.

### **Strength of the study**

However, the strength of our study lies in the fact that we compared five sonographic fetal weight estimation formulas to determine which algorithm may be more valid in the population. To the best of our knowledge, this is the first study to do so in Uganda. Moreover, most of the published studies in the literature heavily relied on retrospective design. Our study however is of a prospective design. It had a relatively bigger sample size compared with previously published prospective studies we could get from the literature.

## **Conclusion**

All five formulas showed good accuracy in determining fetal weight. However, Shepard formula was more accurate in estimating the small (microsomic) and normal birth weight categories while Hadlock 4 for babies with macrosomic birth weight category. Therefore, in Uganda, Shepard (BPD and AC) formula may be used for estimation of microsomic and normal birth weights and Haldlock 4 (BPD/HC/AC/FL) for macrosomic babies. However, future, large, multicenter studies to confirm our findings are welcome.

## **Abbreviations**

ABW: Actual birth weight

APE: Absolute percentage error

AC: Abdominal Circumference

A&B: Altman and Bland

BMI: Body mass index

BPD: Biparietal Diameter

EFW: Estimated fetal weight

FL: Femur Length

HC: Head Circumference

IQR: interquartile range

MPE: Mean percentage error

## **Declarations**

### **Ethics approval and consent to participate**

Written informed consent was obtained from all participants to participate in the study. Ethical approval was obtained from Makerere University School of Medicine Research and Ethics committee (reference number #REC REF 2018-148) and administrative clearance was sought from Mulago National Referral Hospital.

### **Consent for publication**

Not applicable

### **Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

### **Competing interests**

The authors declare that they have no competing interests.

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## Authors' contribution

**SG, OR, OF, SN, KS** participated in the conception, study design, data analysis and manuscript preparation. SG participated in data collection. All authors read and approved final manuscript.

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## Tables

**Table 1. Socio demographic characteristics of parturients in sonographic estimation of actual birth weight at Mulago national referral hospital**

| <b>Median (IQR)</b> | <b>Variable</b>                   |
|---------------------|-----------------------------------|
| 24(21-29)           | <b>Maternal age</b>               |
| 38W5d (38-42)       | <b>Gestational age</b>            |
| <b>N (%)</b>        | <b>Gravidity</b>                  |
| 143(40.2)           | Primi                             |
| 176(49.4)           | Multipara                         |
| 37(10.4)            | Grand multipara                   |
|                     | <b>Maternal BMI before labor</b>  |
| 2(0.6)              | Under weight                      |
| 204(57.3)           | Normal weight                     |
| 123(34.6)           | Over weight                       |
| 27(7.6)             | Obese                             |
|                     | <b>Placentation</b>               |
| 147 (41.3)          | Anterior                          |
| 74 (20.8)           | Posterior                         |
| 134 (37.6)          | Fundal                            |
|                     | <b>Categories of birth weight</b> |
| 21 (5.9)            | Microsomia                        |
| 324 (91.0)          | Normal birth weight               |
| 11 (3.1)            | Macrosomia                        |

**Table 2 Characteristics of estimators of birth weights of 356 neonates in Mulago national referral hospital**

| <b>**Mean ± SD</b> | <b>Over estimation<br/>(n/%)</b> | <b>Under estim<br/>(n/%)</b> | <b>max</b>        | <b>min</b>           | <b>Formula</b> |
|--------------------|----------------------------------|------------------------------|-------------------|----------------------|----------------|
| 3358.9±421.2       |                                  |                              | 4697              | 1642                 | Hadlock 1      |
| 3290.0±417.9       |                                  |                              | 4650              | 1634                 | Hadlock 2      |
| 3243.2±405.4       |                                  |                              | 4644              | 1714                 | Hadlock 3      |
| 3242.3±404.6       |                                  |                              | 4531              | 1675                 | Hadlock4       |
| 3161.4±464.6       |                                  |                              | 4789              | 1750                 | Shepard        |
| 175.3 ± 285.4      | 260(73.0)                        | 96(27.0)                     | 944gm (over est)  | -861gm (under est)   | Hadlock1 diff  |
| 106.4±276.5        | 234(65.7)                        | 122(34.3)                    | 960gm (over est)  | -915gm (under est)   | Hadlock2 diff  |
| 59.6±281.0         | 203(57.0)                        | 153(43.0)                    | 977gm (over est)  | -910gm (under est)   | Hadlock3 diff  |
| 58±274.2           | 204(57.3)                        | 142(42.7)                    | 976gm (over est)  | -922 gm (under est)  | Hadlock4 diff  |
| -22.3±327.0        | 168(47.2)                        | 188(52.8)                    | 1028gm (over est) | -1078 gm (under est) | Shepard diff   |

*\*\*mean other than median was chosen as summary statistics because of the normality of sonographic estimators (formulas)*

**Table 3. Accuracy of sonographic estimators in estimating actual birth weight of 356 neonates at Mulago national referral Hospital**

| Formula/percentage | (n / %)   | MPE# (mean ± SD) | APE (mean ± SD) |
|--------------------|-----------|------------------|-----------------|
| <b>HADLOCK 1</b>   |           | 6.0±9.4          | 8.6±7.0         |
| within 10%         | 238(66.9) |                  |                 |
| within 10-20 %     | 90(25.3)  |                  |                 |
| within 20-30%      | 90(25.3)  |                  |                 |
| ≥ 30%              | 3(0.8)    |                  |                 |
| <b>HADLOCK 2</b>   |           | 3.8±8.9          | 7.4±6.2         |
| within 10%         | 261(73.3) |                  |                 |
| within 10-20 %     | 78(21.9)  |                  |                 |
| within 20-30%      | 14(3.9)   |                  |                 |
| ≥ 30%              | 3(0.8)    |                  |                 |
| <b>HADLOCK 3</b>   |           | 2.3±9.1          | 7.2±5.9         |
| within 10%         | 275(77.3) |                  |                 |
| within 10-20 %     | 63(17.7)  |                  |                 |
| within 20-30%      | 17(4.8)   |                  |                 |
| ≥ 30%              | 1(0.3)    |                  |                 |
| <b>HADLOCK 4</b>   |           | 2.3±8.9          | 7.0±5.8         |
| within 10%         | 279(78.4) |                  |                 |
| within 10-20 %     | 63(17.7)  |                  |                 |
| within 20-30%      | 13(3.7)   |                  |                 |
| ≥ 30%              | 1(0.3)    |                  |                 |
| <b>SHEPARD</b>     |           | -0.4±10.3        | 8.1±6.4         |
| within 10%         | 248(69.7) |                  |                 |
| within 10-20 %     | 88(24.7)  |                  |                 |
| within 20-30%      | 16(4.5)   |                  |                 |
| ≥ 30%              | 4(1.1)    |                  |                 |

# MPE = predicted weight-actual weight/actual weight x 100

**Table 4. Comparison of sonographic estimators with actual birth weight of 356 neonates in Mulago national referral hospital**

| effect size/magnitude of mean diff | p-value      | 95%CI           | t    | SD    | mean diff | Formula   |
|------------------------------------|--------------|-----------------|------|-------|-----------|-----------|
| 0.61                               | <0.001       | (145.6-205.6)   | 11.6 | 285.4 | 175.3     | HADLOCK1* |
| 0.38                               | <0.001       | (77.6-135.2)    | 7.3  | 276.5 | 106.4     | HADLOCK2* |
| 0.21                               | 0.0001       | (30.4-88.9)     | 4.0  | 281.0 | 59.6      | HADLOCK3* |
| 0.21                               | <0.001       | (30.1-87.3)     | 4.0  | 274.2 | 58.7      | HADLOCK4* |
| 0.07                               | <b>0.200</b> | (-11.8 to 56.3) | 1.3  | 327.0 | 22.3      | SHEPARD*  |

\*paired t-test was used because the sonographic estimators (formulas) and actual birth weight were normally distributed, variance assumption was met and before and after weight measurements were taken

**Table 5. Comparison of the mean percentage errors of the different formulas at different strata of birth weights**

| MPE#,<br>[ABW (≥4000g), n=11] | MPE#,<br>[ABW (2500-3999g), n=324] | MPE#,<br>ABW [ <2500g, n=21] | Estimator |
|-------------------------------|------------------------------------|------------------------------|-----------|
| -1.2±6.4                      | 5.9±9.1                            | 11.4 ±11.8                   | HADLOCK 1 |
| -2.9±5.0                      | 3.8±8.8                            | 7.3±10.5                     | HADLOCK 2 |
| -4.3±7.5                      | 2.2±8.8                            | 7.8±11.5                     | HADLOCK3  |
| -4.3±6.0                      | 2.2±8.6                            | 6.7±10.7                     | HADLOCK4  |
| -5.0±7.3                      | -0.3±10.4                          | -0.2±10.6                    | SHEPARD   |

# MPE = predicted weight-actual weight/actual weight x 100

**Table 6. Comparison of the fetal weight estimation formula taken from different studies measuring estimates within ABW ±10%**

| Fetal parameters | Formula      | Year | Senai et al. 2019 (%) | Israel study 2012 (%) | Jordanian study 2012 (%) | German study, 2014 (%) | Southwest Nigeria 2007 (%) | Southeast Nigeria study 2014 (%) |
|------------------|--------------|------|-----------------------|-----------------------|--------------------------|------------------------|----------------------------|----------------------------------|
| BPD/AC           | Shepard      | 1982 | 69.7                  |                       |                          | 65.02                  |                            |                                  |
| BPD/HC/AC/FL     | Hadlock 4(C) | 1984 | 78.4                  | 72.3                  |                          |                        |                            |                                  |
| HC/AC/FL         | Hadlock 3(B) | 1983 | 77.3                  | 65.7                  | 69.9                     |                        |                            |                                  |
| BPD/AC/FL        | Hadlock 2(D) | 1985 | 73.3                  | 60.5                  |                          | 66.43                  | 68                         | 67.5                             |
| AC/FL            | Hadlock 1(A) | 1982 | 66.9                  | 57.8                  |                          | 62.21                  |                            |                                  |

**Table 7. Comparison of Mean percentage errors (MPE) of all the formulas with MPE taken from other studies**

| Formula/Model | Senai et al. 2019 MPE | Israel study 2012 MPE | Jordanian study 2012 MPE | German study 2014 MPE | Southwest Nigeria 2007 MPE | Australian study 2012 MPE | Southeast Nigeria MPE |
|---------------|-----------------------|-----------------------|--------------------------|-----------------------|----------------------------|---------------------------|-----------------------|
| Shepard       | -0.4±10.3             |                       |                          | -1.88                 |                            | -1.4±9.4                  |                       |
| Hadlock 4     | 2.3±8.9               | 3.9±16.7              |                          | (Merz*)<br>-3.97      |                            | 2.5±8.1                   |                       |
| Hadlock 3     | 2.3±9.1               | 5.7±16.5              | 6.2±5.3                  | (Warsof+)<br>-6.44    |                            | -1.9±7.8                  |                       |
| Hadlock 2     | 3.8±8.9               | 7.0±16.7              |                          | -5.40                 | -1.4±9.88                  | -2.5±8.4                  | 5.1±12.51             |
| Hadlock 1     | 6.0±9.4               | 7.4±17.2              |                          | -6.94                 |                            | -2.1±8.0                  |                       |

\* Merz is one of the models used in the German study. The result is for Merz, not for Hadlock 4. Hadlock 4 wasn't evaluate in the study

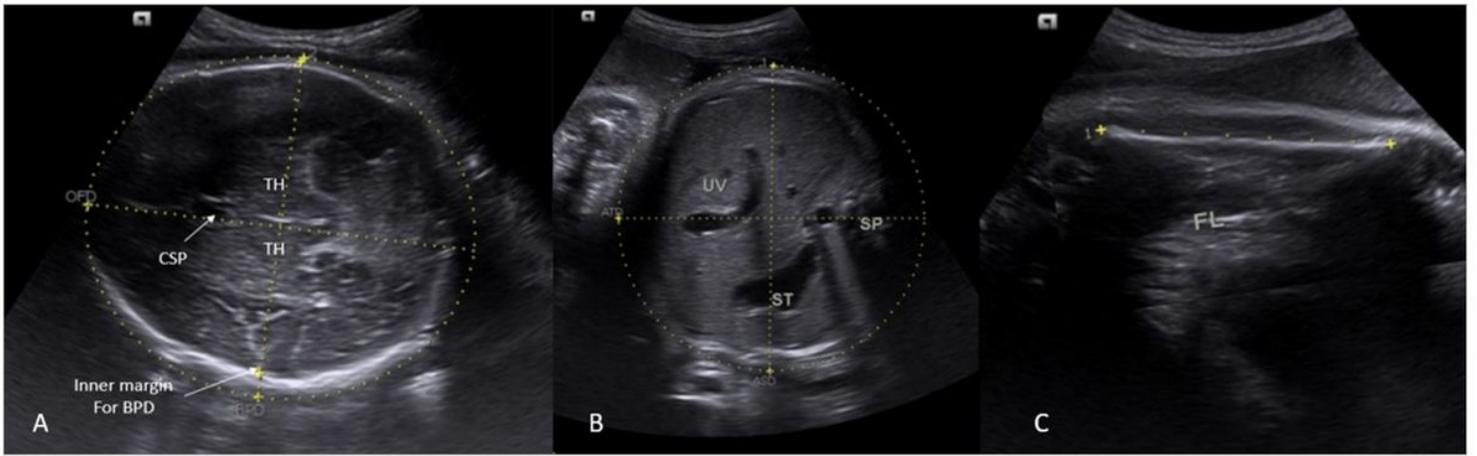
+ Warsof is one of the models used in the German study. The result is hence for Warsof, not for Hadlock 3.

**Table 8. Comparison of Mean percentage errors (MPEs) of all the formulas at different strata of birth weight with MPE taken from other studies**

| Formula/ Strata of birth weights | Senai et al. study 2019 MPE | Australian study* 2012 MPE | Southwest Nigeria study 2007 MPE |
|----------------------------------|-----------------------------|----------------------------|----------------------------------|
| Shepard                          |                             |                            |                                  |
| <2500g                           | -0.2±10.6                   |                            |                                  |
| 2500-3999g                       | -0.3±10.4                   | -1.5±9.1                   |                                  |
| ≥4000g                           | -5.0±7.3                    | -1.1±10.1                  |                                  |
| Hadlock 4                        |                             |                            |                                  |
| <2500g                           | 6.7±10.7                    |                            |                                  |
| 2500-3999g                       | 2.2±8.6                     | -0.2±7.5                   |                                  |
| ≥4000g                           | -4.3±6.0                    | 3.7±9.7                    |                                  |
| Hadlock 3                        |                             |                            |                                  |
| <2500g                           | 7.8±11.5                    |                            |                                  |
| 2500-3999g                       | 2.2±8.8                     | -1.7±7.2                   |                                  |
| ≥4000g                           | -4.3±7.5                    | -2.6±9.6                   |                                  |
| Hadlock 2                        |                             |                            |                                  |
| <2500g                           | 7.3±10.5                    |                            | 8.9±3.1                          |
| 2500-3999g                       | 3.8±8.8                     | -1±7.8                     | -2.2±10.1                        |
| ≥4000g                           | -2.9±5.0                    | -4.3±10.2                  | -4.3±6.9                         |
| Hadlock 1                        |                             |                            |                                  |
| <2500g                           | 11.4 ±11.8                  |                            |                                  |
| 2500-3999g                       | 5.9±9.1                     | -1.3±7.4                   |                                  |
| ≥4000g                           | -1.2±6.4                    | -2.9±9.8                   |                                  |

\* The Australia study had 102 babies in the normal birth weight category and 19 in the macrosomic category.

## Figures



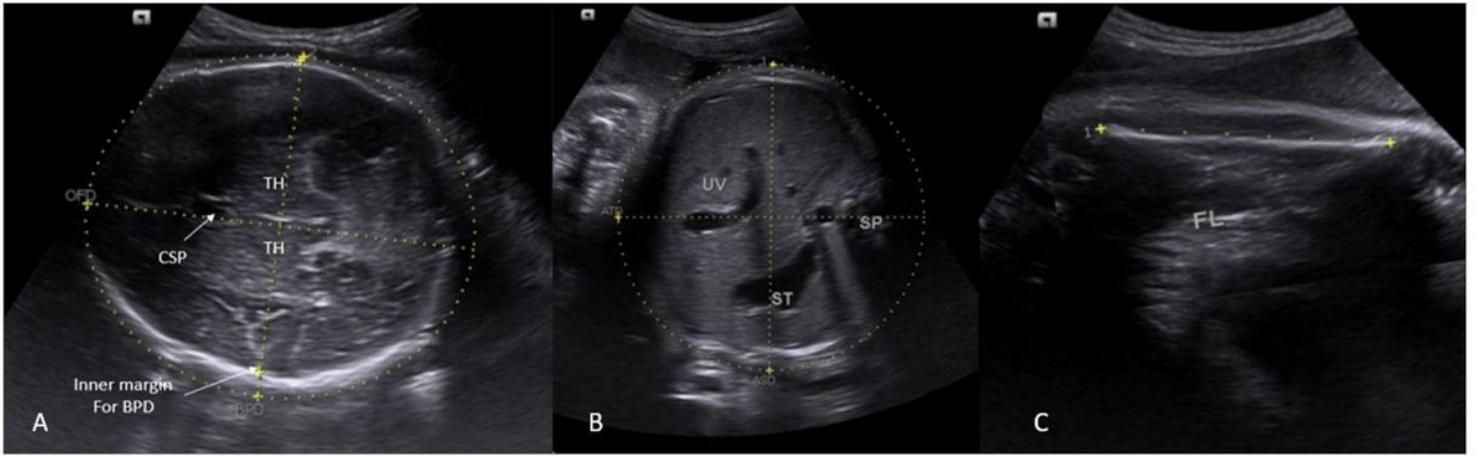
**Figure 1**

Sonographic parameters used to estimate fetal weight. A) demonstrating the fetal head at the level of bithalamic (TH-thalamus), cavum septum pellucidum (CSP) and third ventricle. At this level was the BPD and HC taken B) Abdominal circumference taken at the level of umbilical vein (UV), stomach (ST), spine (SP) and the posterior rib. C) demonstrating femoral length measurement



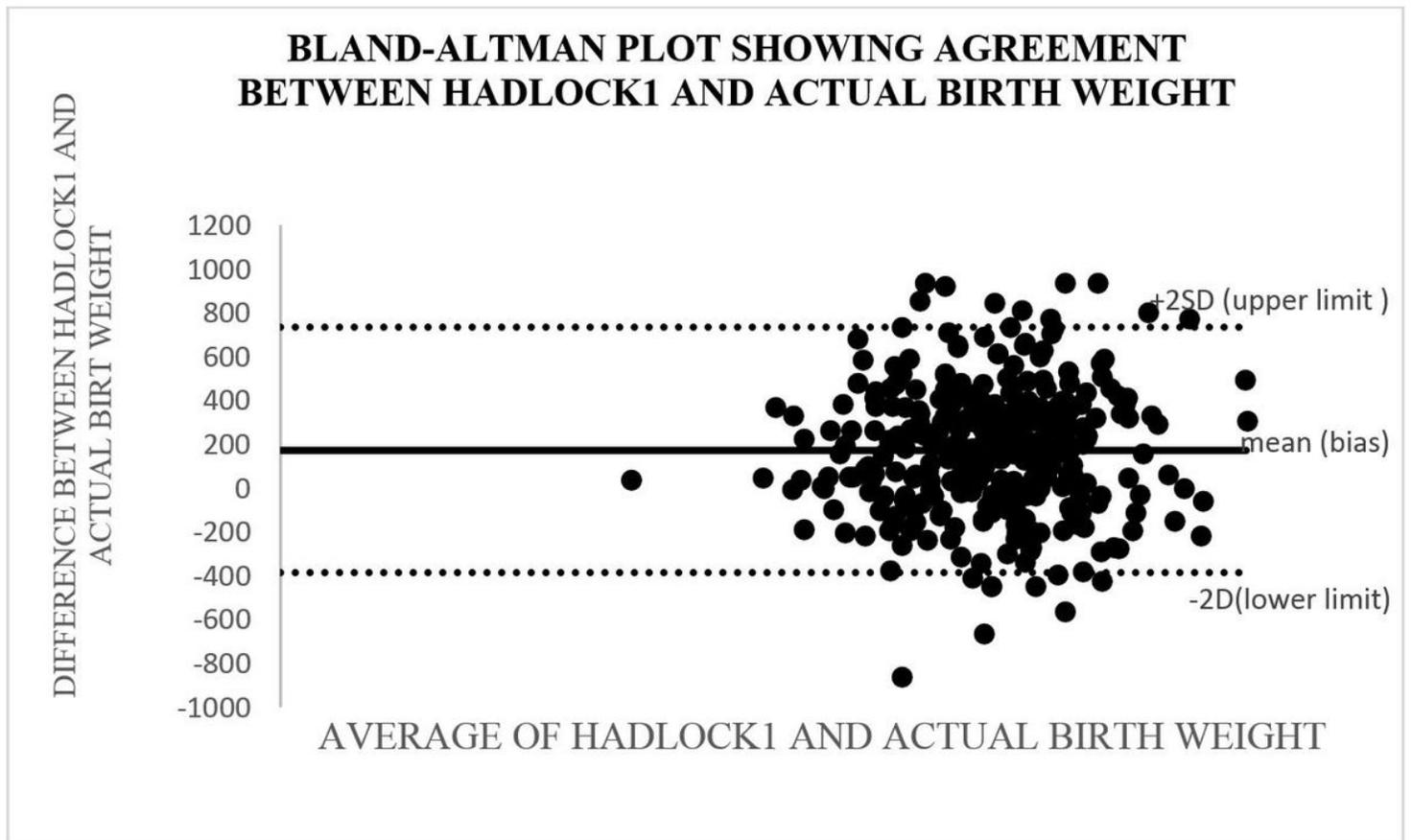
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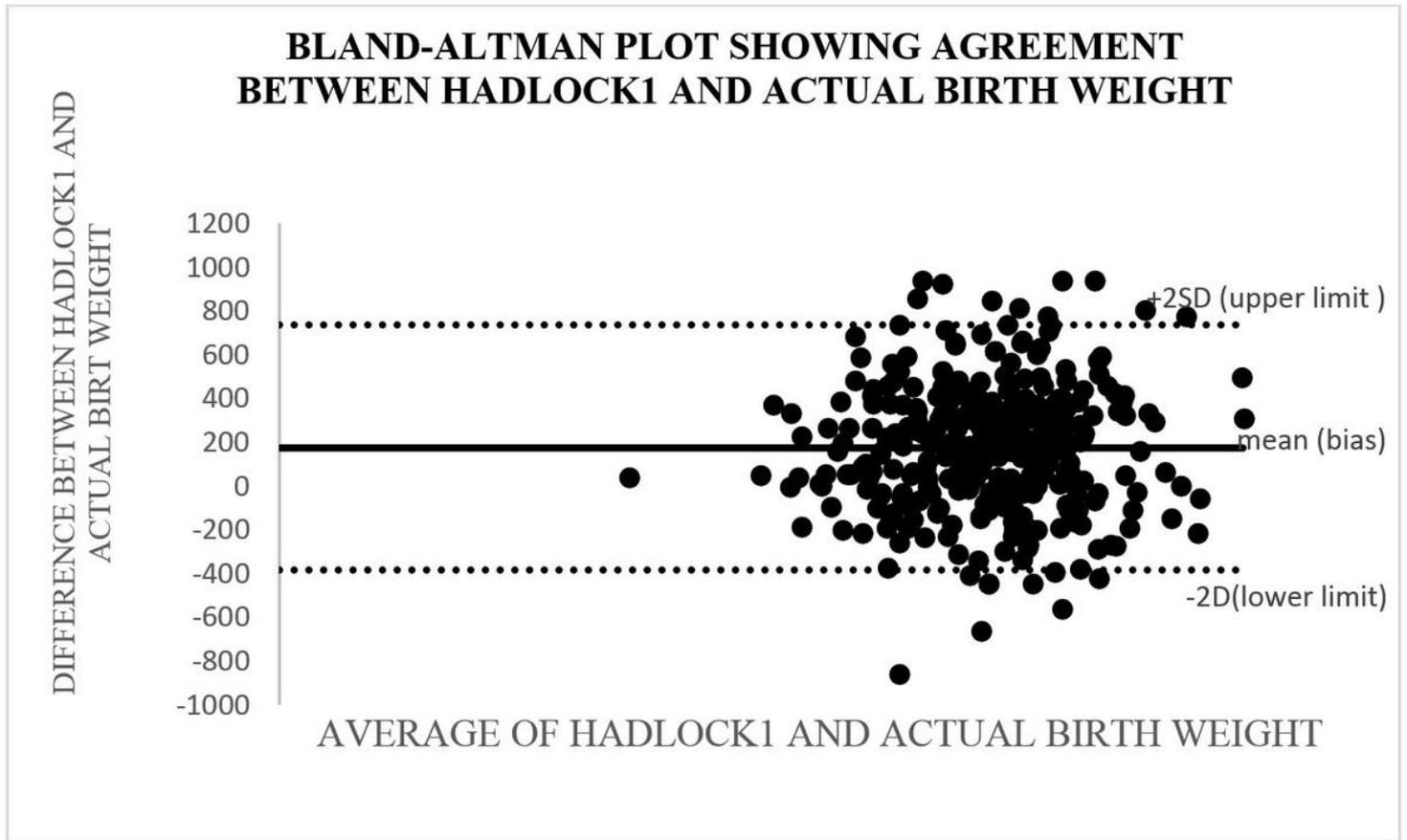
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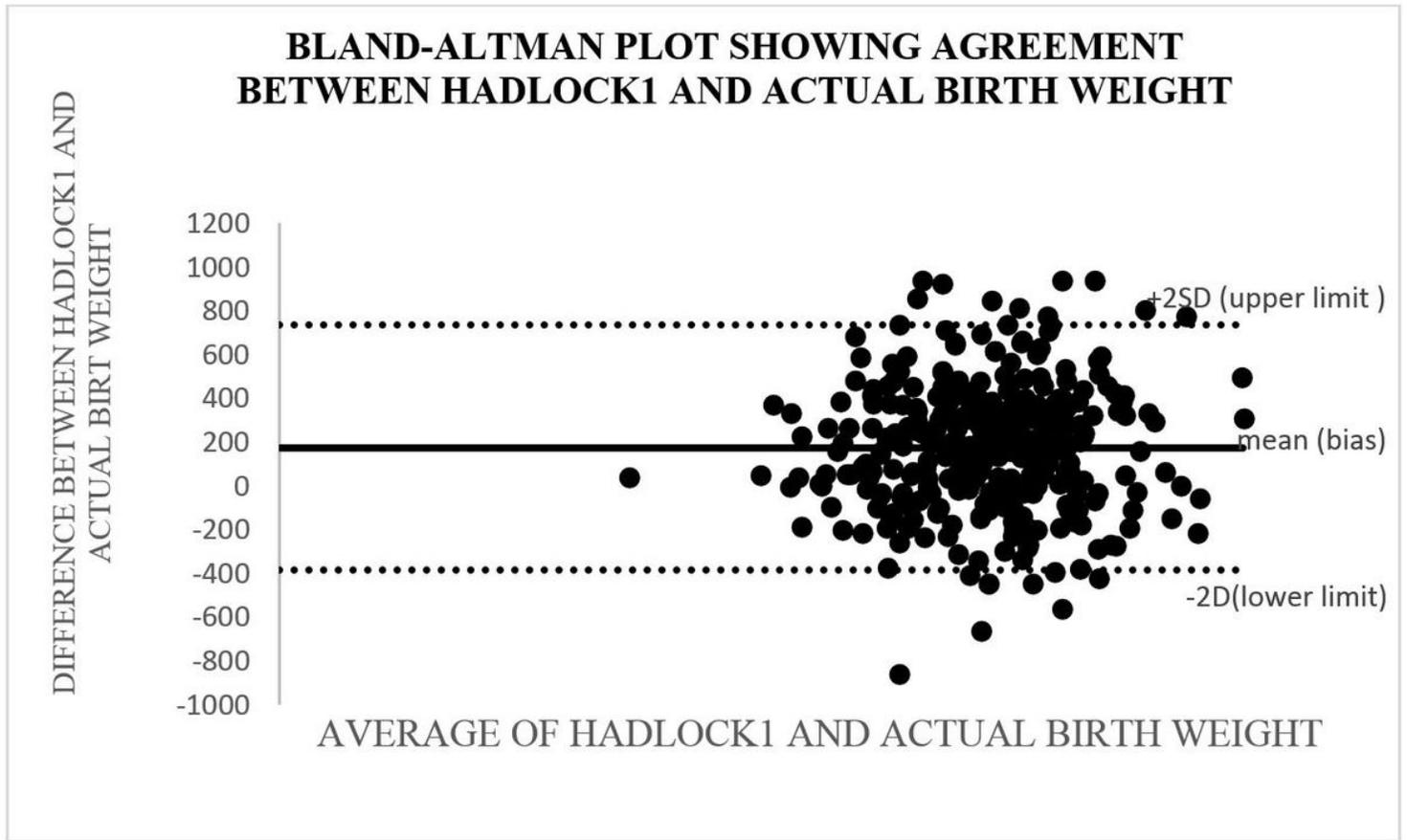
**Figure 2**

Plot showing agreements between HADLOCK1 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



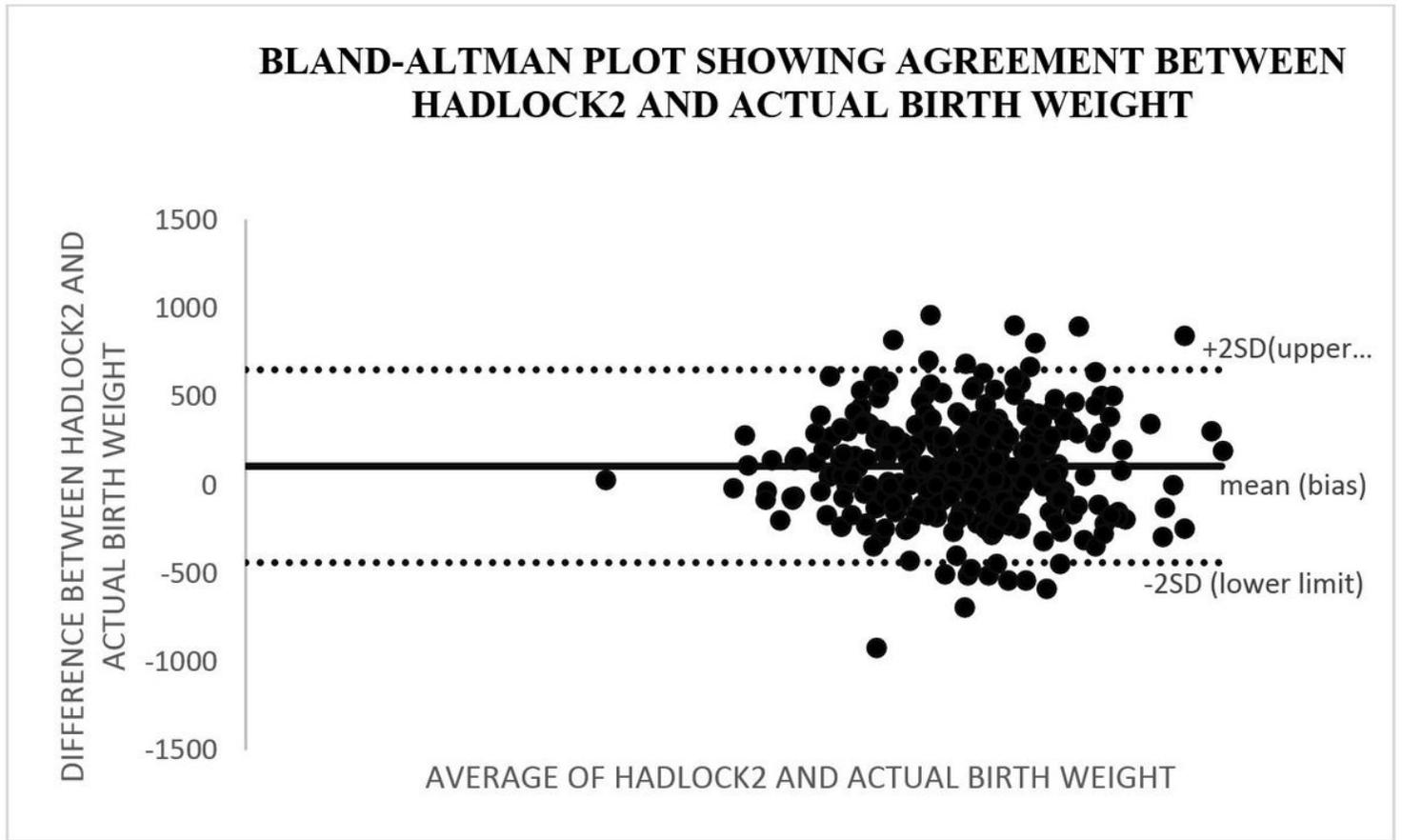
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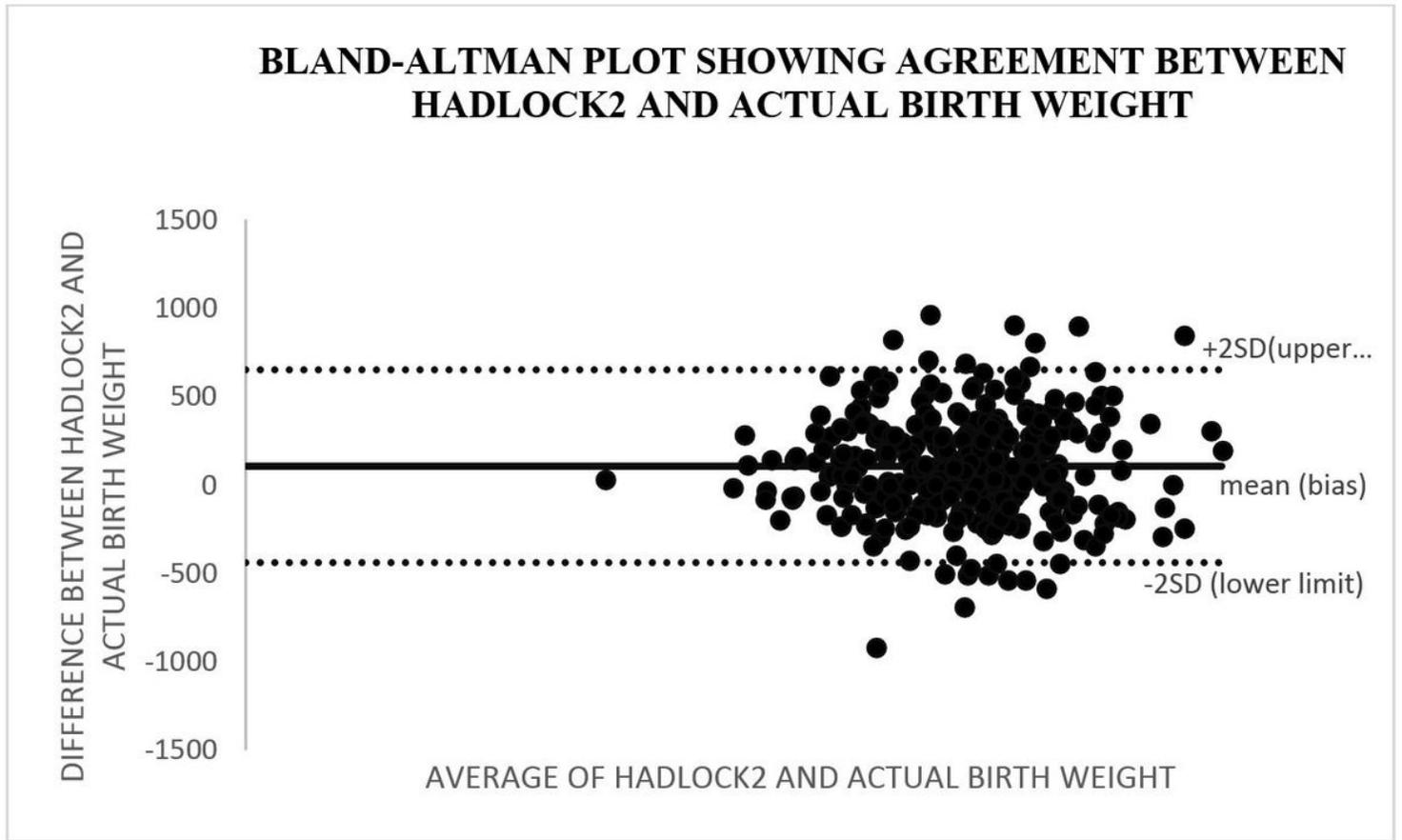
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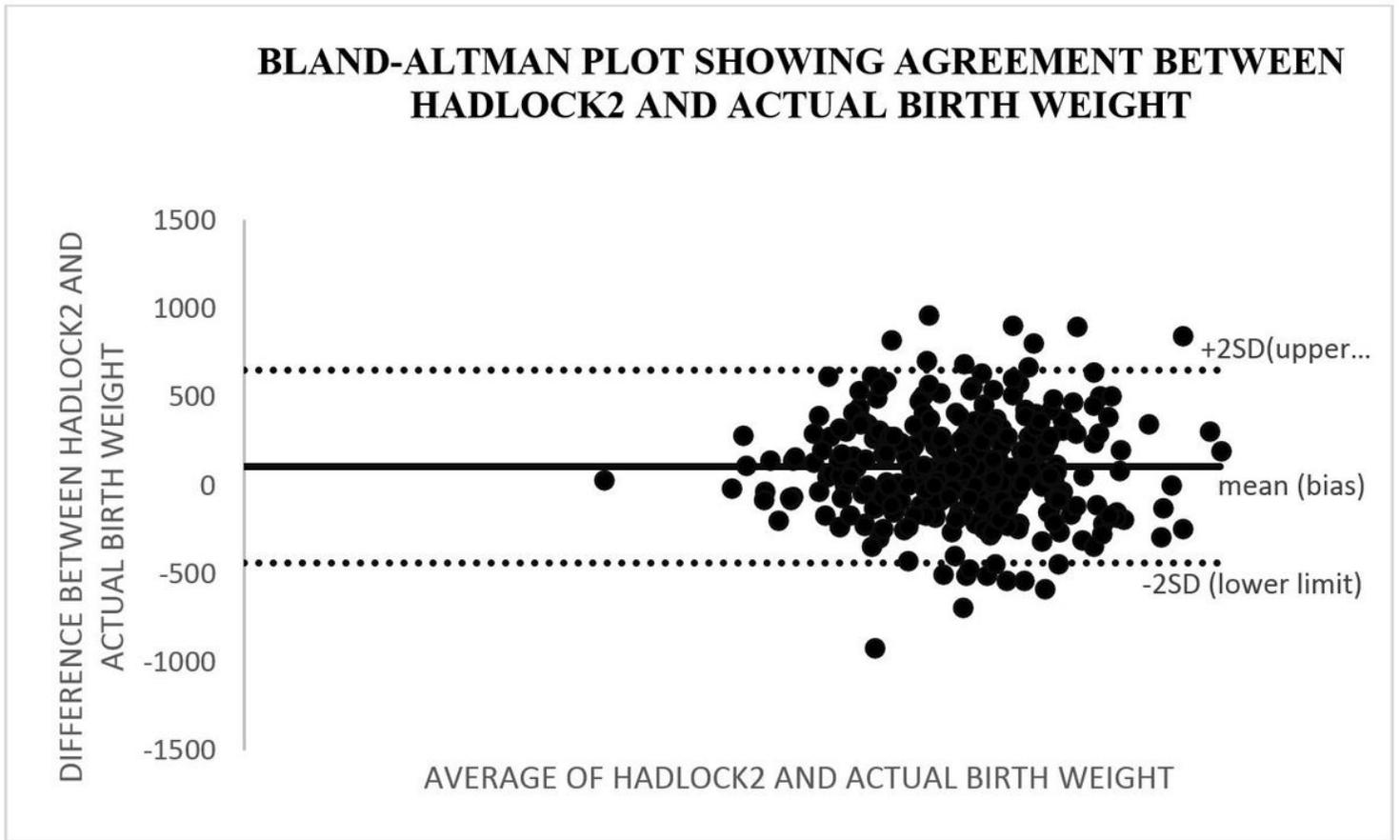
**Figure 3**

Plot showing agreements between HADLOCK2 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



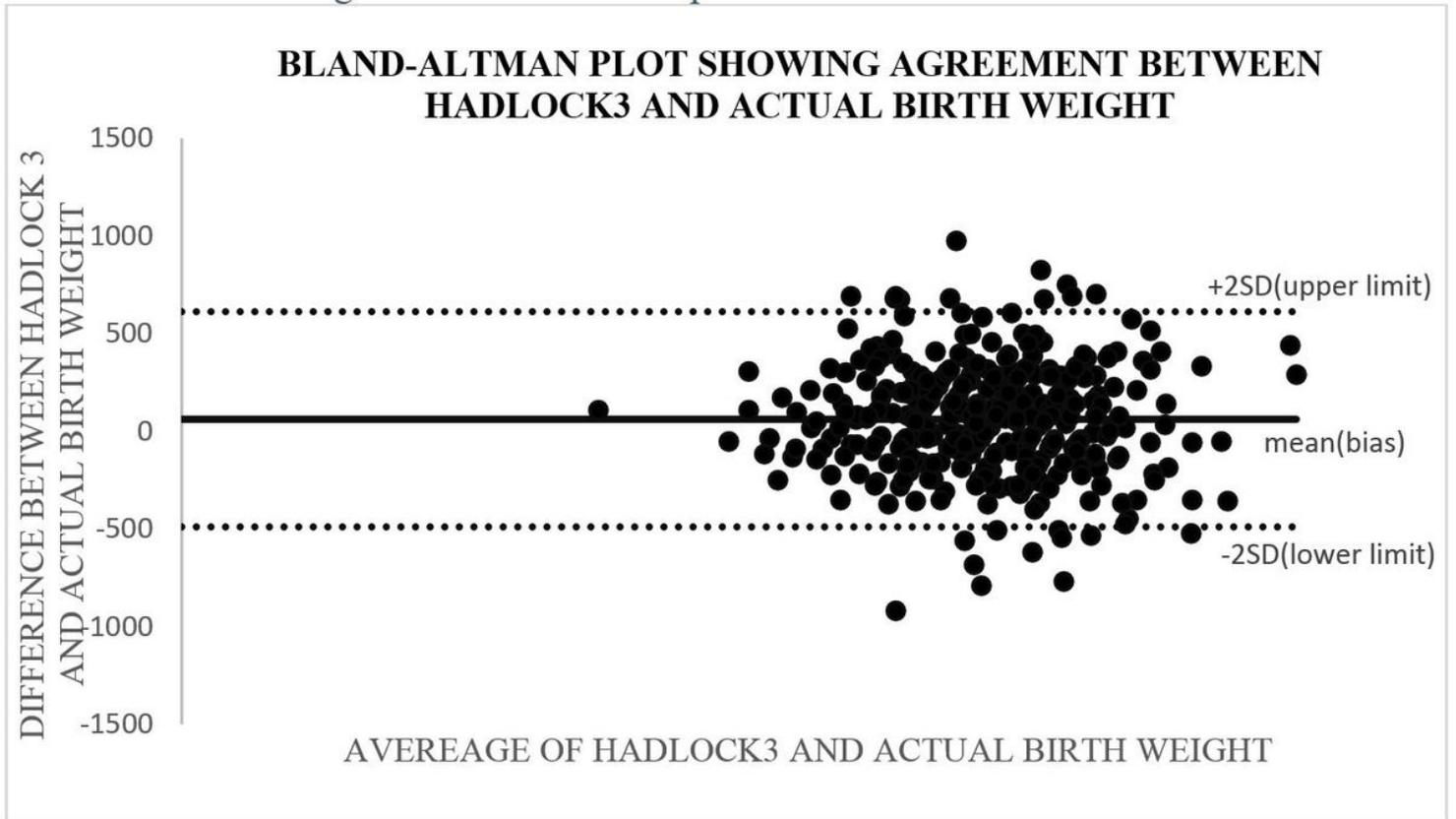
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Plot showing agreements between HADLOCK2 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



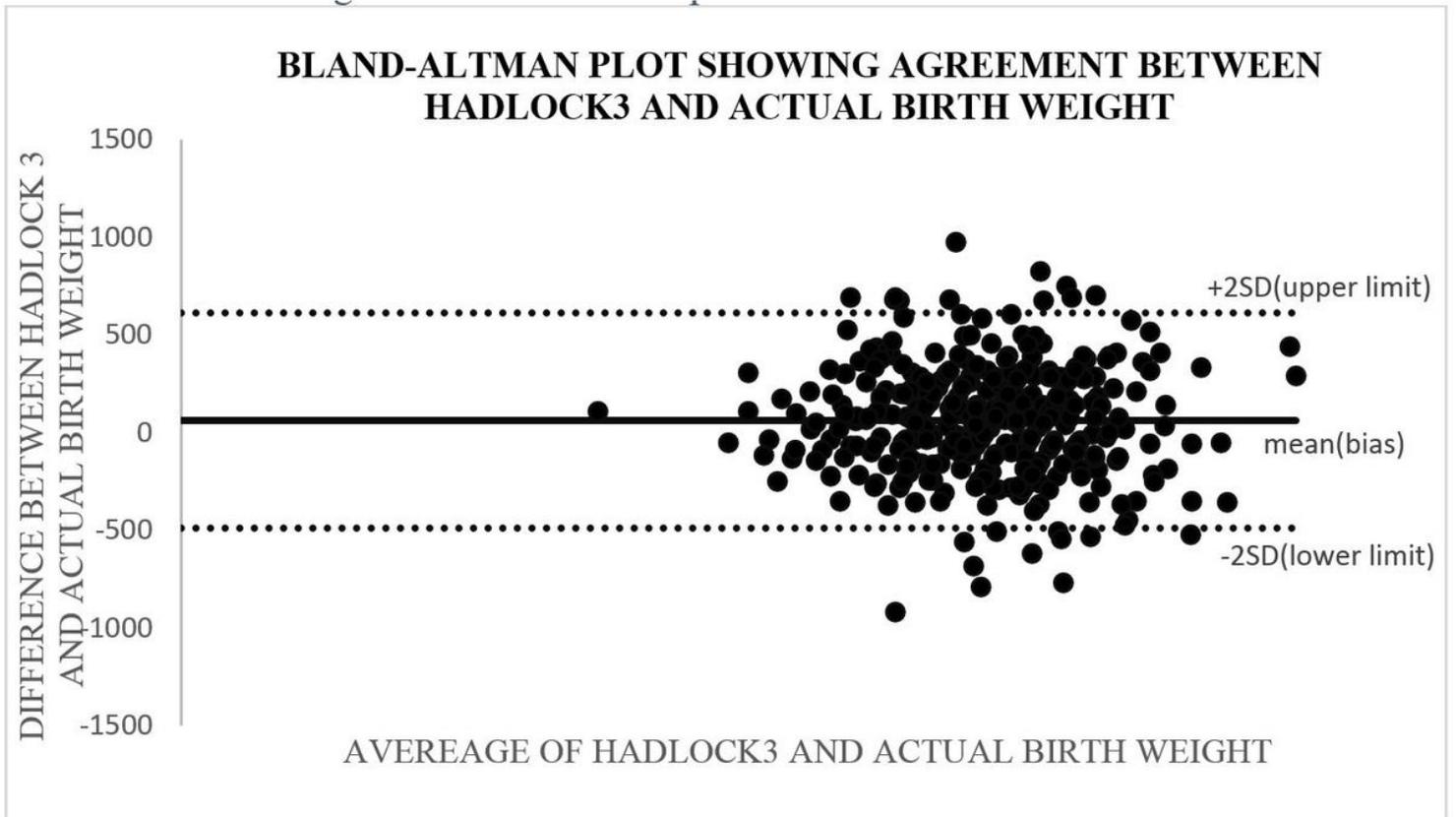
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Plot showing agreements between HADLOCK2 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



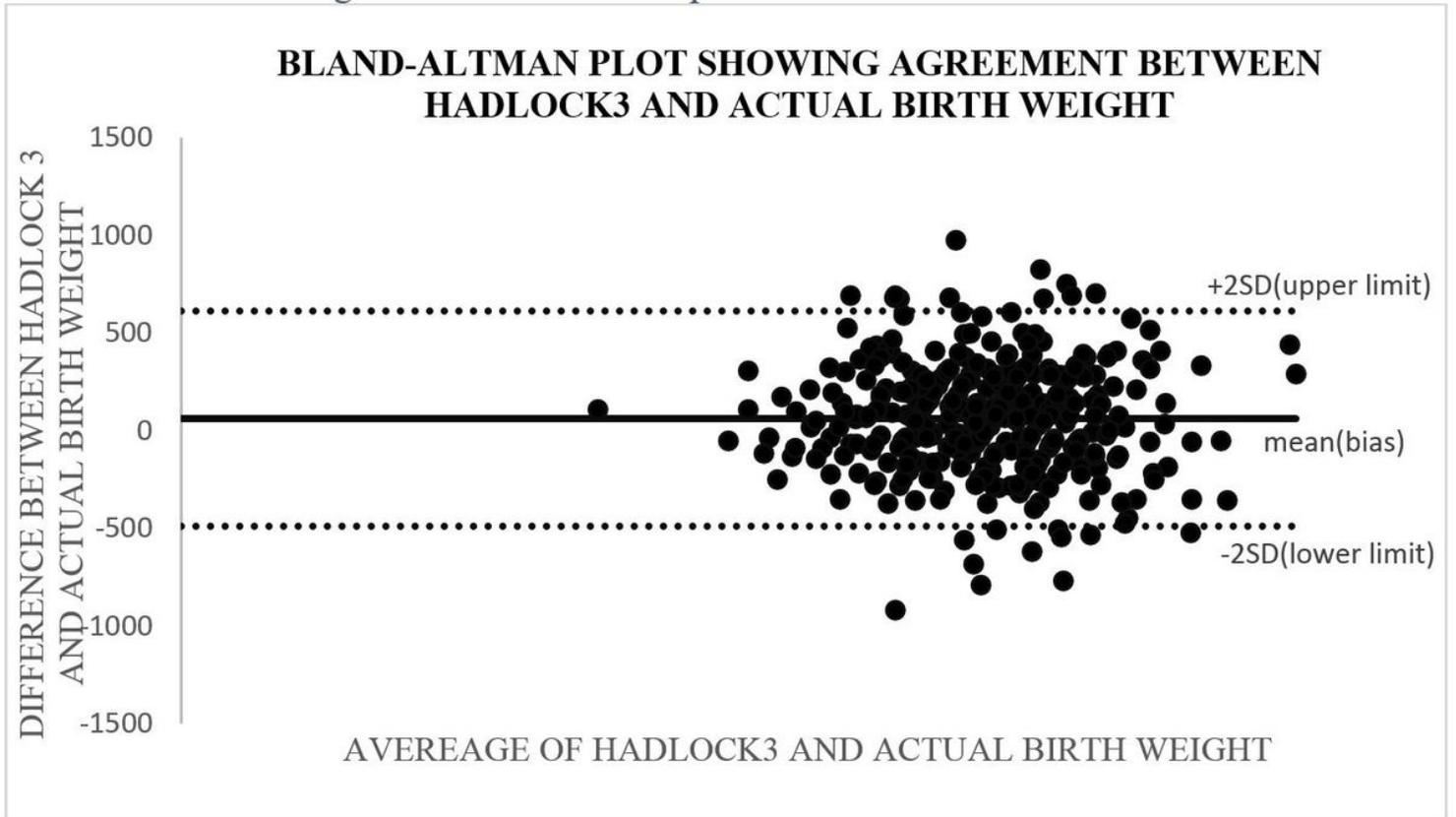
**Figure 4**

Plot showing agreements between HADLOCK3 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



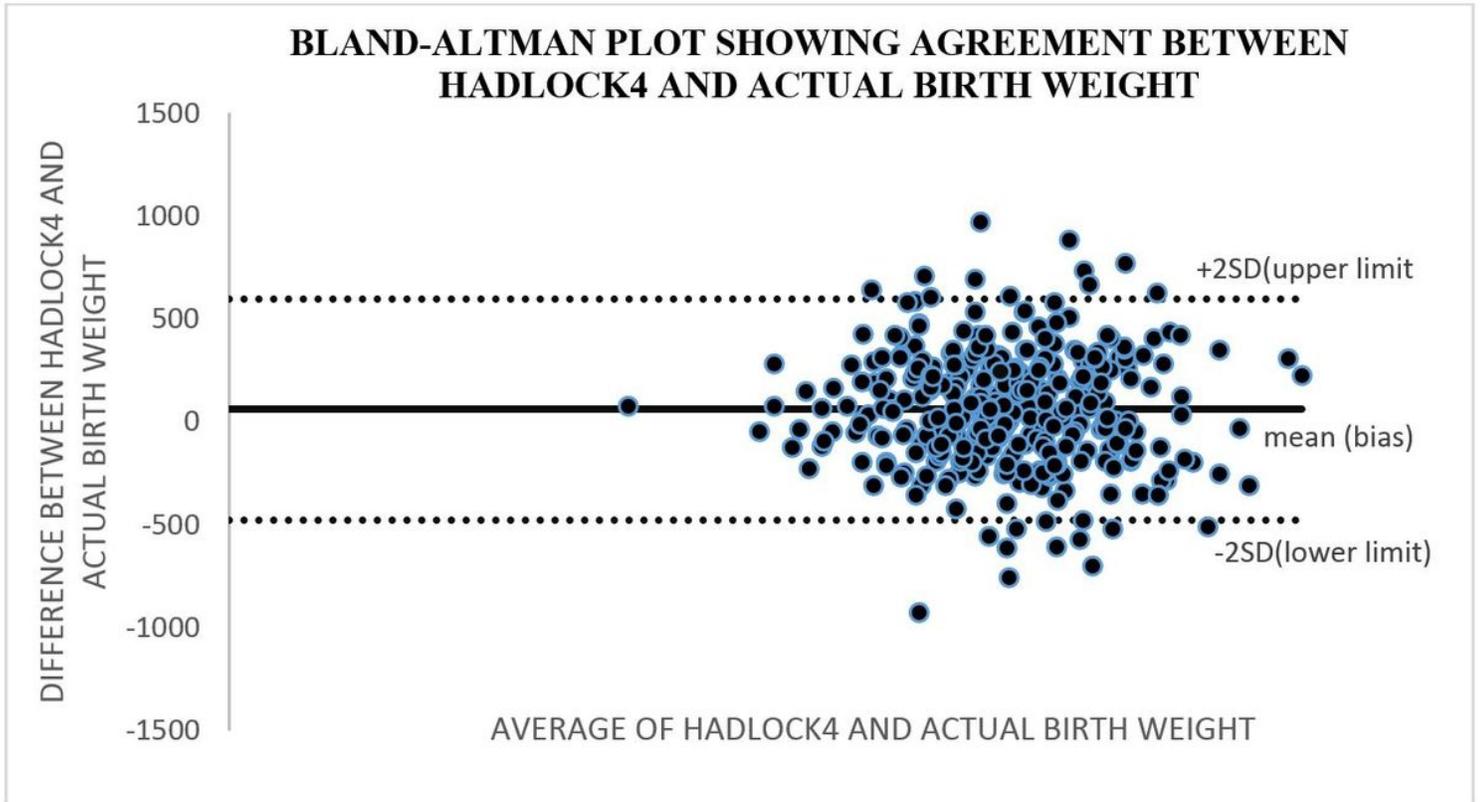
**Figure 4**

Plot showing agreements between HADLOCK3 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



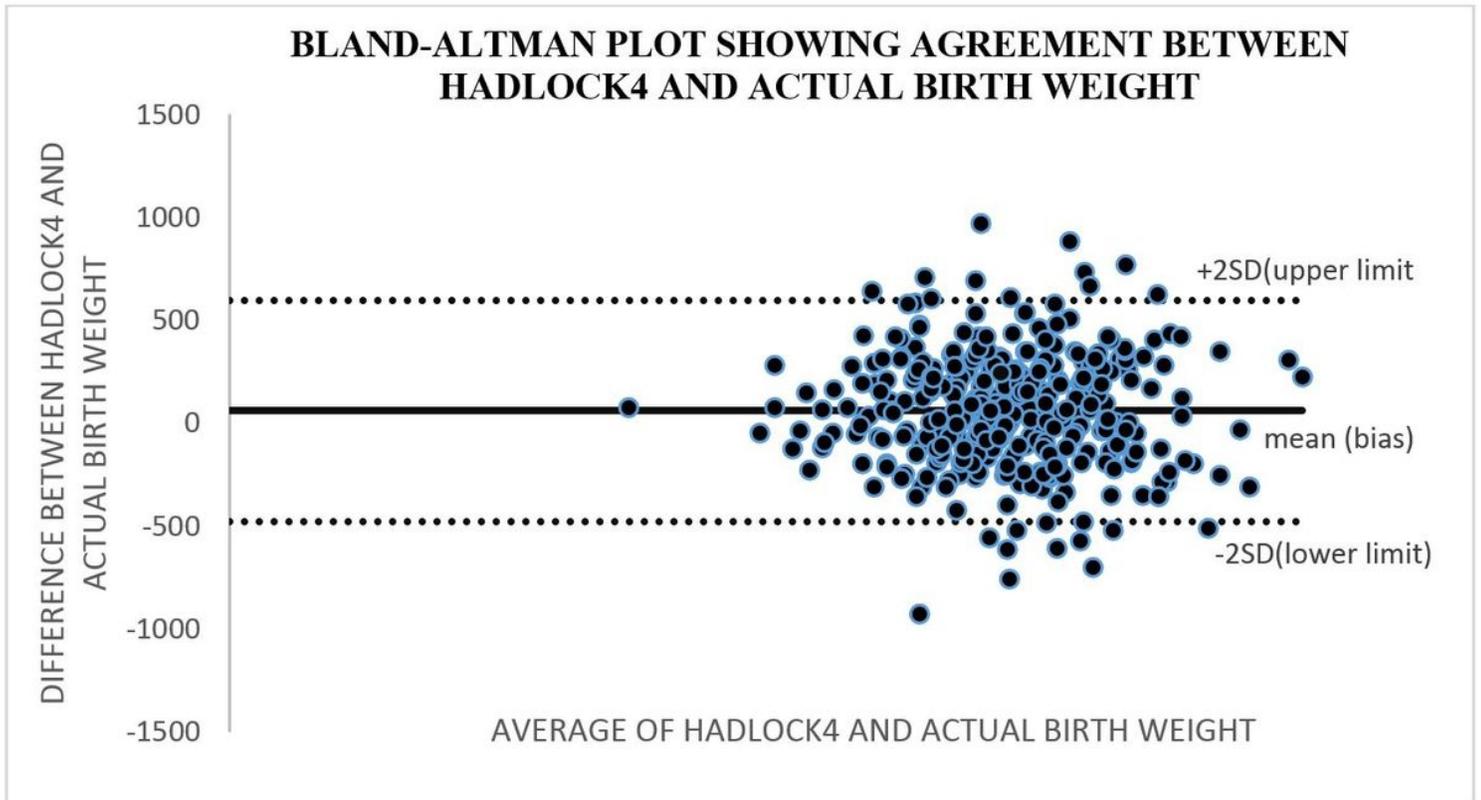
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Plot showing agreements between HADLOCK3 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



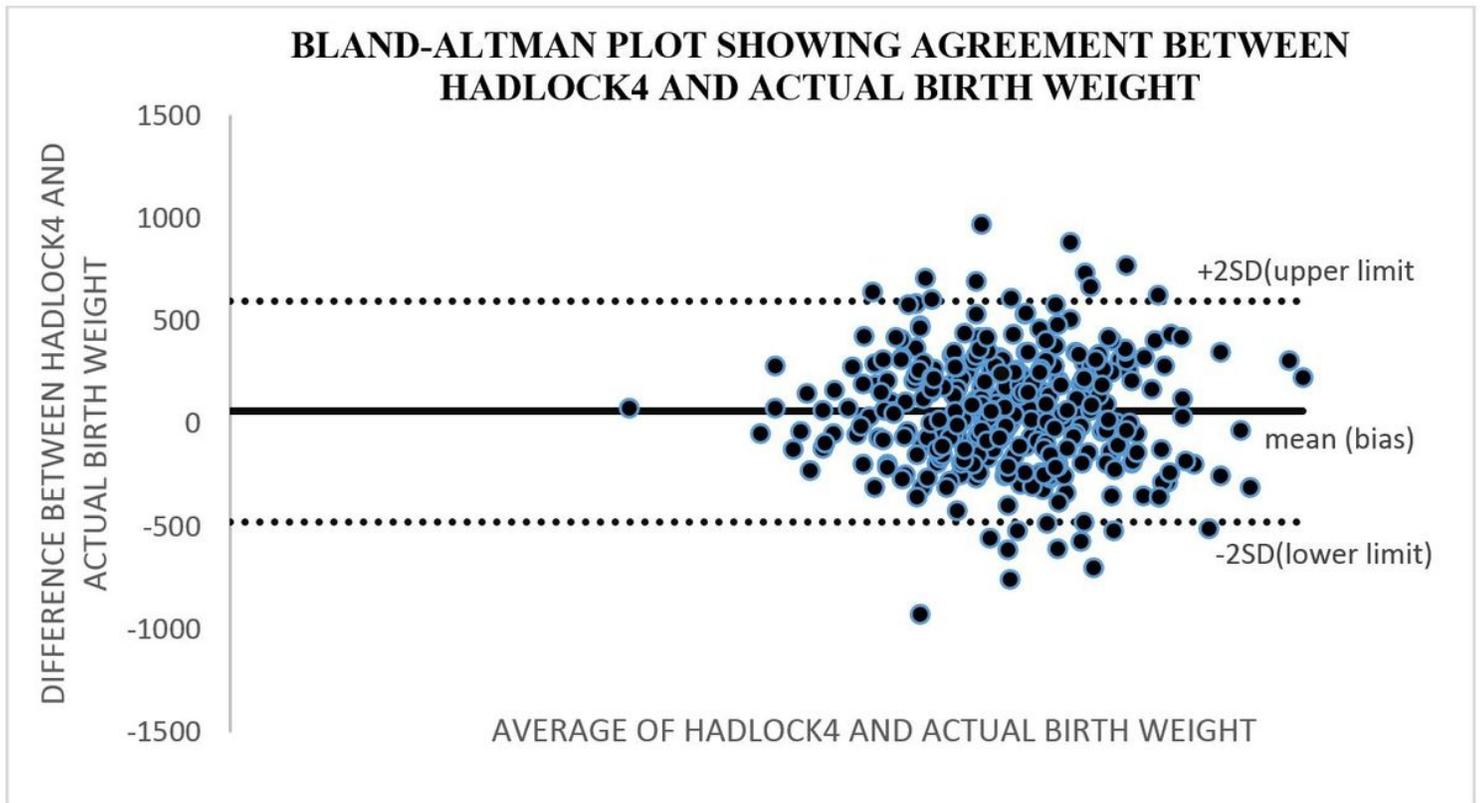
**Figure 5**

Plot showing agreements between HADLOCK4 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



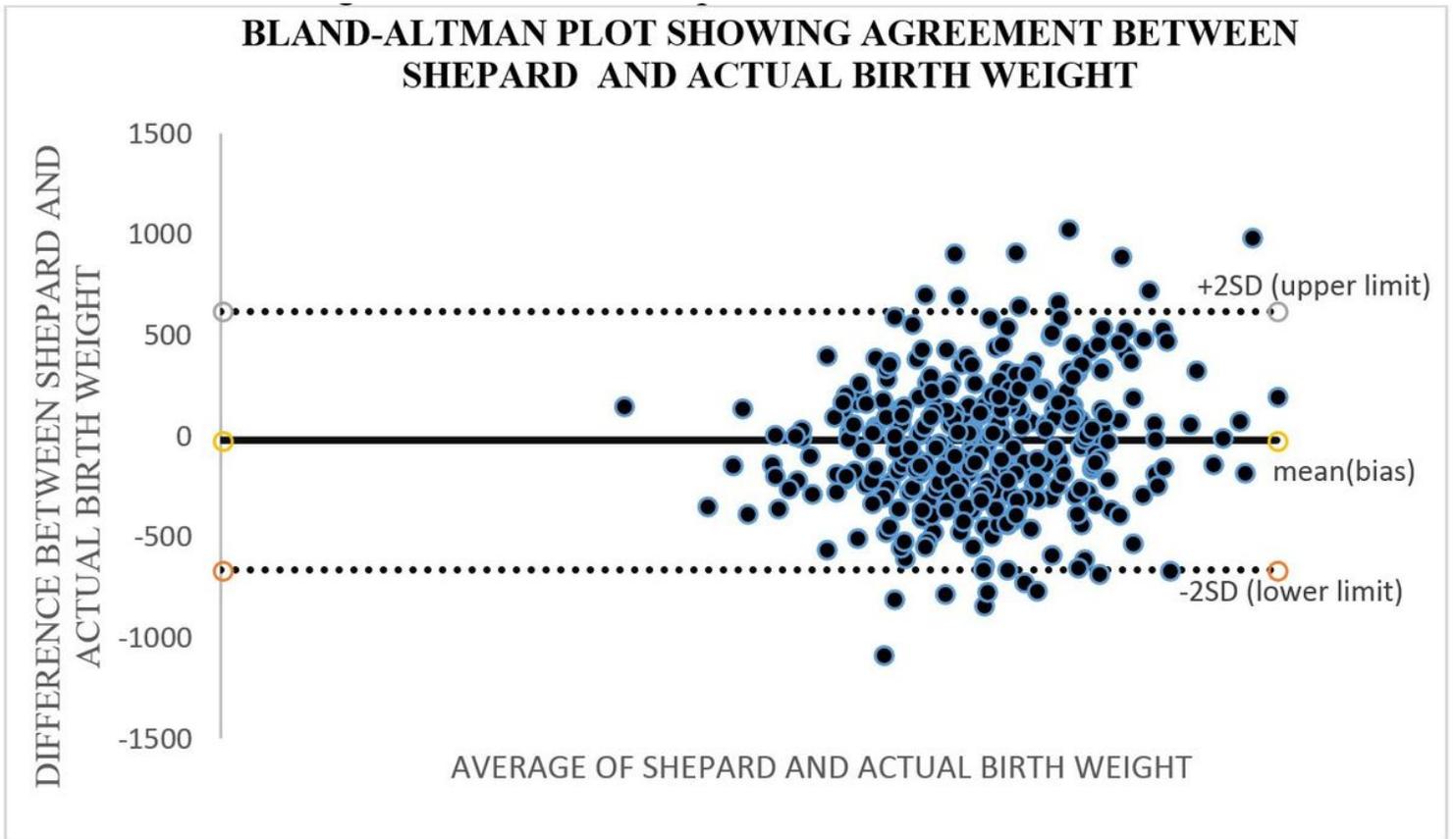
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Plot showing agreements between HADLOCK4 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



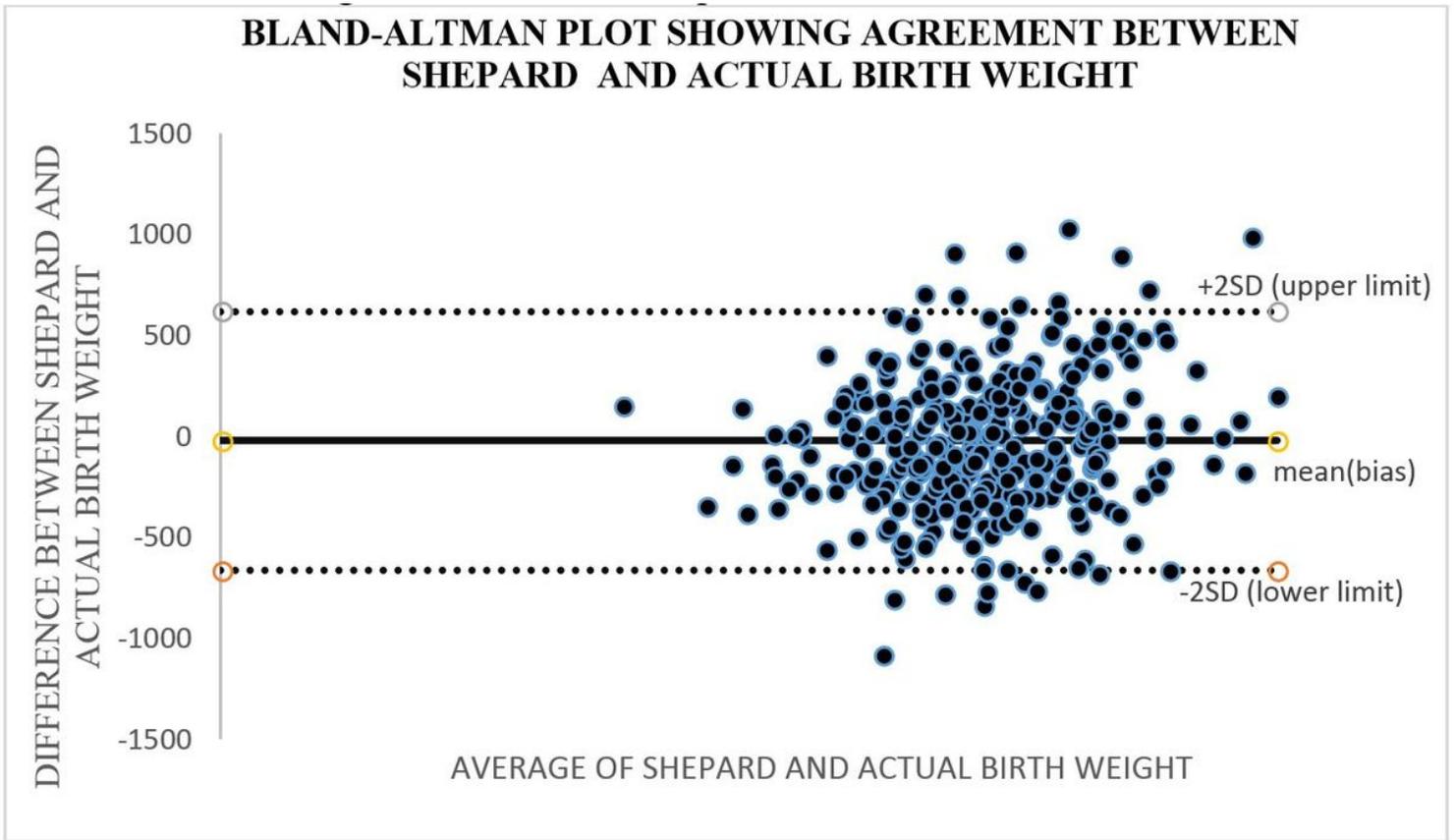
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Plot showing agreements between HADLOCK4 fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



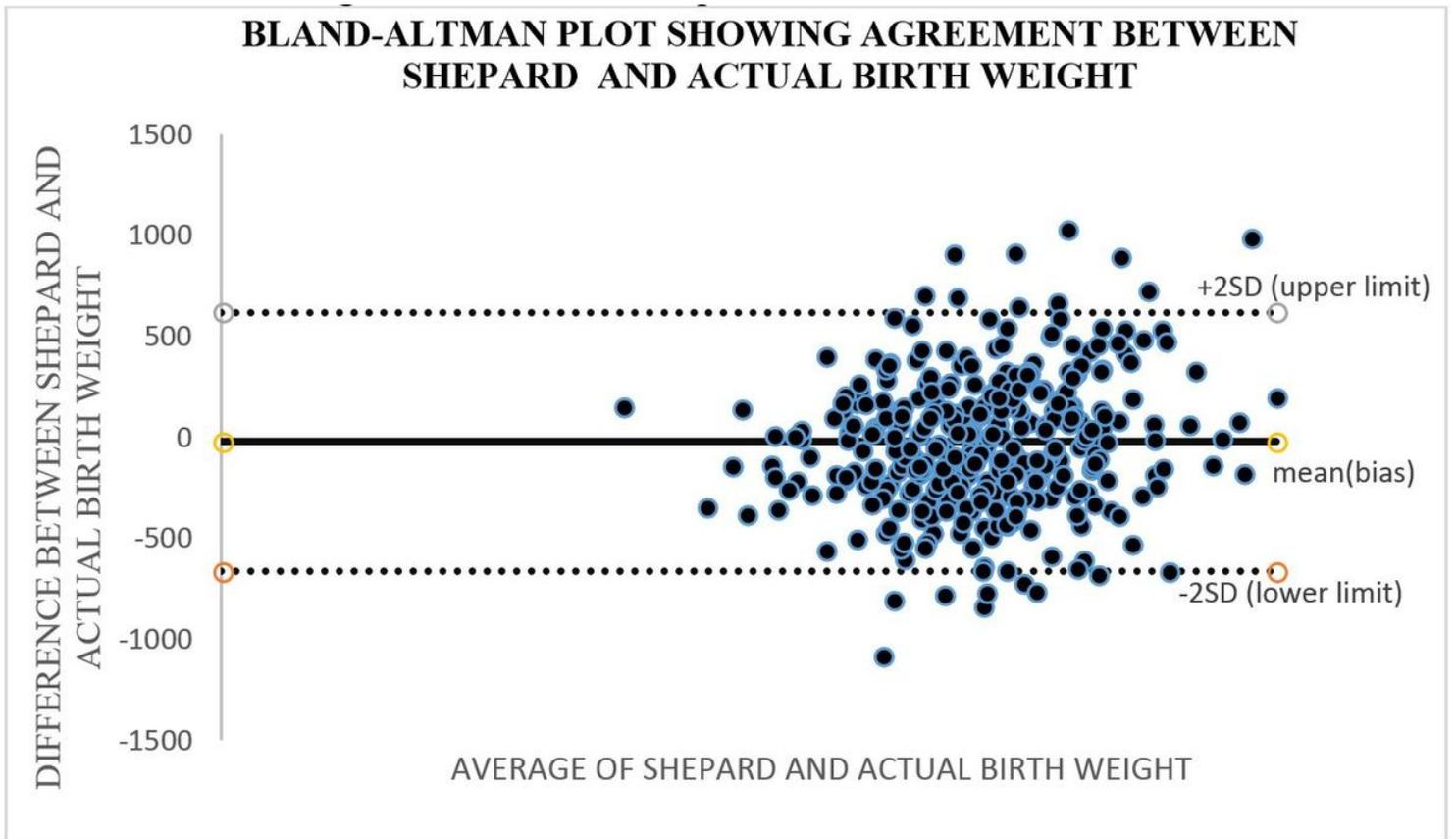
**Figure 6**

Plot showing agreements between SHEPARD fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



**Figure 6**

Plot showing agreements between SHEPARD fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital



**Figure 6**

Plot showing agreements between SHEPARD fetal weight estimator and actual birth weight of 356 neonates at Mulago national referral hospital

## Supplementary Files

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