Donald School Textbook of
ULTRASOUND IN
OBSTETRICS AND GYNECOLOGY

Fourth Edition

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Dedicated to

Ian Donald
(Our Teacher and Friend)
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The Ian Donald International School of Ultrasound bears testament to globalization in its most successful and worthwhile form. The school was founded in Dubrovnik in 1981; in the preface of the first edition in 2004 we were proud to announce that the School had grown to 8 branches. Since then, the growth has been meteoric and now consists of 112 branches in almost every corner of the globe. The reason for this success has been the tireless and selfless efforts of the world’s leading authorities in ultrasound who are willing to dedicate their valuable time without reimbursement to teach sonologists and sonographers throughout the world. Our teachers put national, religious, political, and other parochial considerations aside as they strive to improve the care of all women and fetal patients. Politicians in the countries represented by our School have much to learn from the purity of spirit that exists throughout our international family. We believe that Ian Donald is smiling down from heaven at the School that bears his name.

In the educational efforts of the 112 branches of the Ian Donald School, there is clearly a need for a textbook to complement and supplement lectures and didactic sessions. The first, second and the third textbooks were successful in this endeavor, but with the explosion of knowledge, it was clear that an expanded and updated fourth edition would be invaluable. The current edition of our textbook illustrates the latest developments including silhouette ultrasound and four-dimensional ultrasound which have been pioneered by our school. For the sake of simplicity, our book is divided into three sections. Section one deals with a variety of topics that lay the foundation for the rest of the book. Section two addresses the myriad subtopics in obstetric ultrasound that optimize the care of pregnant women and fetal patients. The last section addresses the essential role that ultrasound plays in the many dimensions of clinical gynecology.

A special word of thanks to Jadranka, our tireless secretary for her hundreds of dedicated hours of quality work.

We are grateful to many course directors and lecturers of the Ian Donald School who have enabled its growth and have selflessly contributed to this volume. In order to maximize the reach of this textbook by minimizing its price, all contributors have waived any honorarium or royalty. Their dedication to the dream of globalized quality ultrasound has enabled its reality.

Asim Kurjak
Frank A Chervenak
Preface to the First Edition

Ultrasound is the backbone of modern obstetric and gynecology practice. For those of us old enough to remember the dark ages of clinical practice prior to ultrasound, this is not an overstatement. Younger physicians may find it hard to imagine the clinical realities of doctors who delivered undiagnosed twins presenting at delivery, who performed unnecessary surgeries for the clinical suspicion of a pelvic mass that was not present, and who consoled anguished parents when an anomalous infant was born unexpectedly. Recent technological breakthroughs in diagnostic ultrasound, including the advent of color Doppler, power Doppler, three-dimensional and four-dimensional imaging, have led ultrasound to surpass the expectations of Ian Donald, its visionary father.

The Ian Donald School was founded in 1981 and is devoted to international education and research cooperation concerning all aspects of diagnostic ultrasound. The first chapter was founded in Dubrovnik at that time and has now expanded to 7 additional national branches.

To facilitate the educational efforts of the Ian Donald School, we believed a textbook would be of value. The text is divided into three parts general aspects, obstetrics, and gynecology. All contributors are either present or former teachers in the 8 branches of the Ian Donald School. We believe this comprehensive text with state-of-the-art images will be of value for both new learners and experienced practitioners.

We are grateful to all of the teachers in the School and especially to all of the contributors to this textbook for their tireless efforts to enhance the quality of ultrasound practice throughout the world.

Asim Kurjak
Frank A Chervenak
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Accurate assessment of gestational age is fundamental in managing both low- and high-risk pregnancies. In particular, uncertain gestational age has been associated with adverse pregnancy outcomes including low birth weight, spontaneous preterm delivery and perinatal mortality, independent of maternal characteristics. Making appropriate management decisions and delivering optimal obstetric care necessitates accurate appraisal of gestational age. For example, proper diagnosis and management of preterm labor and post-term pregnancy requires an accurate estimation of fetal age. Many pregnancies considered to be preterm or post-term are wrongly classified. Unnecessary testing, such as fetal monitoring and unwarranted interventions, including induction for supposed post-term pregnancies may lead to an increased risk of maternal and neonatal morbidity. In addition, pregnancies erroneously thought to be preterm may be subject to avoidable and expensive hospitalization stays as well as excessive and potentially dangerous medication use including tocolytic therapy. In one study by Kramer et al. that assessed over 11,000 pregnant women who underwent early ultrasound, one-fourth of all infants who would be classified as premature and one-eighth of all infants who would be classified as post-term by menstrual history alone would be misdiagnosed. Accurate pregnancy dating may also assist obstetricians in appropriately counseling women who are at imminent risk of a preterm delivery about likely neonatal outcomes.

Precise knowledge of gestational age is also essential in the evaluation of fetal growth and the detection of intrauterine growth restriction. During the third trimester, fundal height assessment may be helpful in determining appropriate fetal growth by comparing the measurement to a known gestational age. In addition, dating a pregnancy is imperative for scheduling invasive diagnostic tests, such as chorionic villus sampling (CVS) or amniocentesis, as appropriate timing can influence the safety of the procedure. Certainty of gestational age is also important in the interpretation of biochemical serum screening test results and may help avoid undue parental anxiety from miscalculations and superfluous invasive procedures, which may increase the risk of pregnancy loss. Assessment of gestational age is also crucial for counseling patients regarding the option of pregnancy termination.
ASSESSMENT OF GESTATIONAL AGE BY LAST MENSTRUAL PERIOD

Traditionally, the first day of the last menstrual period (LMP) has been used as a reference point, with a predicted delivery date 280 days later. The estimated date of confinement (EDC) can also be calculated by Nägele’s rule by subtracting three months and adding seven days to the first day of the last normal menstrual period. However, there are inherent problems in assessing gestational age using the menstrual cycle. One obstacle in using the LMP is the varying length of the follicular phase and the fact that many women do not have regular menstrual cycles. Walker et al. evaluated 75 ovulatory cycles using luteinizing hormone levels as a biochemical marker and found that ovulation occurred within a wide range of 8–31 days after the LMP. Similarly, Chiazze et al. collected over 30,000 recorded menstrual cycles from 2,316 women and found that only 77% of women have average cycle lengths between 25 and 31 days. Another barrier in using a menstrual history is that many women do not routinely document or remember their LMP. Campbell et al. demonstrated that of more than 4,000 pregnant women, 45% were not certain about their LMP as a result of poor recall, irregular cycles, bleeding in early pregnancy or oral contraceptive use within two months of conception.

Clinical Methods for Determining Gestational Age

Other methods used to assess gestational age have included uterine size assessment, time at quickening and fundal height measurements. However, these clinical methods are often suboptimal. Robinson noted that uterine size determination by bimanual examination produced incorrect assessments by more than two weeks in over 30% of patients. Similarly, fundal height estimation does not provide a reliable guide to predicting gestational age. Beazly et al. found up to eight weeks variation in gestational age for any particular fundal height measurement during the second and third trimesters. In addition, quickening or initial perception of fetal movement can vary greatly among women. While these modalities may be useful adjuncts, they are unreliable as the sole tool for the precise dating of a pregnancy.

Ultrasound Assessment of Gestational Age

In recent years, ultrasound assessment of gestational age has become an integral part of obstetric practice. Correspondingly, prediction of gestational age is a central element of obstetric ultrasonography. Fetal biometry has been used to predict gestational age since the time of A-mode ultrasound. Currently, the sonographic estimation is derived from calculations based on fetal measurements and serves as an indirect indicator of gestational age. Over the past three decades, numerous equations regarding the relationship between fetal biometric parameters and gestational age have been described and have proven early antenatal ultrasound to be an objective and accurate means of establishing gestational age.

First Trimester Ultrasound

Ultrasound assessment of gestational age is most accurate in the first trimester of pregnancy. During this time, biological variation in fetal size is minimal. The gestational sac is the earliest unequivocal sonographic sign of pregnancy. Historically, gestational sac size and volume had been used as a means to estimate gestational age. This structure sonographically resembles a fluid filled sac surrounded by a bright echogenic ring, the developing chorionic villi, within the endometrial cavity (Fig. 10.1). This sac can be visualized as early as five menstrual weeks using transvaginal sonography. More recently, studies have shown that fetal age assessment by gestation sac measurement is not reliable, with a prediction error up to two weeks. Another imprecise yet often used modality is the sonographic visualization of distinct developing structures. During the fifth menstrual week, the yolk sac—the earliest embryonic structure detectable by sonography, can be visualized prior to the appearance of the fetal pole. And, by the end of the 6th menstrual week, a fetal pole with cardiac activity should be present (Fig. 10.2). Subsequently, the presence of limb buds and midgut herniation can be seen at approximately 8 weeks of gestation. However, these
has been well documented in the medical literature. Specifically, gestational age can be estimated safely with a maximal error of 3–5 days in the first trimester.\textsuperscript{6,16,32,33} In summary, first trimester ultrasound is a useful and reliable tool in the assessment of gestational age. In particular, sonographic measurement of the CRL during the first trimester is the best parameter for estimating gestational age and is accurate within five days of the actual conception date.\textsuperscript{30,32}

**Second Trimester Ultrasound**

Although routine ultrasonography at 18–20 weeks gestation historically has been controversial,\textsuperscript{34} it is currently practiced by most obstetricians in the United States.\textsuperscript{35} In addition to screening for fetal anomalies, sonographic gestational age assessment may be of clinical value in that it has been shown to decrease the incidence of post-term as well as preterm diagnoses and thus the administration of tocolytic agents.\textsuperscript{36,37} In addition, uncertain gestational age has been associated with higher perinatal mortality rates and an increase of low birth weight and spontaneous preterm delivery.\textsuperscript{1}

**Ultrasound Parameters**

When choosing the optimal parameter for estimating gestational age, it is essential that the structure has little biologic variation, is growing at a rapid pace and can be measured with a high degree of reproducibility.\textsuperscript{38} In the past, the biparietal diameter (BPD) had been described as a reliable method of determining gestational age.\textsuperscript{9,12} While the BPD was the first fetal parameter to be clinically utilized in the determination of fetal age in the second trimester, more recent studies have evaluated the use of several other biometric parameters including head circumference (HC),\textsuperscript{39} abdominal circumference (AC),\textsuperscript{40} femur length (FL),\textsuperscript{41} foot length,\textsuperscript{42} ear size,\textsuperscript{43} orbital diameters,\textsuperscript{44,45} cerebellum diameter\textsuperscript{46,47} and others. In a large study by Chervenak et al. that evaluated pregnancies conceived by IVF and thus had known conception dates, HC was found to be the best predictor of gestational age compared with other commonly used parameters (Table 10.1).\textsuperscript{48} This finding is in agreement with that of Hadlock,\textsuperscript{10} Ott\textsuperscript{11} and Benson\textsuperscript{49} who compared the performance of HC, BPD, FL and AC in different populations.

The HC should be measured in a plane that is perpendicular to the parietal bones and traverses the third ventricle and thalami (Fig. 10.3). Three adequate CRL measurements should be taken and the average used for gestational age determination.\textsuperscript{31} The accuracy of the CRL measurement developmental landmarks can only provide rough estimates to the actual fetal age.

In 1973, Robinson reported using the CRL for determining gestational age.\textsuperscript{28} Since that time, ultrasound equipment, techniques and prediction formulas have substantially improved and allow for more rapid and precise measurement of the CRL and determination of gestational age.\textsuperscript{29,30} For the best results, the fetus should be imaged in a longitudinal plane. The greatest embryonic length should be measured by placing the calipers at the head and rump of the fetus (Fig. 10.3). Three adequate CRL measurements should be taken and the average used for gestational age determination.\textsuperscript{31} The accuracy of the CRL measurement has been well documented in the medical literature. Specifically, gestational age can be estimated safely with a maximal error of 3–5 days in the first trimester.\textsuperscript{6,16,32,33}

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parameters, it is important to take the images in the proper plane and place the calipers appropriately. For example, when assessing FL, the long axis of the femur should be aligned with the transducer measuring only the osseous portions of the diaphysis and metaphysis of the proximal femur. While not included in the FL measurement, the proximal epiphyseal cartilage (future greater trochanter) and the distal femoral epiphyseal cartilage (future distal femoral condyle) should be visualized to assure that the entire osseous femur can be measured without foreshortening or elongation (Fig. 10.5).31,51 Similarly, the AC must be measured appropriately in order to obtain an accurate estimate. The image should be taken in a plane slightly superior to the umbilicus at the greatest transverse abdominal diameter, with the liver, stomach, spleen and junction of the right and left portal veins visualized (Fig. 10.6).31

**Table 10.1**: Comparison of stepwise multiple linear regression in estimation of fetal age for singletons using different second trimester biometric parameters by Chervenak et al.47

<table>
<thead>
<tr>
<th>Biometric parameters</th>
<th>Random error (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>3.77</td>
</tr>
<tr>
<td>AC</td>
<td>3.96</td>
</tr>
<tr>
<td>BPD</td>
<td>4.26</td>
</tr>
<tr>
<td>FL</td>
<td>4.35</td>
</tr>
<tr>
<td>HC+AC</td>
<td>3.44</td>
</tr>
<tr>
<td>HC+FL</td>
<td>3.55</td>
</tr>
<tr>
<td>HC+AC+FL</td>
<td>3.35</td>
</tr>
</tbody>
</table>


The fetal head without including the scalp. The BPD can be taken in the same plane by placing the calipers on the outer edge of the proximal calvarium wall and on the inner edge of the distal calvarium wall.50 The BPD, while highly correlated with HC, is less accurate as a predictor of gestational age as a result of variation in head shape.48

Multiple parameters have been shown to improve the accuracy of gestational age assessment.48 Along with HC, the addition of one parameter (AC or FL) or two parameters (AC and FL) is slightly superior to HC alone in the prediction of fetal age. Table 10.1 demonstrates the relative error associated with the use of different biometric parameters. The use of multiple parameters also reduces the effect of outliers caused by biologic phenomena (i.e. congenital anomalies or growth variation) or technical error in measurement of a single structure. Still, with multiple parameters, it is important to take the images in the proper plane and place the calipers appropriately. For example, when assessing FL, the long axis of the femur should be aligned with the transducer measuring only the osseous portions of the diaphysis and metaphysis of the proximal femur. While not included in the FL measurement, the proximal epiphyseal cartilage (future greater trochanter) and the distal femoral epiphyseal cartilage (future distal femoral condyle) should be visualized to assure that the entire osseous femur can be measured without foreshortening or elongation (Fig. 10.5).31,51 Similarly, the AC must be measured appropriately in order to obtain an accurate estimate. The image should be taken in a plane slightly superior to the umbilicus at the greatest transverse abdominal diameter, with the liver, stomach, spleen and junction of the right and left portal veins visualized (Fig. 10.6).31
Most modern ultrasound machines are equipped with computer software that will automatically calculate the estimated gestational age based on the entered measurements. Using a large singleton IVF population from 14–22 weeks, Chervenak et al. derived an optimal gestational age prediction formula using stepwise linear regression with a standard deviation (SD) of 3.5 days between the predicted and true gestational age. This formula was compared to 38 previously published equations. Nearly all equations produced a prediction within one week demonstrating that fetal biometry in the midtrimester for assessment of gestational age is applicable and accurate across populations and institutions. Clinically, when a discrepancy greater than seven days (2SD) exists between the menstrual and ultrasound dating in the second trimester, the biometric prediction should be given preference.

Recently, we published a study evaluating and comparing the accuracy of first- and second-trimester ultrasound assessment of gestational age using pregnancies conceived with IVF. Our data showed that first- and second-trimester estimates of gestational age had small differences in the systematic and random error components for an estimated gestational age that was based on fetal CRL or biometry. On the basis of this data derived from pregnancies with known conception dates, ultrasound scanning can determine fetal age to within less than five days in the first trimester and less than seven days in the second trimester in more than 95% of cases. This data further confirms the findings of Wisser et al. and Chervenak et al. regarding the precision of ultrasound scans to assess gestational age in the first and second trimester, respectively.

**Third Trimester Ultrasound**

While ultrasound has proven to be useful in the assessment of gestational age in the first and second trimesters, accuracy in the third trimester is not as reliable. Biologic variation can be a major factor that affects accuracy in gestational age prediction, and this variability greatly increases with advancing pregnancy. Doubilet and Benson evaluated late third-trimester ultrasound examinations of women who had also received a first-trimester examination and found the disparity in gestational age assessments to be 3 weeks or greater. Thus, third-trimester sonographic estimates of gestational age should be used with caution, if at all.

**MULTIFETAL PREGNANCIES**

Dating equations generated for singletons can be applied to twins and triplets in order to accurately predict fetal age. Chervenak et al. used multiple linear regression to determine an optimal dating formula for multiple gestations. In twin pregnancies, a single averaged prediction of the gestational age of each fetus is appropriate and was found to yield the most accurate results. This approach of averaging the two fetal age estimates is reasonable as the combined biologic and measurement variability among twins is larger than the decrease in average size of twins relative to singletons. In contrast, using the maximum or minimum estimate in a twin set yielded a slightly larger systematic error than an averaged prediction (Table 10.2). In the case of triplets, one day can be added to the average of the largest and shortest gestational age prediction among these fetuses for the most accurate gestational age assessment.

Slightly larger deviations in the predictions are not unexpected for individual twins or triplets as the formulae have been derived from a singleton population. However, this imprecision is partially compensated for by the fact that multiple pregnancy predictions are based on more information, namely two or three times as many measurements as for singletons. As singleton and multiple gestations grow at similar rates during the second trimester, the difference in the uncertainty of the prediction for gestational age is small using a singleton gestation formula. Indeed, using IVF pregnancies with known conception dates, we have published data confirming that gestational age predictions for twin and triplet gestations have similar accuracy as singleton gestations (Table 10.3).

---

**Table 10.2: Application of a singleton multiple linear regression formula for estimation of fetal age to multiple gestations by Chervenak et al.**

<table>
<thead>
<tr>
<th>Pregnancy type</th>
<th>Prediction type</th>
<th>Mean error (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twins</td>
<td>GA of larger twin</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>GA of smaller twin</td>
<td>-1.3</td>
</tr>
<tr>
<td></td>
<td>Mean GA of both fetuses</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>GA of larger twin</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>GA of smaller twin</td>
<td></td>
</tr>
<tr>
<td>Triplets</td>
<td>GA of largest triplet</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>GA of smallest triplet</td>
<td>-3.4</td>
</tr>
<tr>
<td></td>
<td>Mean GA of all fetuses</td>
<td>-1.3</td>
</tr>
<tr>
<td></td>
<td>GA of largest triplet</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>GA of smallest triplet</td>
<td></td>
</tr>
</tbody>
</table>

CHOOSING A DUE DATE

When the date of conception is unequivocal, as in cases of IVF, the estimated date of confinement should not be changed based on ultrasound. However, more often than not, this is not the case. In the first trimester, an estimated date of confinement (EDC) based on the LMP that is greater than five days different from the CRL measurement should be changed to the sonographic derived EDC (Flowchart. 10.1). In the second trimester, a combination of biometric parameters that includes the HC should be used to predict the EDC. In the face of a discrepancy of more than seven days in the second trimester, the sonographic biometric prediction should be given preference, provided there is no anomaly or severe growth delay (Flowchart. 10.2). In fact, some authors argue that biometric prediction in the first and second trimesters should be given preference in every case.

One of the most common and serious mistakes made when determining gestational age is changing the due date based on a second or subsequent ultrasound examination. The inaccuracy of ultrasound dating increases with gestational age. If the LMP and clinical findings suggest a gestational age within 5 days of a first trimester scan or within 7 days of a second trimester scan, no further investigation is necessary. If the initial first or second trimester sonographically determined gestational age is outside these ranges, the due date should be changed. However, as the pregnancy progresses, revision of a due date that was based on a previous ultrasound is never warranted. If there is a discrepancy between the gestational age assessments of two ultrasound examinations, considering explanations such as intrauterine growth restriction (IUGR), macrosomia or other pathological conditions may be appropriate.

### Table 10.3: Discrepancies between ultrasound estimates and true gestational age for the first and second trimester in singleton, twin, and triplet pregnancies

<table>
<thead>
<tr>
<th></th>
<th>Systematic Errora</th>
<th>Random Errorb</th>
<th>Absolute Errorc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First Trimester</td>
<td>Second Trimester</td>
<td>First Trimester</td>
</tr>
<tr>
<td>Singleton</td>
<td>+1.3 ± 0.2 days</td>
<td>-0.1 ± 0.4 days</td>
<td>2.4 days</td>
</tr>
<tr>
<td>Twin</td>
<td>+1.4 ± 0.2 days</td>
<td>-0.6 ± 0.3 days</td>
<td>1.7 days</td>
</tr>
<tr>
<td>Triplet</td>
<td>+0.8 ± 0.4 days</td>
<td>-0.6 ± 0.5 days</td>
<td>2.1 days</td>
</tr>
</tbody>
</table>

Systematic error, average difference between estimated and true gestational age; Random error, residual standard deviation between estimated and true gestational age; Absolute error, average absolute value of the discrepancy between estimated and true gestational age

*a mean ± standard error of the mean
*b standard deviation
*c for gestations with both assessments


### FLowchart 10.1 Gestational age assessment using first trimester ultrasound

1. First trimester ultrasound
2. ≤5 days discrepancy between LMP and US estimate of GA
   - Choose LMP derived GA prediction
3. >5 days discrepancy between LMP and US estimate of GA
   - Choose US derived GA prediction

(Abbreviations: LMP, last menstrual period; US, ultrasound; GA, gestational age)

### Flowchart 10.2 Gestational age assessment using second trimester ultrasound

1. Second trimester ultrasound
2. ≤7 days discrepancy between LMP and US estimate of GA
   - Choose LMP derived GA prediction
3. >7 days discrepancy between LMP and US estimate of GA
   - Choose US derived GA prediction

(Abbreviations: LMP, last menstrual period; US, ultrasound; GA, gestational age)

### ULTRASOUND PITFALLS

Recent advances in ultrasound image quality and the wide availability of accurate biometric formulas have greatly improved physicians’ ability to calculate gestational age. However, properly dating a pregnancy sonographically still depends on adherence to good ultrasound technique. Obtaining a clear and precise image of each biometric indicator is essential. Errors in estimation may arise from technical difficulties including obtaining the proper axis for measurement, movement of the mother or fetus, machine
sensitivity settings or caliper placement. If a certain biometric indicator is not well visualized or is difficult to measure, it is better to use an alternative indicator rather than include a suboptimal measurement. In addition, it is helpful to obtain several measurements of each indicator and use an average to ensure a more precise calculation of fetal age.

CONCLUSION

Knowledge of gestational age is of great importance in obstetric practice. Optimal assessment requires good judgment by the obstetrician caring for the patient. Since clinical data such as the menstrual cycle or uterine size are often not reliable, the most precise parameter for pregnancy dating should be determined by the obstetrician early in the pregnancy. Ultrasound is an accurate and useful modality for the assessment of gestational age in the first and second trimester of pregnancy and, as a routine part of prenatal care, can greatly impact obstetric management and improve antepartum care.

REFERENCES


