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● *Original Contribution*

A PRENATAL ULTRASOUND SCANNING APPROACH: ONE-TOUCH TECHNIQUE IN SECOND AND THIRD TRIMESTERS

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Abstract—This study was aimed at evaluating the performance of the innovative technique Smart Fetus (SF) developed to recognize the planes and obtain the basic biometric measurements of fetuses automatically. This prospective study included 1005 uncomplicated singleton pregnancies undergoing routine examinations. For every pregnancy, planes, including the transverse section of the thalami, transverse section of the abdomen and longitudinal section of the femur, were acquired, and standard biometric measurements, including biparietal diameter, head circumference, abdominal circumference and femur length, were obtained using SF and traditional ultrasound technique (TUT). The accuracy, reproducibility and time required for the analysis of SF were compared with those of TUT. In 998 of 1005 cases (99.30%), SF successfully acquired the sections and made all measurements. The agreement between the techniques was high for all measurements. The time to obtain sections and measure biometric parameters or solely measure biometric parameters was significantly shorter with SF than with TUT. No significant differences were found in SF repeated measurements obtained by two independent observers. The SF technique helped in the acquisition of reliable standard sections and biometric measurements and saved time. It might serve as a novel ultrasound scanning approach and improve workflow efficiency. (E-mail: lishengli63@126.com)

Key Words: **Artificial intelligence, Biometric measurement, Fetus, Prenatal ultrasonography, Standard plane.**

INTRODUCTION

As a part of routine antenatal care, ultrasound is used to estimate gestational dates, monitor fetal growth and screen for anomalies (Degani 2001; Papp and Fekete 2003). However, it is still a manual process highly dependent on the user. A well-trained operator is a prerequisite for ultrasound more than for any other imaging modality. This affects the variability not only in the acquisition of required sections but also in the measurements of growth parameters. Efforts to reduce this variability include good training, standardization and quality control (Salim et al. 2019). Automatic acquisition and measurements during obstetric scanning are attractive options in the attempt to increase reliability and reproducibility, while also reducing scanning time (Espinoza et al. 2013; Yazdi et al. 2014; Rizzo et al. 2016).

To break through the bottleneck of prenatal ultrasound automation, the one-touch technique—Smart Fetus (SF)—was developed. SF consists with two applications: Smart Fetus acquisition (SFA) and Smart Fetus measurement (SFM). SFA is a technique in which only one finger touch is used during real-time scanning and automatically distinguishes acquired standard sections in the cine loop that contain the specific standard section and then automatically measures related growth parameters. During scanning, the operator touches the key "S-FETUS(acq.)" on the board, and SFA automatically freezes the frame, distinguishes and acquires a standard section from the cine loop and measures the parameter, in that order. The SFM technique measures basic growth parameters automatically from acquired standard planes. The standard sections obtained by SF include the transverse section of the thalamus (section A), the transverse section of the abdomen (section B) and the longitudinal section of the femur (section C). Growth parameters include biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC) and femur length (FL).

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The aims of the study described here were (i) to evaluate the efficacy of SF in obtaining basic standard sections and biometric measurements in a clinical setting; (ii) to test the agreement between the traditional ultrasound technique (TUT) and SF on biometric measurements of fetal structures; and (iii) to compare the times required by TUT and SF to complete the sections and measurements.

METHODS

This was a prospective cross-sectional study of women with low-risk pregnancies undergoing routine second- or third-trimester (16−41 wk) ultrasonographic examinations in Shenzhen Maternal and Child Healthcare Hospital. All pregnancies were singletons, accurately dated by the first-trimester ultrasonographic examination, and all fetuses were free from structural anomalies. The exclusion criterion was the lack of follow-up of pregnancy outcomes and delivery. This research project was approved by our institutional review board (File No. SFYLS[2020]019), and informed consent for the study was obtained from all mothers.

Two certified sonographers , both with more than 3 y of experience in fetal ultrasound scanning, carried out the scans. All examinations were performed using Sonoscape S60 (with SF software) ultrasound equipment (Sonoscape Co., Ltd, Shenzhen, China) with a 1- to 6-MHz transabdominal probe.

Both TUT and SF were used to acquire sections and measure parameters according to the mid-trimester fetal ultrasound scan guideline (Salomon et al. 2011). Standard sections included a transverse section of the thalamus (section A), a transverse section of the abdomen (section B) and a longitudinal section of the femur (section C). Growth parameters included BPD, HC, AC and FL. All measurements of SF were automatic results without any adjustment. Figure 1 illustrates the sections acquired and parameters measured with TUT and SFA.

Criteria for standard sections and measurements follow Salomon's audit method (Salomon et al. 2006). Sections and measurements meeting all the criteria were considered as standard, and those not meeting all the criteria were considered non-standard. Non-standard measurements were divided into overmeasured and undermeasured based on caliper placement.

All images and dates of measurements were saved, and the time used to obtain sections and measurements was recorded. The number of times successful sections and accurate measurements were acquired with SF was noted.

The specific process included the following steps:

Step 1.1. Acquire section and measurement with TUT. In the process of using TUT, the times used to acquire three standard sections and measure four parameters and the date of measurement were recorded.

The TUT was performed under the supervision of an expert to ensure all sections and parameters were standard.

The time for acquiring standard sections included the times for scanning, freezing and playback. The time for parameter measurement included parameter selection, caliper placement and adjustment and confirmation.

Step 1.2. Make the measurement with SFM based on the section acquired with TUT. In the process of using SFM, the time and date for measuring four parameters were recorded.

The accuracy of measurements and caliper placement was determined by experts as overmeasured/undermeasured/standard. Re-measurement on a different section was performed if the result was not qualified. A measurement repeated more than three times was considered a failure.

The time taken for parameter measurement included the time for clicking the S-FETUS (meas.) key and waiting for the results to be displayed automatically on the monitor.

Step 2. Acquire the section and make the measurement with SFA. SFA was used to obtain the sections, record the time and make the measurement independently.

All sections and measurements were classified respectively into standard/non-standard and overmeasured/undermeasured/standard by experts. Non-standard sections and overmeasured/undermeasured measurements were re-acquired or re-measured. A successful acquisition re-acquired more than three times was considered a failure.

The time for acquiring standard sections and measurements included three parts: scanning, touching the key S-FETUS (acq.) and waiting for the measurements to be displayed on the monitor.

For every case, both steps 1 and 2 were necessary, but the order of the steps was randomized.

Measurements were made twice on the same section with TUT to assess intra-observer variability in 60 fetuses. Furthermore, a second operator, blinded to the measurements obtained by the first operator, performed SFM and TUT on the same section to assess the inter-observer variability of parameter measurement.

In this study, manual expert measurement or judgment was considered the gold standard. Agreement between TUT and SFA on fetal parameters was determined using intraclass correlation coefficients (ICCs). The limits of agreement and under- or overestimation of SFA compared with TUT were calculated as described by Bland and Altman (2003). The time required to obtain sections and measurements with the two techniques was evaluated, and the differences were analyzed using the Wilcoxon signed-rank test. ICCs were assessed and the Bland−Altman plots were constructed to quantify intra- and inter-observer agreements. A p value <0.05 was considered to indicate statistical significance.

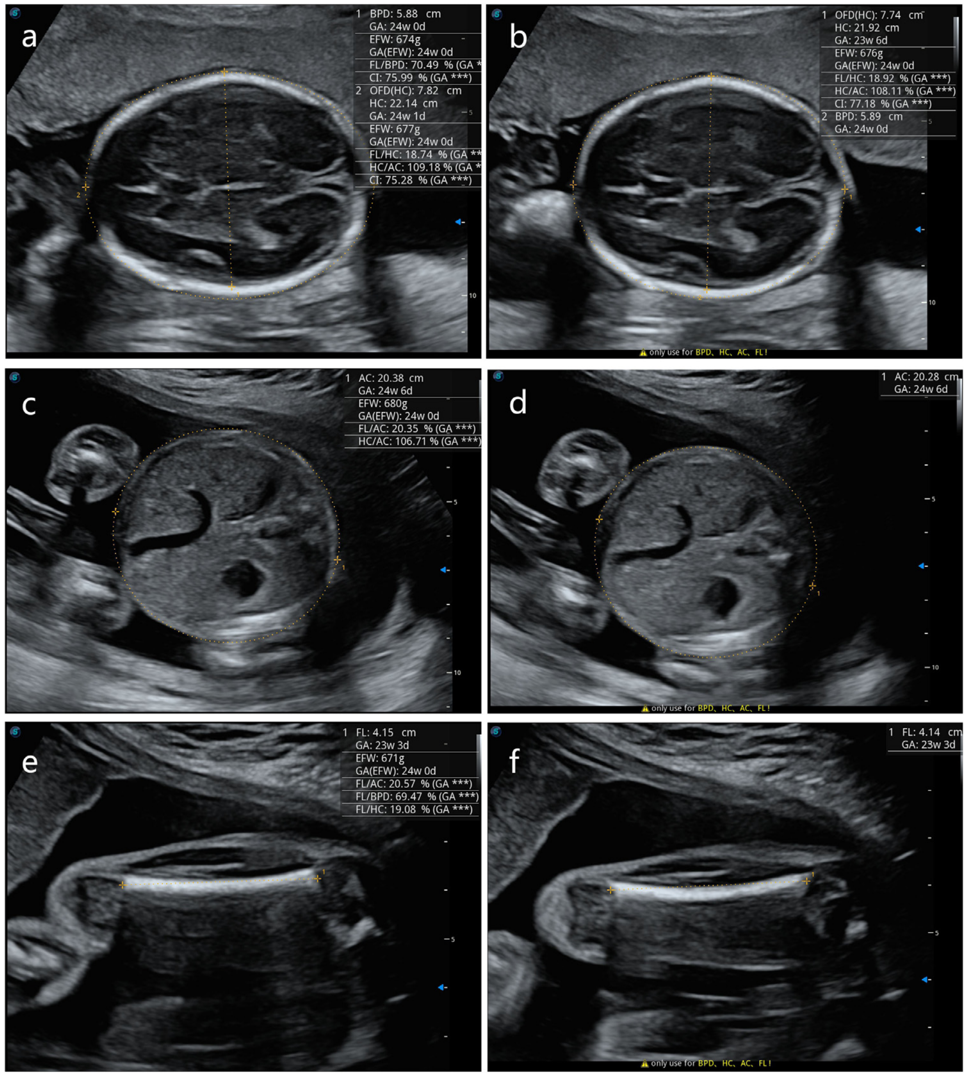

Fig. 1. Sections acquired and parameters measured with the traditional ultrasound technique (TUT) and Smart Fetus acquisition (SFA). (a) Acquisition of a transverse section of the thalamus and measurement of biparietal diameter (BPD) and head circumference (HC) with TUT. (b) Acquisition of a transverse section of the thalamus and measurement of BPD and HC with SFA. (c) Acquisition of a transverse section of the abdomen and measurement of abdominal circumference (AC) with TUT. (d) Acquisition of a transverse section of the abdomen and measurement of AC with SFA. (e) Acquisition of a longitudinal section of the femur and measurement of femur length (FL) with TUT. (f) Acquisition of a longitudinal section of the femur and measurement of FL with SFA.

Results

A total of 1005 gravidas were enrolled in the study between August 2018 and January 2019. The mean gestational age at scanning was 36 ± 7 wk (range: 16−41 wk). The average maternal age was 31 ± 6 y (range: 17−47 y) and the maternal body mass index was 25 ± 6 kg/m^2 (range: 17−36 kg/m^2). In all cases, the full set of sections and parameters was obtained with TUT and SF (including SFA and SFM).

Intra- and inter-observer agreement

Intra-observer agreement for TUT and inter-observer agreement for both TUT and SFM are summarized in Table 1. TUT and SFM measurements were based on the same images. Standard deviations of SFM were almost 0. The ICCs was slightly higher for SFM than for TUT measurements.

Quality assessment of SF

A total of 998 sections were obtained successfully with SFA (including sections obtained more than once). In a subjective quality assessment of sections automatically acquired with SFA (Table 2), 985 (98.00%), 996 (99.10%) and 1001 (99.60%) were judged to be clinically acceptable transverse sections of the thalami,

Table 1. Inter-observer variability in fetal biometric measurements acquired with TUT and intra-observer variability in TUT and SFM assessed using intraclass correlation coefficients and mean differences

Variable	Inter-observer variability of TUT		Intra-observer variability of TUT		Intra-observer variability of SFM	
	ICC (95% CI)	Mean difference* (SD)	ICC (95% CI)	Mean difference* (SD)	ICC (95% CI)	Mean difference* (SD)
BPD	0.998 (0.997−0.999)	0.001 (0.072)	0.998 (0.997−0.999)	0.005 (0.076)	1.000 (1.000−1.000)	—
HC	0.997 (0.995−0.998)	0.324 (0.327)	0.999 (0.998−0.999)	0.165 (0.235)	1.000 (1.000−1.000)	—
AC	0.998 (0.996−0.999)	0.262 (0.359)	0.999 (0.998−0.999)	0.092 (0.284)	1.000 (1.000−1.000)	0.0002 (0.001)
FL	0.997 (0.996−0.998)	0.019 (0.080)	0.999 (0.998−0.999)	0.035 (0.051)	1.000 (1.000−1.000)	0.0012 (0.009)

SFM = Smart Fetus measurement; TUT = traditional ultrasound technique; ICC = interclass correlation coefficient; BPD = biparietal diameter; HC = head circumference; AC = abdominal circumference; FL = femur length; SD = standard deviation; CI = confidence interval.
* Mean difference in centimeters.

transverse sections of the abdomen and longitudinal sections of the femur, respectively.

In automatic measurements with SFM on standard sections acquired with TUT (Table 2), 1005 (100%), 1005 (100%), 989 (98.41%) and 1003 (99.8%) cases were judged to have acceptable measurements of BPD, HC, AC and FL respectively. No failure in measurement of the head was noted. In cases measured more than once (including failure cases), overmeasured and undermeasured cases were close to 50% each (Table 3).

Agreement between TUT and SF

A high degree of reliability was observed between TUT and SFA measurements of BPD (ICC = 0.998, 95% confidence interval [CI]: 0.998−0.998); HC (ICC = 0.995, 95% CI: 0.995−0.996); AC (ICC = 0.998, 95% CI: 0.997−0.998); and FL (ICC = 0.998, 95% CI: 0.998−0.9998). In Figure 2 are the Bland−Altman plots for mean difference, 99% limits of agreement and 95% limits of agreement between TUT and SFA measurements.

Time comparison of TUT and SF

Tables 4 and 5 outline the times required in different techniques and their comparison. The average time required to analyze fetuses with SFA was 21.62 s (range: 8.00−47.11 s), which was significantly shorter than the 52.21 s (range: 26.36−106.04 s) needed to obtain the same sections and measurements with TUT ($z = -27.366$, $p < 0.001$). The average time to analyze fetal measurements with SFM was 2.78 s (range: 1.99−7.25 s), which was also significantly shorter than the 35.7 s (range: 13.48−74.19 s) with TUT ($z = -27.352$, $p < 0.001$).

DISCUSSION

Deep learning and artificial intelligence have greatly improved in many fields with the rapid development of computer technology. Medical imaging techniques, such as computed tomography and magnetic resonance imaging, have been well developed and provide standardized, high-quality images. Ultrasound, especially prenatal ultrasound, is not that easy. The examination of only superficial organs with simple images has been explored, for example, breast and thyroid ultrasound.

Fetal ultrasonic intelligence is more difficult than other imaging examinations. First, the position of the fetus is changeable and cannot be acquired by the fixed position of gravidas. Second, the inevitable ultrasonic artifacts, such as acoustic shadow, speckle noise, edge blur, lack of internal information and structural deformation caused by compression, make artificial intelligence difficult with strict standard requirements. Third, fetal anatomic structures, especially the fetal nervous system, change greatly throughout development, which is also a large challenge to automation.

In obstetric ultrasound, the quality of the examination depends on two parts: acquiring the correct diagnostic sections and making proper measurements on frozen images. The efficiency of both steps is mainly secondary to the skill and experience of the sonographer. The examination usually involves many steps. For example, during the acquisition of transabdominal sections and measurement of AC, the sonographer must perform about 10−15 procedures: scan, freeze, replay cine loop and judge the sections, select the parameter "AC," move the first cursor, confirm, move the second cursor, confirm, adjust the measurement calipers 2−5 times, and complete, which take about 10−25 s in the case of skilled operators.

The global shortage of sonologists and concurrent increase in indications for ultrasound are driving the more efficient use of scanning time. Automation of fetal standard sections and biometry is one possible way to increase efficiency in the workflow while, at the same time, offering the potential for improved accuracy and reproducibility. Yazdi et al. (2014) reported that automated measurements have the potential to be close to the gold standard. Software that can automatically assess fetal biometry on frozen images was developed in the past, and evidence indicates that the use of this software might decrease intra- and inter-observer variability and reduce the time required to perform measurements

Table 2. Subjective quality assessment of SF

	Acquisition with SFA*			Measurement with SFA†				Measurement with SFM‡			
	Section A	Section B	Section C	BPD	HC	AC	FL	BPD	HC	AC	FL
Clinically acceptable in one attempt	955 (95.00%)	972 (96.70%)	995 (99.00%)	985 (100%)	985 (100%)	984 (98.80%)	998 (99.70%)	1005 (100%)	1005 (100%)	989 (98.41%)	1003 (99.8%)
Clinically acceptable in two attempts	23 (2.30%)	18 (1.80%)	2 (0.20%)	0	0	6 (0.60%)	3 (0.30%)	0	0	9 (0.89%)	2 (0.2%)
Clinically acceptable in three attempts	7 (0.70%)	6 (0.60%)	4 (0.40%)	0	0	2 (0.20%)	0	0	0	2 (0.2%)	0
Failure	20 (2.00%)	9 (0.90%)	4 (0.40%)	0	0	4 (0.40%)	0	0	0	5 (0.5%)	0
Total clinically acceptable	985 (98.00%)	996 (99.10%)	1001 (99.60%)	985 (100%)	985 (100%)	992 (99.60%)	1001 (100%)	1005 (100%)	1005 (100%)	1000 (99.50%)	1005 (100%)

SF = Smart Fetus; SFA = Smart Fetus acquisition; SFM = Smart Fetus measurement; BPD = biparietal diameter; HC = head circumference; AC = abdominal circumference; FL = femur length; Section A = Transverse section of the thalami; Section B = transverse section of the abdomen; Section C = longitudinal section of the femur.

* Assessment of sections acquired with SFA.

† Assessment of SFAs based on sections acquired with SFA.

‡ Assessment of SFMs based on the sections acquired with TUT.

Table 3. Subjective quality assessment of acquired with Smart Fetus method in clinically acceptable more than once cases (including failure cases)

	BPD	HC	AC	FL
No. of cases	0	0	16	2
No. overmeasured	0	0	9	1
No. undermeasured	0	0	7	1

BPD = biparietal diameter; HC = head circumference; AC= abdominal circumference; FL = femur length.

(Zalud et al. 2009; Espinoza et al. 2013). Ultrasound companies have developed the artificial intelligence technology, such as Mindray's Smart Planes Central Nervous System (CNS) (Ambroise Grandjean et al. 2018) and a series of 5D technologies of Samsung (5-D heart and 5-D CNS) (Rizzo et al. 2016). These are image reconstruction techniques of 3-D volume. Post-reconstruction stage and positioning structure labeling are required.

SF is an embedded deep learning achievement applied in Sonoscape S60 ultrasound equipment. In real-time scanning, SF intelligently identifies the standard section, automatically measures corresponding fetal growth parameters and records the results in a report. The 10−20 steps of the procedure are condensed into one touch, greatly simplifying the obstetric examination. The acquirement of each standard section and measurement of each growth parameter are obtained during scanning with the touch of only one key, "S-FETUS(acq.)." All procedures—freeze the image, playback and search for the standard section in the cine loop, parameter selection, caliper placement and adjustment and confirmation—are completed with one key touch, S-FETUS (acq.). The technique is applicable to scanning in the second and third trimesters (14−40 wk), covering three standard sections and four growth parameters. SF has lower requirements with respect to size ratio compared with other techniques. The enlarged image can also be recognized, acquired and measured.

Compared with present automatic techniques, SF is more relevant to the current routine scanning process. SF is based on 2-D scanning. It masters the characteristics and recognize the standard section by analyzing mass expert judgment on different gestational weeks and sections. In practice, SF identifies and scores images acquired in real time frame by frame. Images with the highest score are selected as the standard sections and displayed on the monitor automatically. This process does not require marking the structures or reconstructing images compared with the current 5-D technique. The deep learning technique used in SFA has its own assessment, which differs from Salomon's method (Salomon et al. 2006) used by experts. In the study, the

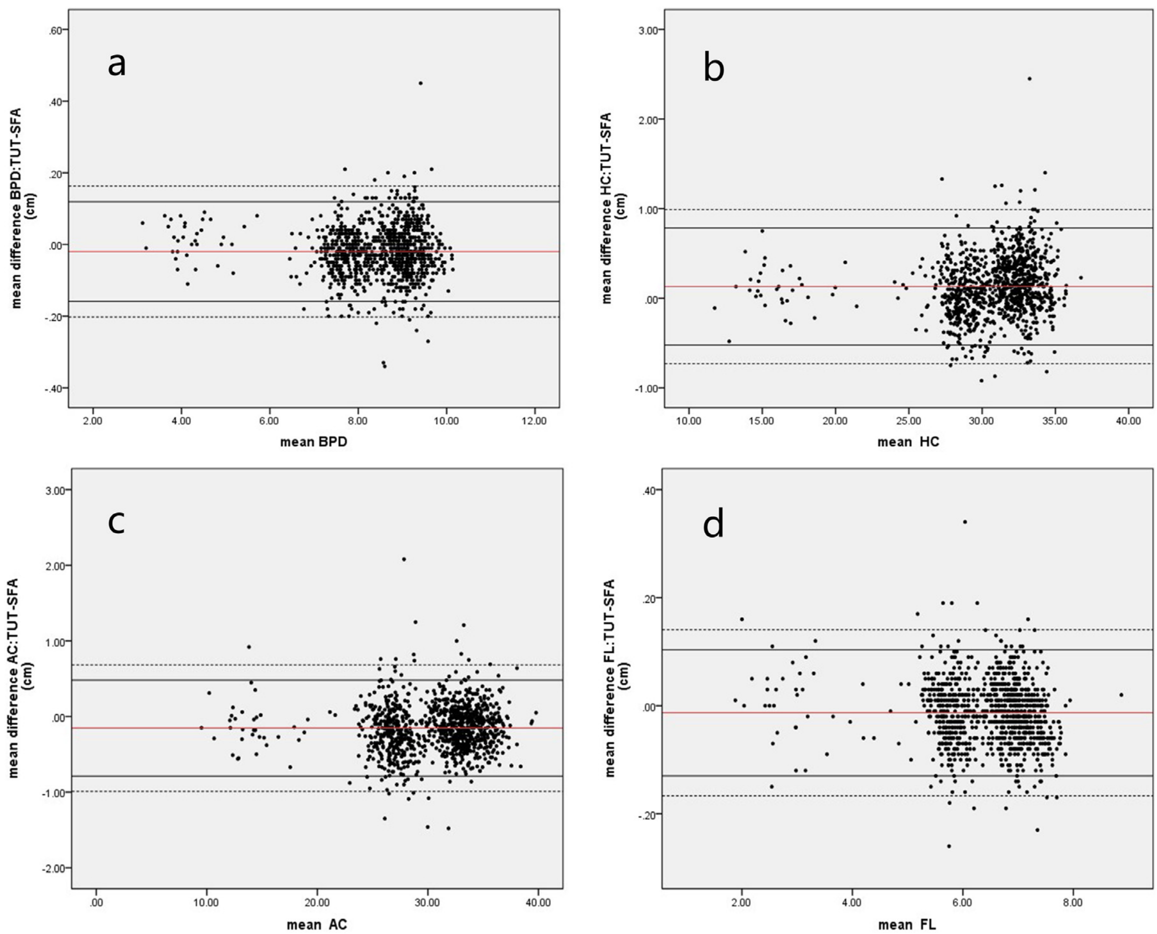

Fig. 2. Bland−Altman plots of differences (cm) against the mean for measurement with the traditional ultrasound technique (TUT) and Smart Fetus acquisition (SFA) of fetal parameters on sections obtained with TUT and SFA, respectively. The mean difference is represented by the *red line*; the 99% limits of agreement by the *black dotted line*; and the 95% limits of agreement by the *black line*. (a) Biparietal diameter (BPD). (b) Head circumference (HC). (c) Abdominal circumference (AC). (d) Femur length (FL).

Table 4. Time required to complete the sections and measurements with TUT and SFA

Method	T-A + BPD/HC (s)	T-B + AC (s)	T-C + FL (s)	Total time (s)
TUT	23.02 ± 6.56	18.55 ± 7.29	9.01 ± 3.85	52.24 ± 14.90
SFA	7.04 ± 2.21	6.95 ± 2.39	6.61 ± 1.82	21.62 ± 5.24
Z	−27.366	−27.322	−23.143	−27.366
p	<0.001	<0.001	<0.001	<0.001

TUT = traditional ultrasound technique; SFA = smart fetus acquisition= T-A + BPD/HC = time to complete acquisition of transverse section of the thalamus and measurement of biparietal diameter and head circumference; T-B + AC = time to complete acquisition of transverse section of the abdomen and measurement of abdominal circumference; T-C + FL = time to complete acquisition of longitudinal section of the femur and measurement of femur length; BPD = biparietal diameter; HC = head circumference; AC = abdominal circumference; FL = femur length, Section A = transverse section of the thalami; Section B = transverse section of the abdomen; Section C = longitudinal section of the femur.

*median ± quartile range.

standard sections acquired have fulfilled the main criteria of anatomy, although SF did not assess anatomy directly.

SF enables identification of the area of interest and the characteristics of measurement by analyzing the labels of standard images in each gestational week and each section, finally achieving the purpose of automatic measurement. With this technique, growth parameters can be measured automatically (not the mainstream semi-automatic measurement) with only one touch. Selection of growth parameters, cursor placement and continuous adjustment in the traditional parameter measurement process are reduced, saving time and workflow.

Table 5. Time required to complete the sections and measurements with TUT and SFM

Method	Time to complete (s)				
	BPD	HC	AC	FL	Total
TUT	5.62 ± 1.86	11.93 ± 3.69	12.58 ± 4.43	4.92 ± 1.47	35.7 ± 8.25
SFM	0.68 ± 0.2	0.59 ± 0.2	0.73 ± 0.22	0.75 ± 0.23	2.78 ± 0.66
Z	−27.366	−27.366	−27.295	−27.357	−27.352
p	<0.001	<0.001	<0.001	<0.001	<0.001

TUT = traditional ultrasound technique; SFM = Smart Fetus measurement; BPD = biparietal diameter; HC = head circumference; AC = abdominal circumference; FL = femur length.

In this study, the automated technique for obtaining fetal sections and biometry measurements was assessed. More than 98% of cases were successfully acquired. The re-acquisition or failure rate was higher for the transverse section of the thalamus in late third-trimester pregnancy when the fetal head fell into the pelvis. When the fetal head is too low, obtaining the transverse section of the thalamus is also difficult with TUT either. The results indicated that more than 99% of cases were successfully measured; re-measurement was a little more common for AC measurements. The accuracy was lower for AC because the detection and ellipse-fitting tasks were more difficult for AC than for other parameters: the contrast between the abdomen and surrounding tissues was low, with more variability in shape and appearance for the abdomen. For the simplification of workflow, the acquisition and measurement time with SFA was 41.38% of that with TUT, cutting the time in half. The time required for one-touch automatic measurement was only 7.78% of that with TUT, which saved more than 90% of measurement time. In this study, the inter-observer variability of automated measurement was zero, meaning that the technique could be relied on for reproducibility.

The cases in the study was selected mainly in the third trimester, because (i) growth screening is the main purpose of ultrasound examination in the third trimester, (ii) the three sections and four biometric parameters are the main context for the growth screening, and (iii) before the study, use of SF in our group was better in the second trimester than in the third trimester, another reason we were more focused on the third trimester in this study.

The strengths of this study were the large number of scans assessed using both automation and traditional technique. One limitation was that the image acquisition in SF was undertaken by highly skilled sonographers, and the technique might not work as well if the image quality is less optimal.

CONCLUSIONS

In general, SF is an intelligent, accurate and efficient technique for acquiring standard sections and measuring growth parameters. It is widely used in second- and third-trimester (14−40 weeks) scanning, covering three standard sections and four growth parameters. More than 98% and 99% of cases were successfully acquired and measured, respectively. The resulting measurements had a high degree of accuracy and compared well with manually obtained measurements. The technique condensed the operation requiring more than 10 steps into one touch, greatly simplifying the process of prenatal screening. This approach might improve workflow efficiency; less experienced operators might also be able to perform basic prenatal ultrasound examinations.

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Conflict of interest statement—The authors declare they have no conflicts of interest with respect to the work described here.

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