EC GYNAECOLOGY
Review Article

Objective Studies on the Fetus in the Past, Present and Future

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Received: December 09, 2017; **Published:** February 19, 2018

The Past

Fetal study was unable in old ages, it was subjective in the palpation and auscultation, namely Obstetrics was closed in subjective decision. It was objectively open in the recent 60 years.

Figure 1: *Stethoscopic listening to fetal heart sound.*

Fetal heart sound was faint in the stethoscopic listening (Figure 1). Fetal heart rate count by listening fetal heart sound was incorrect. Fetal descent was detected by vaginal examination, namely old obstetrics was closed in subjective diagnosis.

Fetal electrocardiogram (FECG)

Objective fetal diagnosis developed in the recent 60 years. The fetus was diagnosed alive when abdominal lead FECG was positive after 14 gestational weeks in 1960s by us, if fetal QRS appeared on abdominal lead fetal electrocardiogram. The fetal well-being must be known with the study on fetal S-T segment of which importance had been known in adult ECG. However, fetal P and T waves were usually masked by noises of abdominal muscular action potentials (Figure 2).

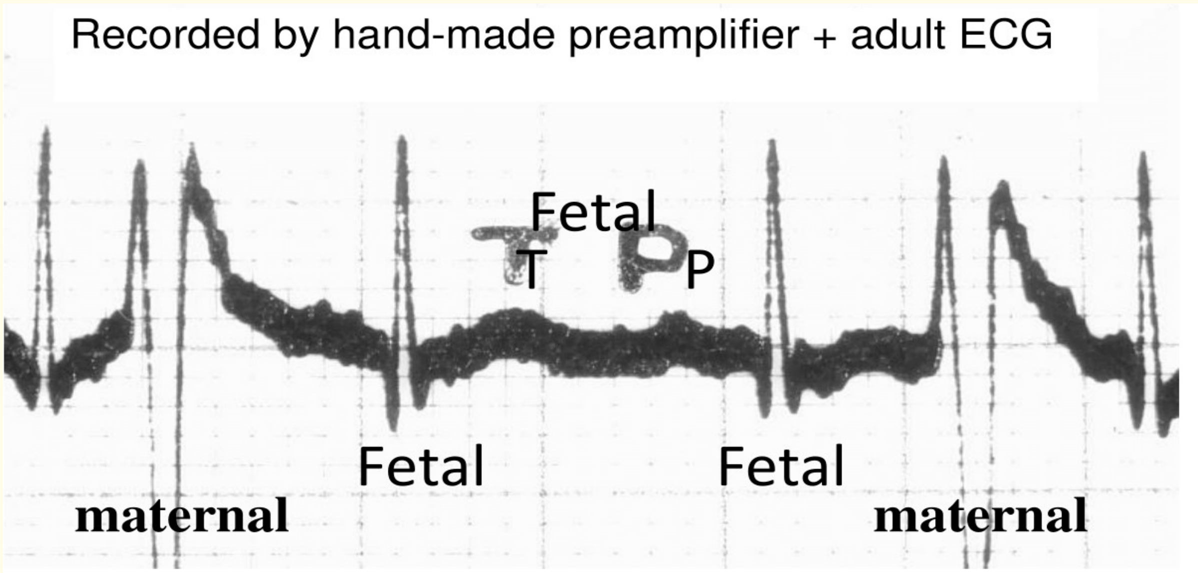

Figure 2: *Fetal electrocardiogram (FECG).*

Fetal life was confirmed by stethoscopic listening after 20 gestational weeks. It was truly subjective information, i.e. it was useful only to the listener of fetal heart sound. Large speaker was needed in electronic fetal heart sound listener, because fetal heart sound frequency was as low as 60 Hz, namely graphic record was studied in objective study, where the standard PCG microphone, 80 Hz high-pass filter was utilized for graphic record, however, fetal heart sound signal was usually disturbed by noisy systolic murmur of ductus arteriosus (arrow) even in normal pregnancy, thus abnormal pathologic fetal heart was unable to differentiate from normal fetal phonocardiogram as shown in the following illustration, which was displayed on a CRT and recorded by a film camera (Figure 3).

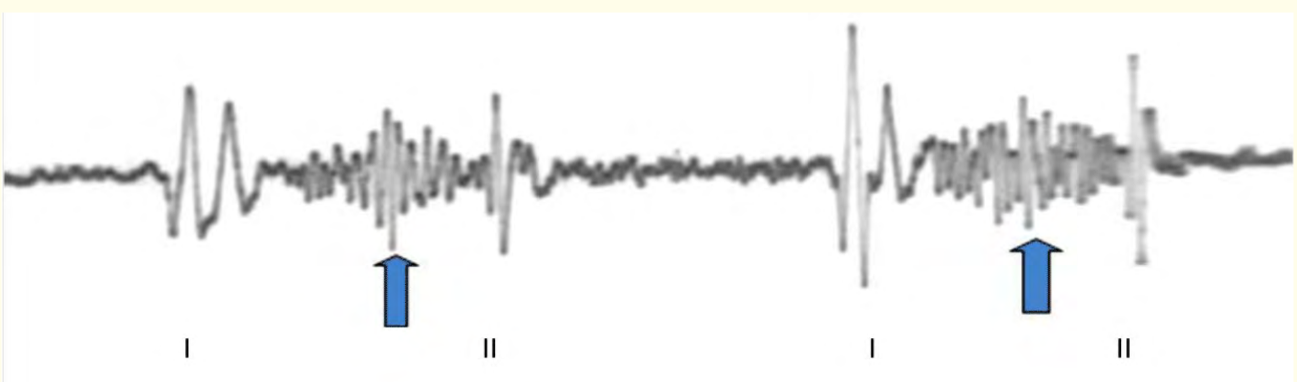

Figure 3: *Fetal phonocardiogram (FPCG).*

Therefore, high-pitched fetal heart sound listener was hand-made by the author in 1966. The1,000 Hz high pitched sound was oscillated by 60 Hz fetal heart sound wave, thus fetal heat tone was the most clearly listened using small speaker of transistor radio. The tone was clearly listened by the members in the room, transferred by telephone and recorded by common audio frequency tape recorder, instead of a data recorder. It was thought to be ideal objective fetal heart tone monitor. However, there was a pitfall in the device, because the fetus who received intra-abdominal blood transfusion due to fetal anemia, which was monitored by the FPCG device in 1966, died at the final stage of transfusion. The sinusoidal FHR was confirmed by the CTG using the tape reproduction of heart sound as shown in the following figures, namely, the human listening did not recognize dangerous pathologic sinusoidal FHR (Figure 4). Thus, we stopped listening fetal heart beat, and moved to study FHR curve in fetal monitoring of which large machine was produced in 1964 (Figure 7).

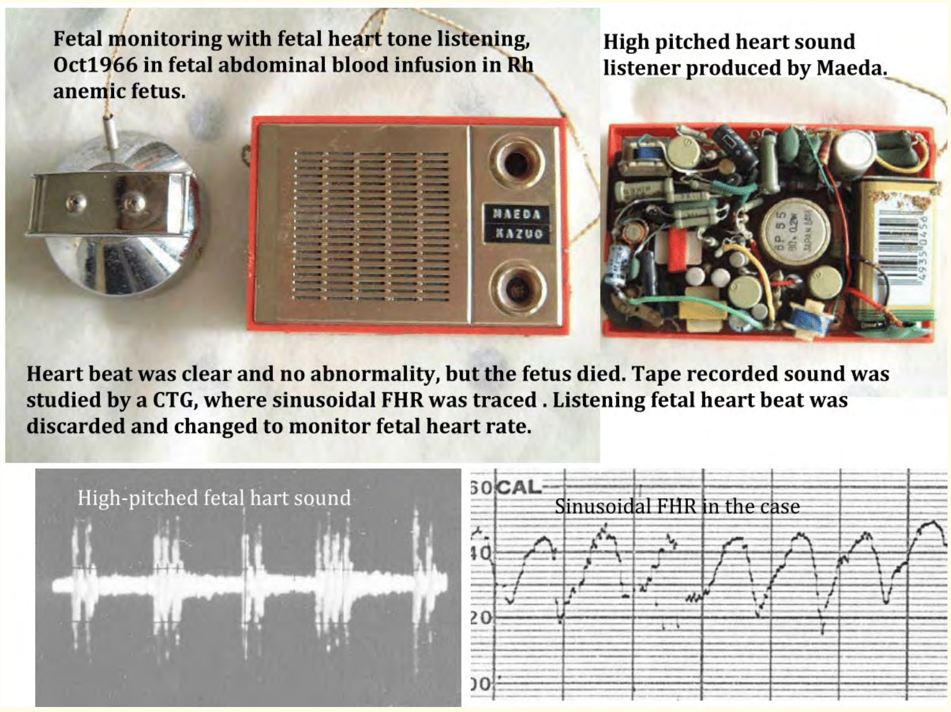

Figure 4: *High-pitched fetal heart sound listrner.*

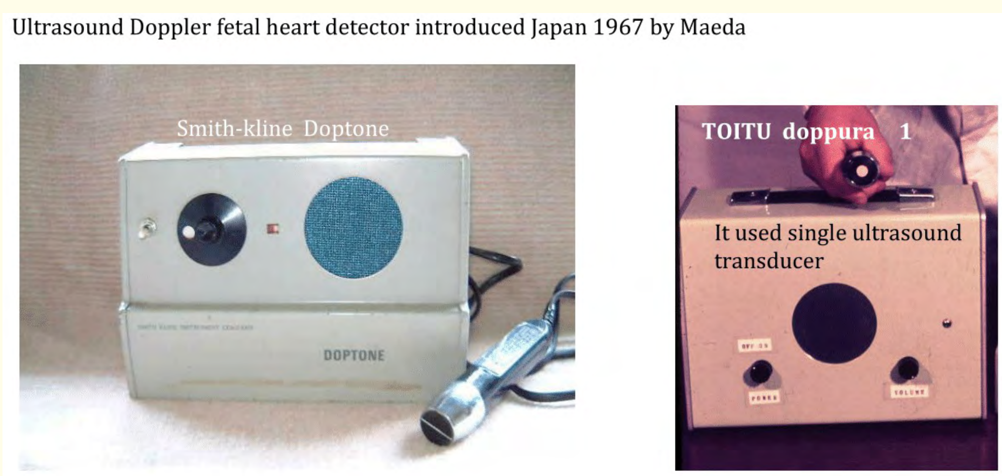

Figure 5: *Fetal heart beat was detected in 7 weeks deciding fetal life in early pregnancy, and fetal heart beat was clearly detected also in the labor, thus, objective fetal diagnosis was achieved.*
Ultrasonic Doppler autocorrelation fetal monitor achieved the most clear external FHR record.

World first continuous wave Doppler ultrasound of fetal arterial flow was reported by Maeda using frequency demodulation as follows in 1969 [1].

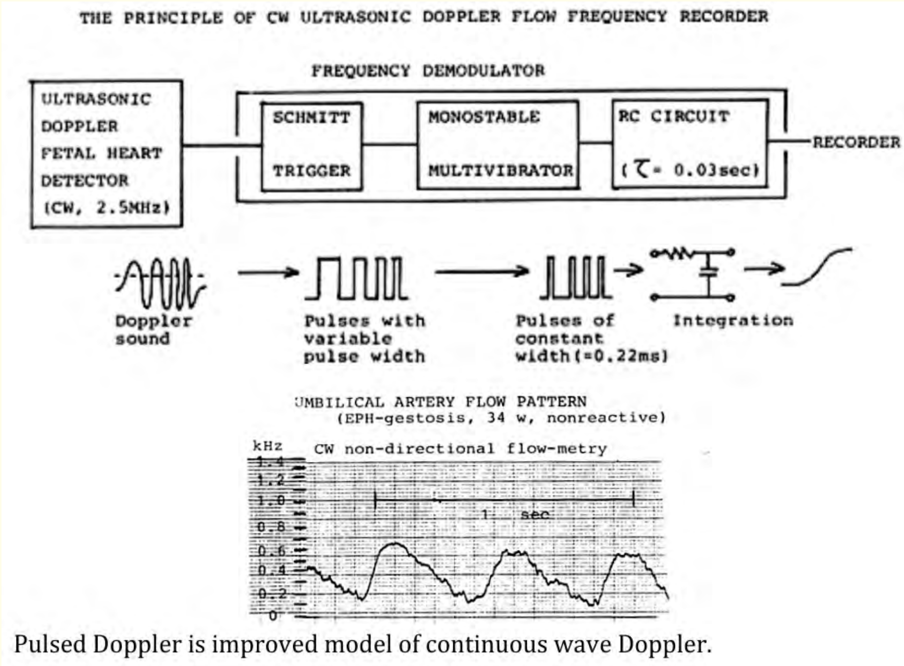

Figure 6: *World first continuous wave ultrasound Doppler fetal arterial flow wave.*

The first fetal monitor in Asia was designed by Maeda in 1964 [2,3].

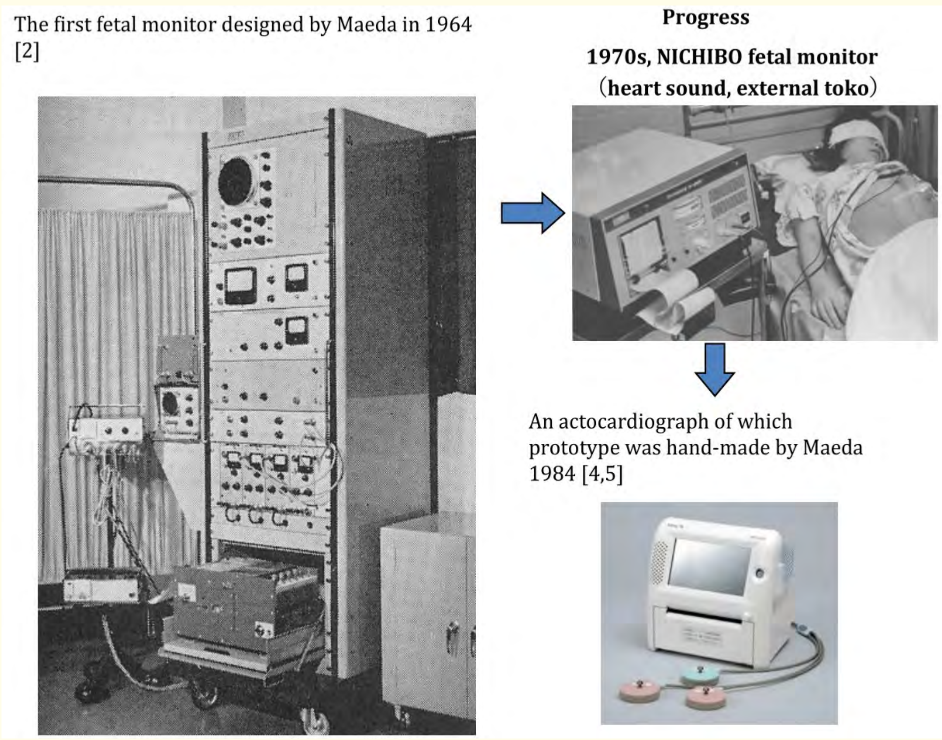

Figure 7: *The progress of fetal monitor in Japan.*

FHR was diagnosed with the deceleration patterns by Hon EH as follows [3]:

Early deceleration due to fetal head compression } Uniform shape

Late deceleration due to uteroplacental insufficiency } Uniform shape

Cord compression : Variable deceleration: Variable shape

Hon's diagnostic method was widely distributed in the world, while it was controversy, and it was subjective in visual classification.

Figure 8: *FHR was diagnosed with the deceleration patterns by Hon [3].*

Present

Thus, FHR pattern classification was discarded, instead, FHR was studied by quantitative analysis with FHR score by Maeda in 1969 [1].

Quantitative FHR analysis

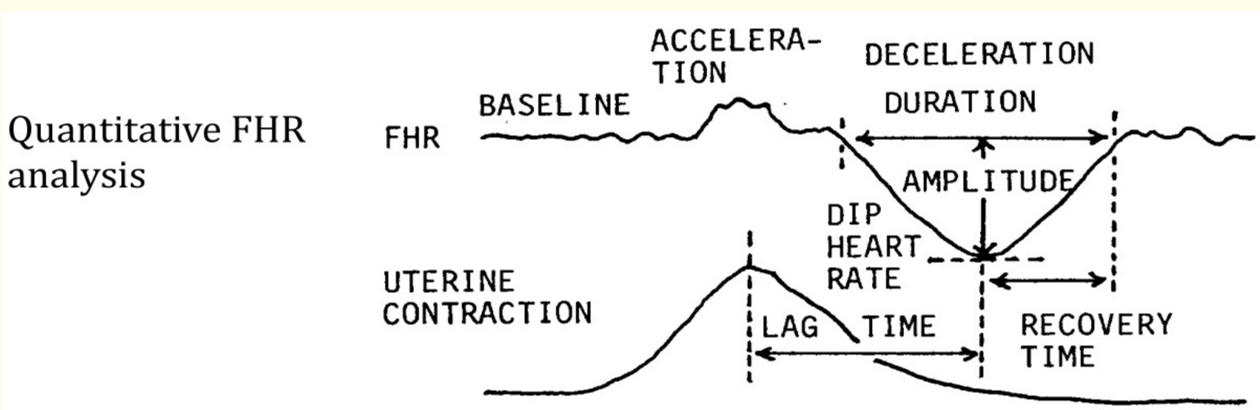

Figure 9

FHR component	Evaluation score
Baseline FHR < 110 or > 180 bpm Deceleration	3
Nadir < 100 bpm	2
Amplitude > 50 bpm	2
Duration > 60s	2
Recovery time > 40 sec	3
Lag time > 40 sec	3
Accompany no acceleration	2
W-type	4

Table 1*: Calculation of FHR score.*

FHR components were evaluated with the incidence (%) of low Apgar sore lower than 7.

FHR score is the sum of evaluation scores in 5 min, it is computerized, 10 or more of FHR score is abnormal, 20 or more is highly abnormal, while less than 10 is normal.

Asphyxia and acidosis is predicted using FHR score, as FHR(X) closely correlated Apgar score (Y) and UA p H (Z): namely, $Y = 9.361- 0.335X$, and $Z = 7.37 – 0.016X$.

Thus, neonatal status is expected by the FHR score.

FHR score	1 min Apgar score	UApH
0	9	7.37
5	8	7.32
10	6 (Mild Asphyxia)	7.27
15	4 (Asphyxia)	7.07 (Acidosis)
20	3 (Severe Asphyxia)	6.97 (Acidosis)

Hypoxia Index (HI)

As fetal bradycardia closely correlated PaO_2 less than 50 mmHg in rabbit, and human fetal PaO_2 was less than 50 mmHg, the duration of FHR deceleration means the duration of fetal hypoxia, HI is the sum of deceleration duration (minutes) divided by the nadir FHR (bpm) of deceleration, and multiplied by 100, where hypoxic effect is evaluated by HI through the full monitoring course, while the FHR score evaluates fetal state in 5 minutes.

As HI was 25 in a case of the loss of variability followed by cerebral palsy and 26 in repeated late decelerations (LD) and the loss of variability followed by severe brain damage, while HI was 20 - 24 in abnormal FHR cases who preserved the variability followed by no cerebral palsy, thus, HI should be less than 25 to prevent cerebral palsy, and therefore, early delivery will be done before the HI elevates to 25 [6]. As the HI was 6 and Apgar score was 9 in case of 3 connected LD and caesarean delivery, the discrepancy of LD was solved by HI. High HI is resulted by repeated decelerations, HI diagnosis is not limited in LD, but all decelerations, including early, late and variable decelerations will be evaluated by HI. In addition, sudden FHR bradycardia will be the subject of HI evaluation too, namely, computerized FHR monitoring will be simplified excluding complicated deceleration pattern classification, despite total diagnosis is fully objective introducing HI.

The outcome is favorable, if the HI is low even in the delivery after 2 - 3 connected late decelerations, while it will be ominous when the baby delivered after highly repeated decelerations and HI was higher than 25, where the fetus has been exposed to the sum of repeated hypoxic effects in multiple decelerations, because the heart rate was highly correlated PaO_2 [7].

A/B ratio

Actocariographic A/B ratio will predict ominous outcome, if the A/B ratio is lower than one, where A is the sum of duration of acceleration, and B is the sum of duration of fetal movement burst in definite duration of fetal monitoring.

A/B ratio is based on the theory that FHR acceleration is the reaction of fetal brain to fetal movement, thus, it is the sign of fetal brain function, where its reduction shows hypoxic brain suppression.

FHR deceleration and maternal posture

As mechanical cause of late deceleration was reported, where contracted pregnant uterus compressed maternal iliac artery interrupting placental blood flow at maternal supine posture, and the late deceleration disappeared at her lateral posture, a case of late deceleration is recommended to change her posture to lateral one.

Not only LD, the deceleration caused by supine hypotension disappears by lateral posture. The deceleration caused by the compression of umbilical cord will be improved by lateral posture. Sudden acute fetal bradycardia also should be treated by lateral posture, since there may be compression or prolapse of umbilical cord, which should be most quickly treated, therefore, the lateral posture will be a simple and the first treatment of deceleration, and can be followed by caesarean delivery.

Progress of Medical Ultrasound

The first imaging device was the contact compound scan B-mode which moved single element probe over the abdomen of pregnant woman. Although rough fetal images were visualized on the cathode ray tube, details were unknown, e.g. total hydatidiform mole was diagnosed by snow storm pattern, but not by imaging molar cysts.

Next invention was early electronic scan real-time B-mode without interlace and focusing, thus, no detailed fetal image was obtained in early pregnancy.

The Octoson ultrasound scanned pregnant woman's abdomen placed above membrane covering water tank where 8 moving transducers scan in the water. The detailed sectional B-mode image was the best one among various B-mode imaging ultrasound devices, although its image was stable, not real-time.

The early electronic scan B-mode image was insufficient, while completed electronic scan B-mode model prepared full focusing function, and it analyzes the embryo in early pregnancy, thus, it was widely distributed with sector, linear, convex scan probes for abdominal and vaginal scans, even at present.

Ultrasonic Doppler study was created by Satomura, and ultrasonic Doppler fetal heart detector was introduced in Japan 1967, 50 years before, by Maeda. The first CW fetal arterial blood flow wave was recorded by the author 1969 [1], then pulsed Doppler flow wave started, where analyzing blood flow shown by color/power flow image, then pulsed Doppler ultrasound was adopted at the vessel to record pulsed Doppler flow image, where arterial flow pulsation was recorded to detect the absent or reverse end-diastolic flow (ARED) in cases of high peripheral blood flow resistance with resistance index (RI) or pulsatility index (PI), peak systolic flow velocity, etc.

Baba created three dimensional technique 1980s, and Kretz technik completed and provided computerized 3D and 4D ultrasound machines, Kurjak studied antenatal CNS lesion with KANET score. Recent progress is 3Dlive system including silhouette function.

Focused intensive ultrasound (FIUS) was introduced in the TRAP sequence ablation [8].

Clinical ultrasound tissue characterization with gray level histogram width (GLHW) was created by the author 1998, where the placenta, placental intervillous fibrin deposit, its heparin therapy, ovarian and endometrial malignancies, fetal lung immaturity [10] etc. were diagnosed with GLHW [9,10].

In diagnostic ultrasound safety, Shimizu reported fetal animal anomaly formation after direct attachment of ultrasound transducer at pregnant small animal, warning the ultrasound use in early pregnancy, while it was an artifact caused by the heated transducer with electric current in the transducer, which were confirmed by no anomaly developed in exposure insulating transducer heat with 37^{o}C stabilized water in the study group of Japan Welfare ministry, where ultrasound was safe to fetal animal, while Maeda, *et al*. found that cultured cell growth curve was suppressed by 240 mW/cm^2 ultrasound exposure by heat insulated exposure, while ultrasound was globally safe, if its thermal and mechanical indices (TI and MI) were lower than 1.0. The 1 TI will be slightly lower than 240 mW/cm^2. Transvaginal scan transducer probe surface temperature should be lower than 41^{o}C, namely, abdominal scan probe can be heated nearly 41^{o}C by electric current flow in the probe, thus, the abdominal scan probe should not be directly attached to pregnant small animal to avoid excess heating of small animal and its fetus, when the probe attached animal for 30 or more minutes, giving damage to the fetus of small animal, studying ultrasound bioeffect.

Ultrasound probes are controlled at the device panel, changing gain, contrast, indicating freezing, photo, Doppler flow, repetition frequency, baseline level, and display ofcolor/power Doppler flow mapping, or pulsed Doppler control.

3D device prepares scanning multiple B-mode plains but the off-line image processing by computer to display 3D images. As 3D B-mode plains are electronic scan 2D modules, it is possible to prepare multiple functions, e.g. overall focusing. New 3D is HD live function to attach the subject shadows from various light angles, getting silhouette function of fetal image and so on.

4D device added the motion of subject, studying more fetal functions.

How will be the safety of 3D and 4D ultrasound ?. As 3-4 D images are based on 2D ultrasound images, they follows common safety of medical ultrasound, i.e. they are safe, if their TI and MI is lower than 1.0. Pulsed Doppler wave image was not disturbed, if the source ultrasound was as low as 0.1 TI [11], according to ALARA principle. However, their handling is limited to the medical purposes, not allowing simple memory or keepsake.

Future

Fetal neurology, antenatal medicine, studies on the diagnosis and therapy of genetic diseases, and objective managements in the birth, namely, fetal descent in the birth canal is known by the real time B-mode, while fetal presenting part and rotation are diagnosed by the perineal scan of 3D and 4D ultrasound, e.g. fetal presentation, rotation of fetal head is diagnosed not by vaginal examination, but with 3D or 4D perineal scan, where mentoanterior face presentation is possible to deliver vaginally, while vaginal delivery is unable in mentoposterior face presentation. Forceps operation is allowed when sagittal suture of fetal head corresponded with antero-posterior pelvic axis using perineal scan 3D ultrasound, which is diagnosed by subjective vaginal examination at present. Presenting part of breech delivery is diagnosed by 3D ultrasound in the future, Vasa previa and cord prolapse will be diagnosed by color Doppler flow mapping of perineal 3D scan.

Thus, real-time B-mode, 3D or 4D ultrasound are the devices mandatory in future birth room.

Intrapartum fetal monitoring utilizes external fetal heart beat signals and myometric muscle action potential in external tocodynamometry. Fetal diagnosis and prediction of risky processes are achieved by automated computer analysis, where multiple simultaneous deliveries are monitored by single computer utilizing multiple time sharing system. Fetal magneto-encephalography and –cardiography will be clinically studied.

Conclusion

Subjective studies was not scientific. Although objective diagnostic techniques have been introduced in obstetrics and gynecology in the past 60 years in the field of the author, objective methods will be furthermore studied in the future.

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Volume 7 Issue 3 March 2018