REVIEW ARTICLE

Fetal Diagnosis with Ultrasonic Actocardiogram and GLHW Tissue Characterization

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ABSTRACT

Actocardiogram: Ultrasonic Doppler actocardiogram was simultaneous tracing of FHR and fetal movement signals on the monitoring chart, created in 1984 by Maeda. Fetal behavior was easily studied, false-positive nonreactive FHR and physiological sinusoidal FHR were differentiated, the severity of fetal CNS lesion and common fetal disorders were determined, short and long-term outcomes were diagnosed in multiple grades.

GLHW: It is clinical tissue characterization by common ultrasonic B-mode apparatus. Placental tissue was characterized and grade-3 placenta was detected. Placental origin of FGR was diagnosed and meconium stained turbid amniotic fluid was differentiated from clear fluid. Fetal periventricular echodensity preceding neonatal PVL was analyzed; 96% of fetal lung immaturity was noninvasively detected endometrial; benign hyperplasia, carcinoma, benign ovarian mass and malignancy were differentiated.

Keywords: Fetus, Ultrasound, Doppler, FHR, Behavior, Nonreactive, Sinusoidal, Severity, CNS lesion, Disorders, Outcome, Tissue characterization, Placenta, Grade-3, FGR, Amniotic fluid, PVE, PVL, Immature lung, RDS, Endometrium, Hyperplasia, Malignancy, Ovary.

ACTOCARDIOGRAM

Creation

Fetal movements were traced by the surface actogram in the past[1] that recorded the movement of maternal abdominal wall which was the same as maternal perception that was only 64% of intrauterine fetal movements and insufficient to scientific studies, while in the present it is recorded by the direct actogram that fully detected fetal body movements by ultrasonic Doppler technique (Maeda 1984).[2]

The actocardiogram traces fetal heart rate (FHR) and direct fetal actogram is detected by ultrasonic Doppler method with single probe. Commercial model also traces uterine contraction. Weak continuous wave ultrasound was reflected from the fetal trunk through maternal abdominal wall, where various movements developed Doppler signals, including fetal body, fetal heart beat and maternal motion. Fetal heart rate is traced by fetal heart beat Doppler signals which was higher than 100 Hz. Fetal movement Doppler was 20 to 50 Hz when the ultrasound was 2 MHz, which was separated from other movements, changed to low-frequency spikes and recorded on fetal monitoring chart. Maternal motion Doppler less than 1 Hz was discarded.[2] Commercial actocardiogram is produced by TOITU (Tokyo).

Fetal Behavior

The resting fetal state, Nijhuis 1F,[3] showed no movement burst and no heart rate acceleration, where small 3 to 6 cpm variability was present (Fig. 1). In the active fetal state, Nijhuis 2F, FHR accelerations synchronized multiple fetal movement bursts (Fig. 2). In the intermediate states, Nijhuis 3F, FHR acceleration and movement burst was definitely small and rare (Fig. 3). Highly active state, Nijhuis 4F, was transient tachycardia associated with prolonged movement burst (Fig. 4).

Fetal behavioral states defined by computer analysis of movement spikes changed during pregnancy, but stable after 34 gestational weeks where basic function would be accomplished its development by that stage.[4]

Actocardiogram will contribute to fetal behavioral study, because the record was objective, continuous, technically easy and useful in prolonged study and off-line analysis.

Fetal Hiccups

Fetal hiccupping was traced as regular spikes with ca at 2 seconds intervals, i.e. its frequency was 0.5 Hz, without FHR acceleration (Fig. 5). Fetuses hiccup frequently, e.g. twice in daytime.[5] Since 12 weeks fetus hiccups in real-time B-mode, hiccupping will be normal physiological process before the establishment of respiratory reflex.

The interval of continuous fetal respiratory movements was ca at 1 second, i.e. the frequency was 1 Hz, also accompanied no FHR acceleration.

Differentiation of Physiological Sinusoidal FHR

The periodic fetal respiration evoked physiologic sinusoidal heart rate, which was differentiated from very ominous
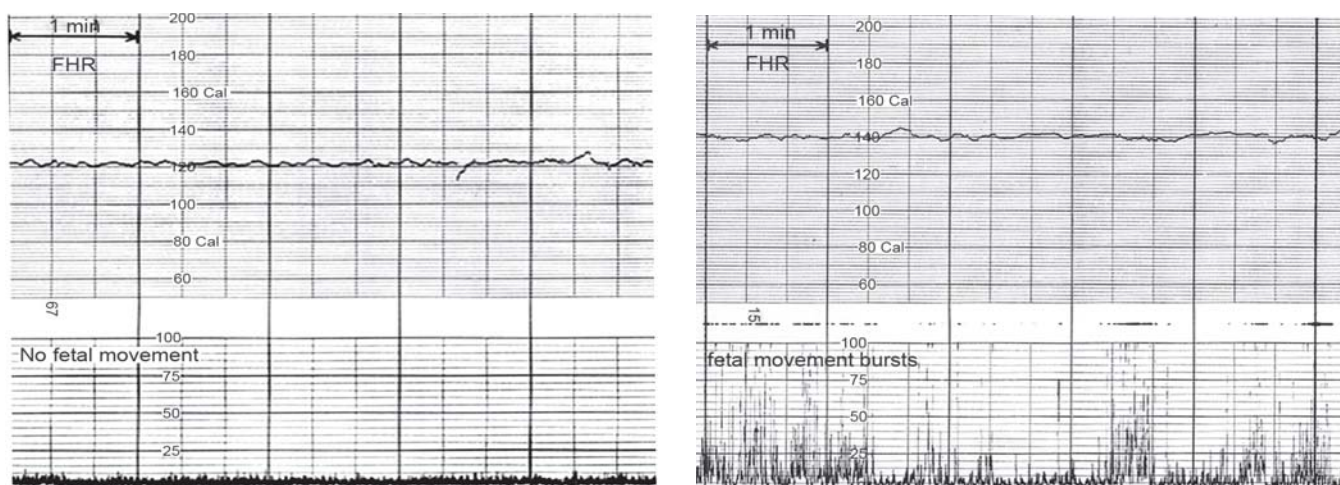
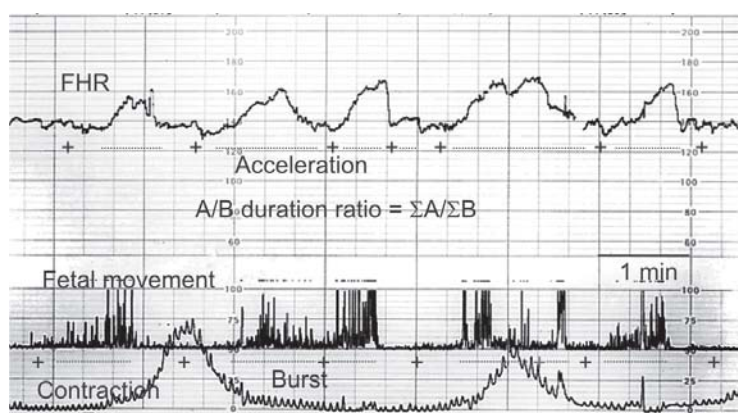Fig. 1: Actocardiogram in fetal resting state and its differentiation from the nonreactive FHR

Fig. 2: Actocardiogram in fetal active state. The FHR acceleration duration ratio to fetal movement burst (A/B ratio) is measured on the accelerations and movement bursts
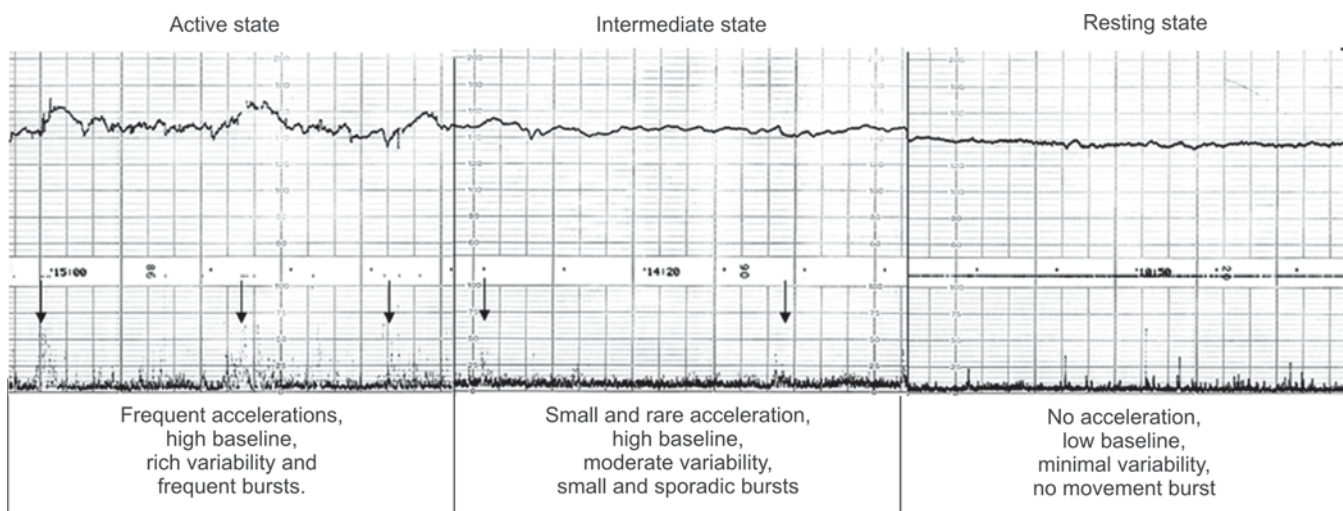

Fig. 3: Actocardiogram in fetal intermediate state. Sporadic and small FHR acceleration and movement bursts were revealed

pathologic sinusoidal FHR by the actocardiogram[6] (Fig. 6). They were also separated by the fast fourier transform frequency analysis of FHR baseline.[7]

Nonreactive Fetal Heart Rate

Ominous nonreactive FHR characterized by the absent FHR acceleration is easily and correctly differentiated by the associated fetal movement bursts from normal resting fetal state which also reveals no FHR acceleration but it was associated with no fetal movement burst at all in the actocardiogram (Fig. 1).

Cross Correlation Coefficient of FHR and Movement

The coefficient was largest when the movement was delayed for 7 seconds from the heart rate signals in fetal active state,
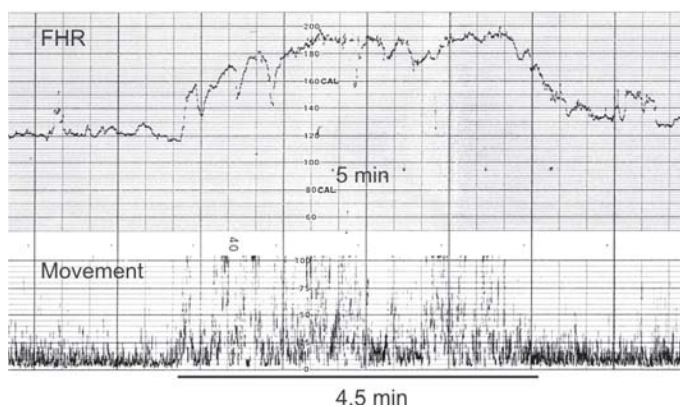
Fig. 4: Actocardiogram in highly active fetal state. Transient tachycardia was associated with the prolonged fetal movement burst
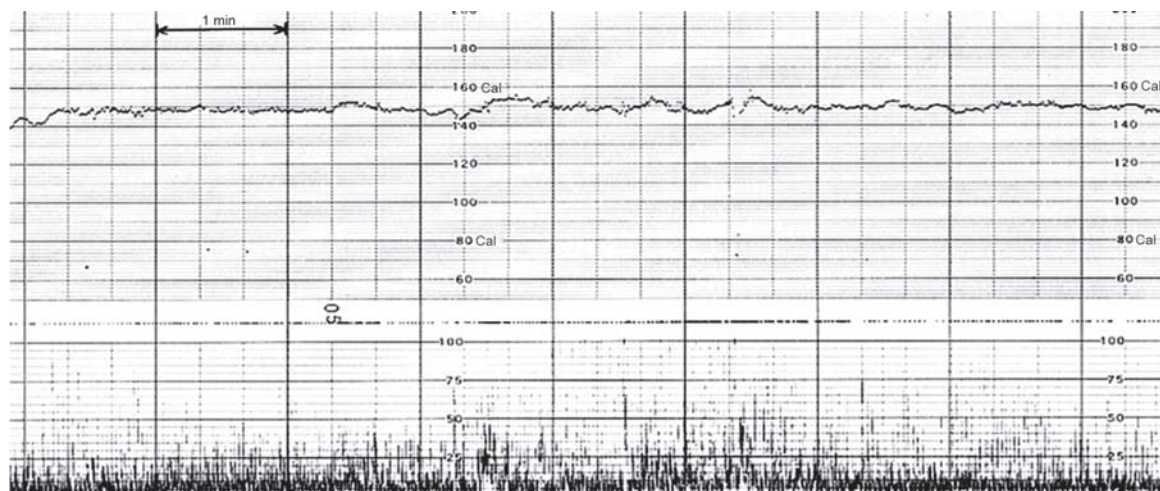

Fig. 5: Actocardiogram in fetal hiccupping movements. The spike interval was 2 seconds (frequency = 0.5 Hz) which was determined by the augmented actogram
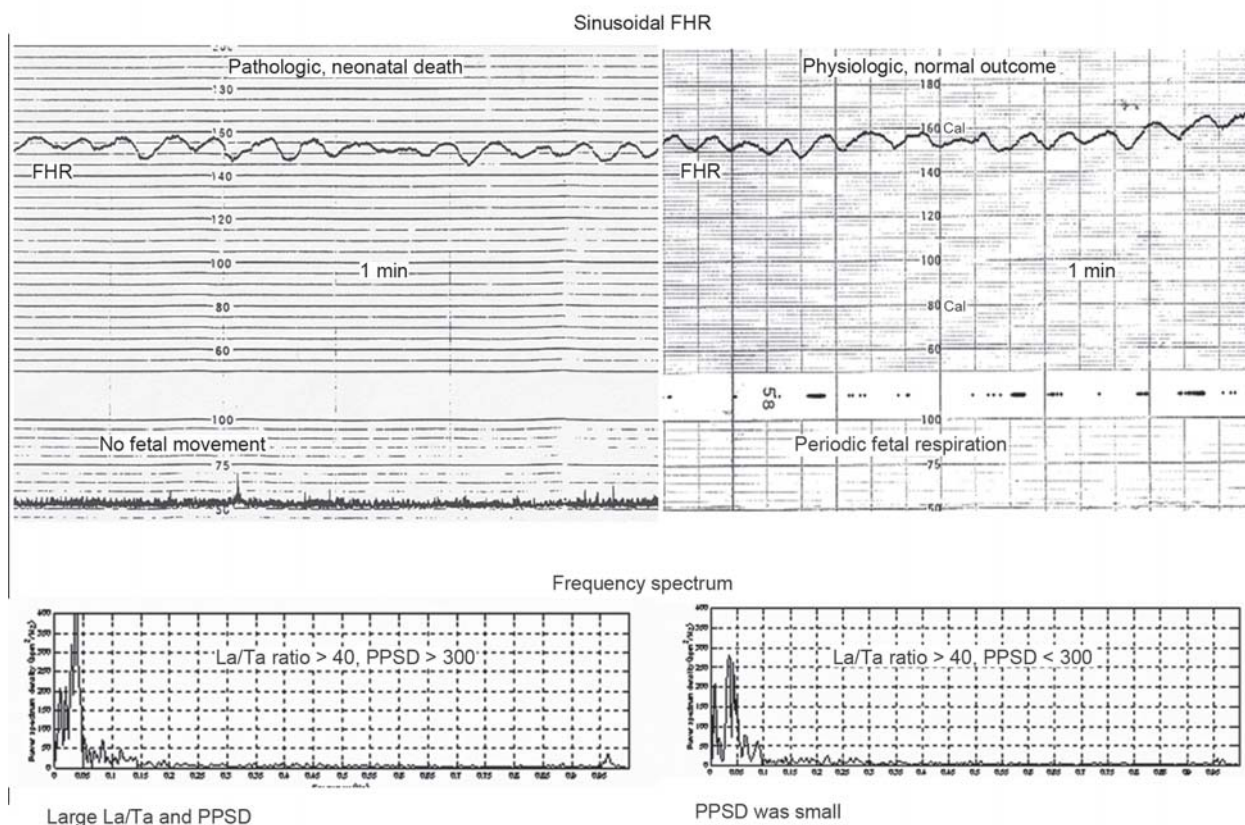

Fig. 6: Physiological sinusoidal FHR (right) of normal outcome was differentiated from pathological one (left) by the accompanied periodic respiratory movements. Frequency spectrum analysis was also useful to the differentiation of physiological and pathological sinusoidal FHR in lower figures

while the coefficient was null in the resting state. From the results, it is suggested that fetal movement precedes FHR change for about 7 seconds, i.e. fetal movement may evoke FHR change with 7 seconds' lag time. Since correlation coefficient was small and delay time was long in young fetus, fetal nervous function will be assessed by the cross-correlation of FHR and movement.[8]

Fetal Response to Sound or Light Stimulation

The fetus was stimulated by pure 1,000 Hz sound and a photographic strobe light of 20 guide number. Fetal response to both stimulations was fetal movement burst followed by FHR acceleration.

The fetus responded 80 dB sound in 28 weeks of pregnancy and 60 dB in 40 weeks, i.e. fetal hearing ability was 10 folds improved in late pregnancy.

The fetus responded the light firstly in 23 weeks when the retina was reported to be formed, and the positive response rate increased until 40 weeks of pregnancy,[4] i.e. fetal audio-visual function definitely augmented in late stage of pregnancy, and antenatal fetal audio-visual function test will be promising by using actocardiogram.

Actocardiograms in Fetal Central Nervous System Lesions

The parameter used in the study was fetal acceleration duration ratio to the movement burst (A/B ratio) (Fig. 2).

The B-mode studies on fetal behavioral function with the five functional steps classified five central nervous system (CNS) lesion fetuses into five ranks,[9] and we studied their actocardiographic A/B ratio separately and classified into five ranks. Since both behavioral and actocardiographic rankings were identical, the A/B ratio was applied to evaluate the severity of fetal CNS lesions. Severity rank was determined by the A/B ratio, which was evaluated in new cases by the regression equation obtained in studied cases of CNS lesion.[10]

Actocardiogram in Anencephalic Fetus

There was no FHR acceleration against the heavy fetal movement burst, and the baseline variability was lost (Fig. 7).[11] Three components of succeeding two movement bursts were identical and the movement intensity attenuated in each bursts. The findings may be characteristic in the fetal movement which was under the loss of cerebral control.

Actocardiograms in the Common Fetal Disorders

Although nonreactive FHR was diagnosed by the loss of acceleration in the CTG, no gradual changes associated with increasing hypoxic damages had been evaluated, therefore the quantitative A/B ratio was studied, i.e. the relation of fetal outcome and A/B ratio was studied.

In short-term outcome, the A/B ratio significantly correlated Apgar scores, i.e. Apgar scores were 9 when A/B ratio was 1.4, Apgar score was 6 when A/B was 1.0, Apgar score was 3 when A/B was 0.6, according to the regression equation (Fig. 8) where $Y(\text{Apgar score}) = 7.16X(\text{A/B ratio}) - 1.12$. Therefore, hypoxic damages of various grades may be determined by the A/B ratio before the established nonreactive heart rate, i.e. advancing course of fetal hypoxia may be monitored in details, and the conservative treatment of abnormal FHR will be evaluated by the A/B ratio.

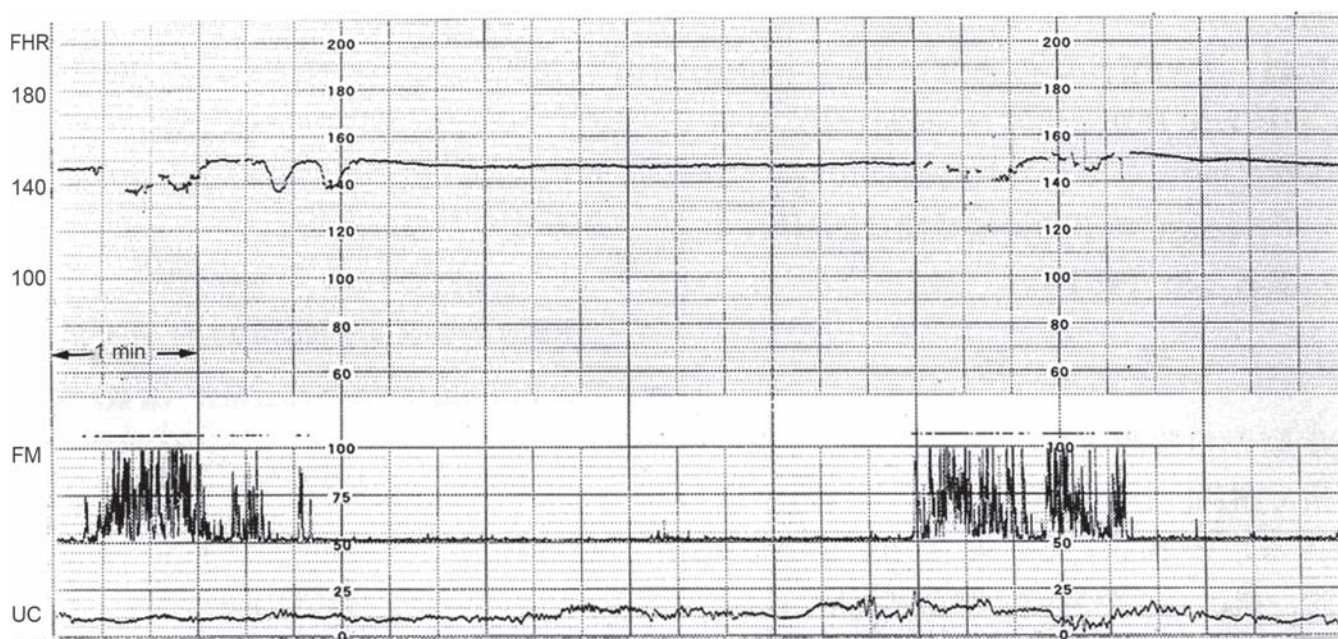The voluntarily quantified long-term outcome also significantly correlated with the A/B ratio (Fig. 9).[12]

Fig. 7: Actocardiogram in anencephalic fetus. There was no FHR acceleration against movement burst, baseline variability was lost, and the shape was identical between two succeeding movement bursts
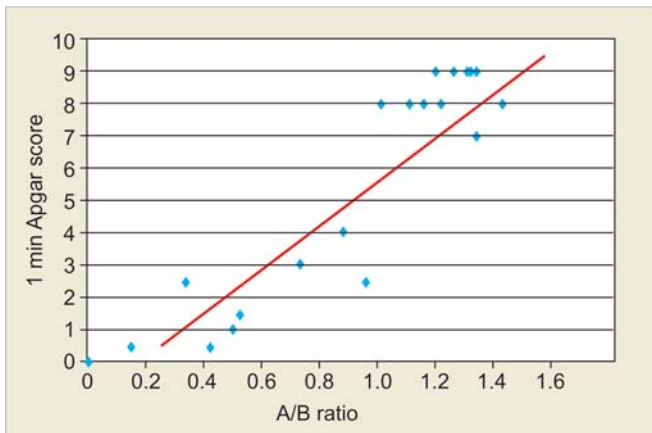
Fig. 8: The A/B ratio of actocardiogram closely correlated short-term outcome (1 minute Apgar score), i.e. the progressive status of fetal hypoxia will be assessed, or the effect of conservative treatment is evaluated by the A/B ratio
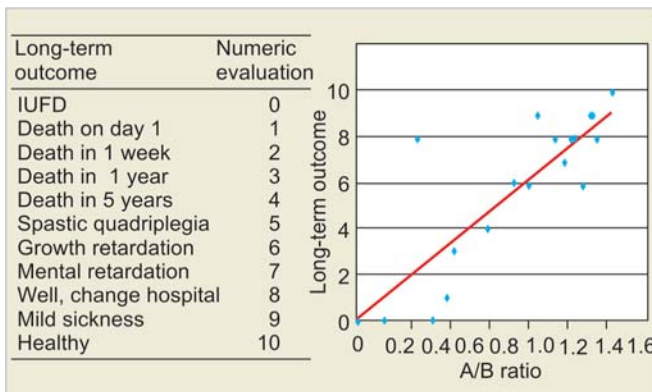

Fig. 10: GLHW is measured by common ultrasound B-mode. Select histogram menu, set the ROI on B-mode image, display histogram, measure the base width (W) and full gray scale (F). GLHW = W/F (%). Automatically measured GLHW (%W) determined by A-B was identical to manual determination

Fig. 9: The A/B ratio of actocardiogram closely correlated (right) quantified long-term outcome (left)

Summary of Actocardiograms

The actocardiogram directly detects intra-amniotic fetal trunk movement, it is useful not only to evaluate fetal movements, including fetal hiccups and continuous breathing, but also to study fetal behavior, to reduce false-positive FHR changes for about 70%, to differentiate nonreactive FHR from resting fetal state and physiological sinusoidal FHR from pathological one. The correlation of FHR and movement, ripening of basic fetal function at 34 weeks, initiation of fetal response to light in 23 weeks and its progress during pregnancy, and increased hearing function in late pregnancy were investigated by the actocardiogram. The severity of fetal CNS lesion was determined by the A/B ratio of actocardiogram. The ratio closely correlated also to short and long-term fetal outcome in common fetal disorders, i.e. advancing course of fetal hypoxia will be clarified by the actocardiogram. Vigorous, uniform and attenuating movements of anencephalic fetus suggests the primitive fetal movements without cerebral control. The loss of fetal brain control may be supposed if the primitive motion is observed in the late stage of pregnancy.
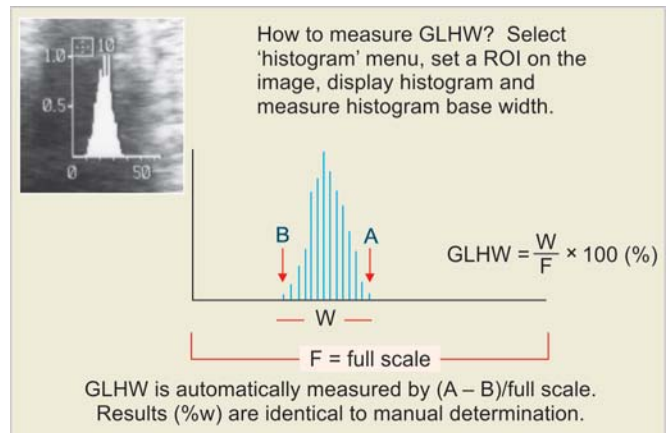
TISSUE CHARACTERIZATION WITH GRAY LEVEL HISTOGRAM WIDTH (GLHW)

Although ultrasound diagnosis had been marvelously advanced, tissue character of human subjects was suspected usually by the morphology, blood flow mapping, flow indices or tissue elasticity. Ultrasonic tissue character was assessed with special computer and software,[13-15] and MR imaging or spectroscopy[16] was special technique in common clinics. The author intended to study tissue characterization by more simple technique hopefully by using common B-mode machines in 1980s.[17] Although mean gray levels in the region of interest (ROI) was varied by the device gain control and the ROI depth, the author found that the gray level histogram base width was stable even if the gain was changed. The base width length was standardized by dividing the histogram width with full gray scale length and the result was called gray level histogram width (GLHW) (Fig. 10). The GLHW of a B-mode model was calibrated to 36% by using RMI ultrasound phantom by the control of image contrast or dynamic range.[19]

Placental GLHW

The GLHW of placenta in every two weeks of pregnancy was obtained to use for various purposes. The GLHW values of grade-3 placenta were larger than mean + SD values in the corresponding gestational weeks.[17]

Fibrinolytic Treatment of High Placental GLHW in FGR

The placental GLHW was high in a case of FGR in the 2nd trimester where previous pregnancy was IUFD after FGR. The mother received daily 5,000 U heparin and adrenal steroid by Dr Utsu for the fibrinolysis of the intervillous space till the GLHW was reduced and fetal body weight increased to normal level in the third trimester. Normal neonate was born by the cesarean section.[17]

The GLHW of Gynecological Cancer

The GLHW of endometrial cancer was more than 50% and significantly higher than that of benign endometrial hyperplasia[18] (Fig. 11).

The GLHW of tumor mass of uterine cervical cancer was larger than 50%.

The GLHW values of five consecutive ROI were studied in the benign and malignant ovarian masses, where the mean GLHW was larger and the coefficient of variation (CV) was smaller in malignant tumor images than in benign masses (Fig. 12).[18]

Meconium Stained Amniotic Fluid

The GLHW of meconium stained turbid amniotic fluid was higher than normal clear amniotic fluid and similar to the GLHW of fetal colon contents (Yamamoto).

Fetal Periventricular Echodensity

Yamamoto et al[19] detected no fetal periventricular leukomalacia (PVL), but instead multiple periventricular echodensity (PVE)
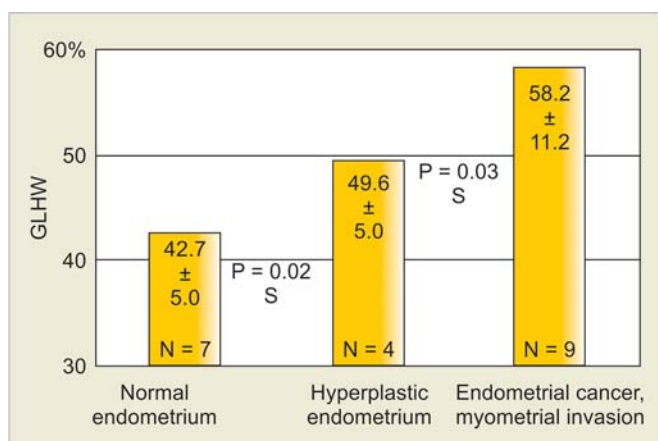

Fig. 11: The GLHW of benign endometrial proliferation was larger than normal endometrium, and endometrial cancer GLHW was significantly larger than benign proliferation
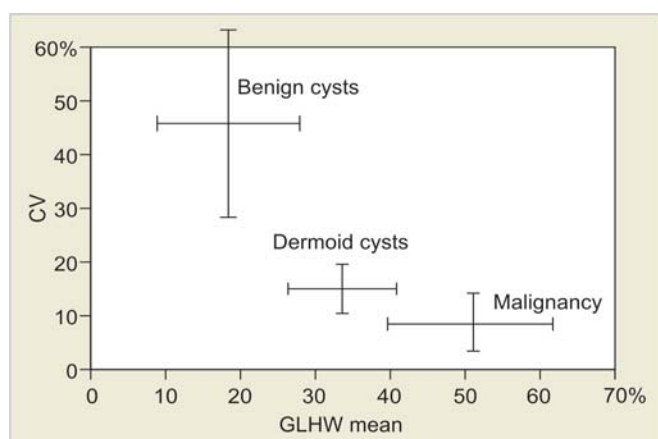

Fig. 12: The mean GLHW was larger and the coefficient of variation (CV) was smaller in malignant ovarian tumor than benign cystic tumor in the GLHW of five consecutive ROI

cases in high risk preterm fetuses by transvaginal scan, where the GLHW value was higher in the PVE than normal fetal brain. The neonate was normal in no PVE or when the PVE disappeared before the births even in preterm cases, while four cases (18%) of 22 persistent PVE until preterm birth developed cystic PVL in neonatal brain and associated with CP (Fig. 13). Since the neonates who had persisted PVE until the birth may develop PVE immediately after preterm births and may have high probability to produce PVL and CP, the brain of neonates will be ultrasonically studied immediately after preterm birth and neonatal PVE cases are pharmaceutically treated in the future to prevent PVL and CP.

Noninvasive Prediction of Immature Fetal Lung

Serizawa and Maeda[20] collected GLHW values of preterm fetal lung and liver in 23 cases of neonatal respiratory distress syndrome (RDS) and those of 25 normal neonates, and receiver operating characteristic (ROC) curves to predict RDS were compared among the estimated fetal birth weight (EFBW), gestational weeks, the ratio of fetal lung and liver GLHW, and the product of gestational weeks and the ratio of fetal lung and
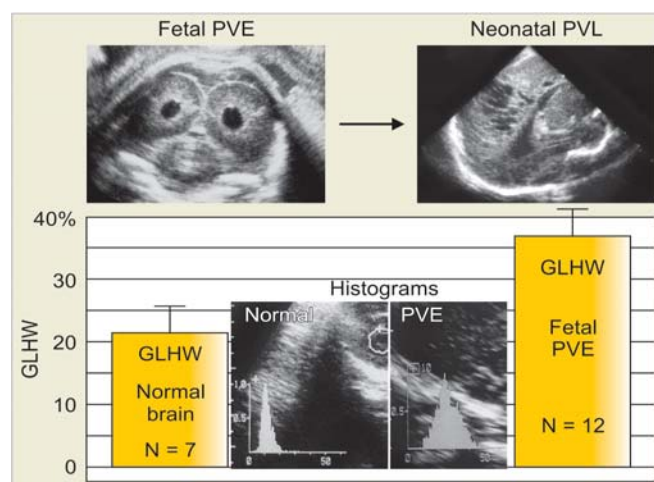

Fig. 13: The GLHW of fetal periventricular echodensity (PVE) was larger than that of normal fetal brain, where the PVE (upper left) preceded neonatal PVL (right) and cerebral palsy after the persistence until preterm birth
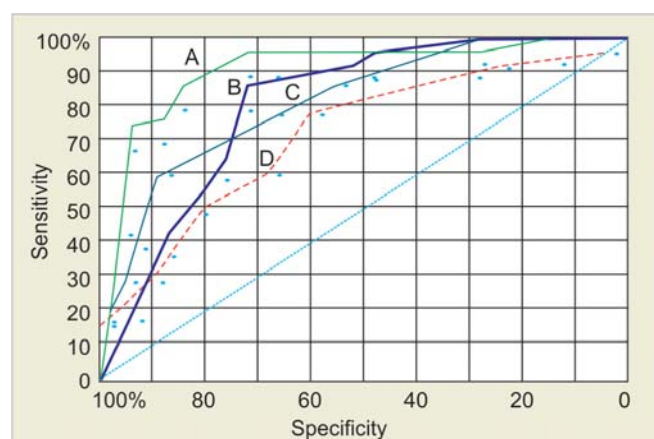

Fig. 14: ROC curves to evaluate the prediction of fetal lung immaturity. (A) The product of lung/liver GLHW ratio and gestational weeks, (B) the lung/liver GLHW ratio, (C) gestational weeks, (D) estimated fetal weight

liver GLHW (Fig. 14). The neonatal RDS was predicted for 96% and the prediction rate was the highest in the product of gestational weeks and the ratio of fetal lung and liver GLHW, which was comparable to the chemical and physical analysis of amniotic fluid, i.e. ultrasonic tissue characterization was effective to noninvasively predict immature fetal lung, and invasive amniocentesis is not mandatory in the diagnosis of fetal lung immaturity.

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