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EDITORIAL

History of Medical Ultrasound

Kazuo Maeda

ABSTRACT

The first medical ultrasund was studied by Prof Dussik in Vienna 1942, using A-mode in early diagnostic ultrasound. Early 2D ultrasound showed images by contact compound scan. Prof Ian Donald studied his own B-mode device in gynecologic subjects in 1950s. Mechanical scan real-time ultrasound was Vidson in 1960s. Multiple 64 units was provided in electronic scan, however, early one had neither interlace nor focussing, thus its image was insufficient. Common electronic scan real time device prepared universal focussing function to achieve details even in early fetuses. The image was applied not only in abdominal ultrasound, but also moving heart and narrow transvaginal scan. Real-time B-mode device was fully applied in fetal study after 1980. Although teratogenic ultrasound bioeffect was warned in Japan, the claim was rejected separating transducer heat in a group study, reporting bioeffect threshold as 240mW/cm^2 by the author group. The first continuous wave (CW) Doppler fetal arterial flow wave was reporded by the author, who also created fetal Actocardiogram, to record fetal movment and fetal heart rate (FHR). Fetal arterial pulsed Doppler flow wave detected fetal compromise. Fetal face and anomalies were clearly demonstrated using 3 and 4 dimensional ultrasound with the devices provided by Kretstechnik after the first report of Prof Baba in 1986. Fetal neurology was published by Dr Pooh. Prof Kurjak created KANET score. Update 4D image is HDlive Silhouette techniques, which further clearly shows fetal images. Focussed intense ultrasound treated brain tumor by Prof Oka, and Prof Okai cauterized vessels of TRAP sequence.

Keywords: Doppler, 3D-4D ultrasound, HDlive Silhouette, Ian Donald, Medical ultrasound.

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EARLY HISTORY

Ultrasound was physically recognized as an inaudible high frequency sound by physicists who utilized it for communicative purposes. Langevan reported ultrasound bioeffect, in 1917. RW Wood and AL Loomis experimented high intensity ultrasound to detect physical and biological effects in 1927. In Japan, ultrasound generator was introduced first to Tohoku University, where Prof Kato studied basic ultrasound effects. Basic medical and biological ultrasound effects were studied in Japan in 1936.

Medical ultrasound was classified into diagnostic and therapeutic ones in the early application of ultrasound.

Therapeutic ultrasound: Common ultrasound therapy was the warning of patient's body by the heating of absorbed ultrasound of few watts, which was contraindicated to pregnancy and young bones.

Another therapeutic one was high intensity focused ultrasound (HIFU), first applied by Dr Oka, Japan in 1952 successfully treating brain tumor, and recently for the therapy of uterine fibroma under monitoring with magnetic resonance imaging, and recently to close nursing vessel of acardiac twin (TRAP sequence), and some fetal diseases by Prof Okai et al in Japan, 2015.

Diagnostic ultrasound progressed after introduction in medicine. Firstly, transparency method, Hyperphonographie was tried by KT Dussik in 1942, while the reflection method was introduced in diagnostic ultrasound, where initially the method was utilized to detect the flaw in such solid materials as metallic one. It was widely utilized in Japan (Fig. 1) and in the product of Kretztechnik in Austria, which was nondestructive metal flaw-detecting equipment.[2]

A-MODE

The A-scope (Fig. 2) was adopted in human medical diagnosis, in ophthalmologic and neurologic application by Prof KT Dussik, Vienna University, in mid 1940s. He was called as the first physician to have employed ultrasonics

Fig. 1: Ultrasound flaw detector in the past

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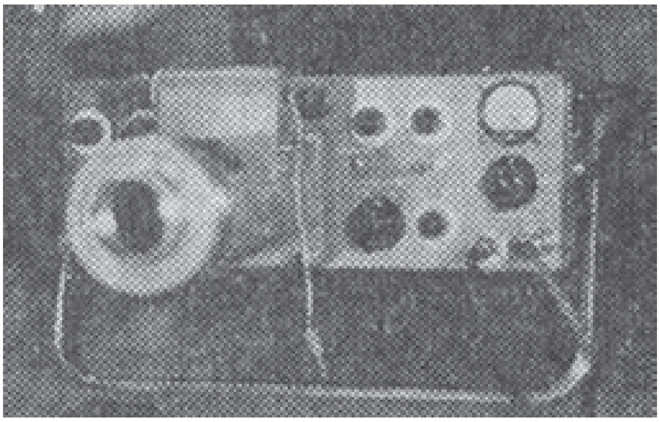

Fig. 2: Clinical ultrasound A-mode device

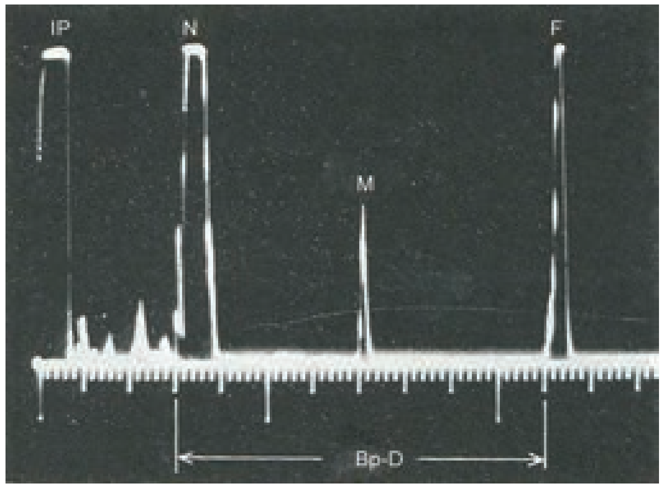

Fig. 3: Ultra A-mode measurement of a fetal head at 33 weeks of gestation (Aloka SSD-30, 2.25 MHz) (*Courtesy:* Professor H Takeuchi)

in medical diagnosis. K Tanaka, T Wagai, R Uchida, Y Kikuchi et al were ultrasound pioneers in Japan.

A-scope or A-mode was one-dimensional reflection method to record original and reflected pulse waves along the order of reflection, where the time of reflection to original pulse was expressed on the cathode ray tube (CRT), and reflection time was translated into the distance from the original pulse, then the distance between reflected pulse was measured, e.g., in fetal head, where the distance between near parietal bone and that of far parietal bone was fetal biparietal diameter (BPD) (Fig. 3). Fetal heart beating was shown in the vibration of fetal heart signal on the A-mode image by Kratochwil in 1967, which was demonstrated in his lecture in Japan and impressed Maeda.

PROGRESS TO B-MODE

The A-mode was the base of all modern ultrasound imaging, because the A-mode spikes were changed to bright dots, and distributed on the two-dimensional (2D) B-mode plane on the screen (Fig. 4). The B-mode images were displayed by moving the single ultrasound transducer on the patient's abdominal wall along the vertical scanning plane to show 2D image of subjects in the abdomen, which was the contact compound scan B-mode (Figs 5 to 10). The reflection spots were shown on the screen, which was recorded on the 35 mm camera film, namely total image of single subject was observed after developing film and its print, then the image was shown on the memorizing CRT, where the scanning image was shown at the same time with the transducer scanning. Original image of memorizing CRT was two tones of black and white, then changed to gray scale (Fig. 9). These were the contact compound scan technique.

The contact compound scan image was the B-mode image of large subjects, e.g., whole fetal body, fetal head, placenta previa, or large ovarian cyst, while such delicate subject as embryo was unclear, e.g., round hydatidiform mole was not shown as small cysts, but shown as snowstorm image (Fig. 10).

IAN DONALD IN OBSTETRICS AND GYNECOLOGY

Professor Ian Donald (1910–1987) graduated medical school at St. Thomas Hospital, 1937 and appointed Regius Chair of Midwifery at the University of Glasgow, 1954. He created own B-mode machine and reported results first in obstetric and gynecologic field, 1958 (Fig. 11) and also used real-time B-mode ultrasound machine (Fig. 12). The contact compound scan ultrasound was widely utilized in the world in 1970s.

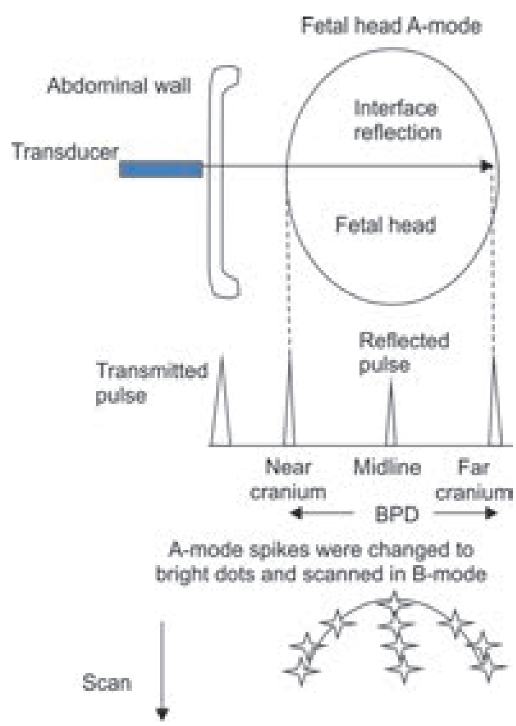

Fig. 4: Upper: Principle of fetal head A-mode. Lower: Change to B-mode from A-mode

Fig. 5: Contact compound scan in Tottori University

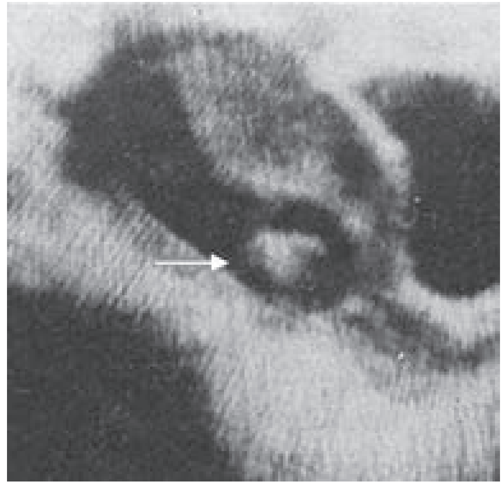

Fig. 6: Contact compound scan of a fetus in 12 weeks (*Courtesy:* Prof Morohashi, Keio University)

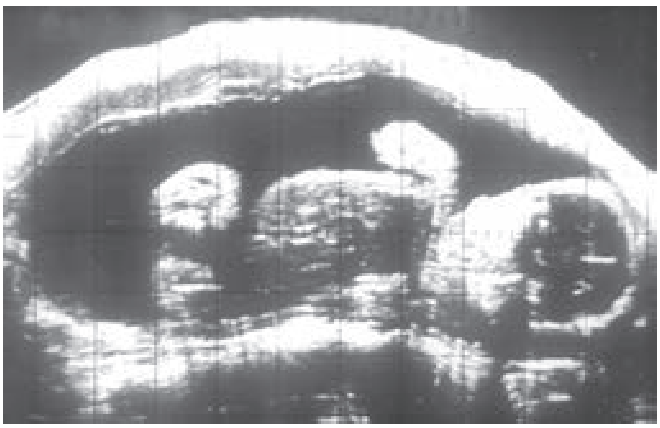

Fig. 7: Black and white two-tone contact compound scan of a normal fetus in 1978 by Prof Tottori

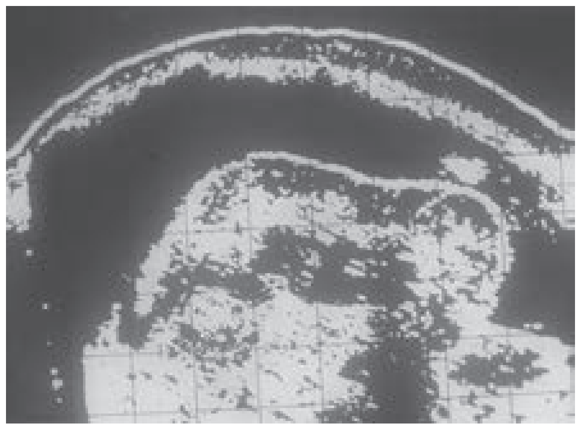

Fig. 8: Anencephalic fetus recorded by B-W contact compound scan, 1970s, Tottori

Fig. 9: Gray scale contact compound scan of fetal hydrops, 1970s (*Courtesy*: Dr Terahara)

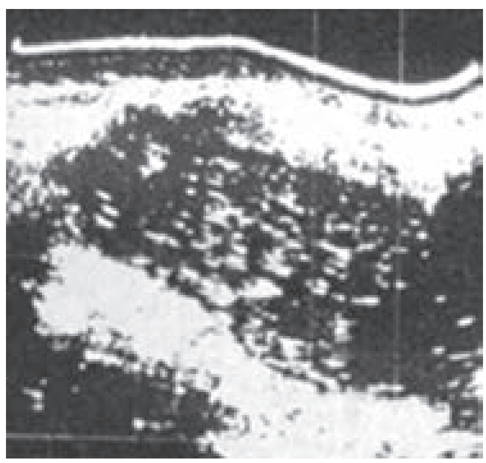

Fig. 10: Complete hydatidiform mole, contact compound scan. No cysts but snow-storm sign

Ian Donald studied and reported abdominal masses by pulse wave ultrasound B-mode (Lancet 1958), and measured fetal head by ultrasound (J Obstet Gynecol British Commonwealth 1962), namely, he was the pioneer of ultrasound in Obstetrics and Gynecology. A Kurjak and others learned medical ultrasound by the education of Professor Ian Donald (Fig. 13).

IAN DONALD SCHOOL OF ULTRASOUND IN MEDICINE

Prof Asim Kurjak recognized the importance of diagnostic ultrasound education in Obstetrics and Gynecology, and created Ian Donald School of Ultrasound in Medicine,

Fig. 11: First B-mode scanner of Prof Donald

Fig. 12: Prof Donald utilized real-time B-mode scanner

Fig. 13: Prof Donald, Kurjak and colleagues

Fig. 14: First Ian Donald School in the Inter-University Center, Dubrovnik, Croatia, 1992

1992 (Fig. 14). After some courses held in Dubrovnik, Croatia and in the other countries, the first Japanese Ian Donald course was held in Fukuoka, organized by Professor H Nakano, and the 18th Course of Japanese branch is held by R. Matsuoka in November 2016 in Tokyo. More than 110 Ian Donald School branches have been established in the world.

Prof Donald was invited to a special lecture in Japan Society of Medical Ultrasonics in 1981 (Fig. 15).

Fig. 15: Prof Donald was invited to plenary lecture in the Japan Society of Medical Ultrasound Congress in 1981

DOPPLER ULTRASOUND

S Satomura first studied medical ultrasound Doppler method of adult in 1959. Ultrasound Doppler method was widely distributed in blood flow studies including color Doppler flow mapping, pulsed Doppler flow waves, fetal movement, fetal HR curve, diagnosis of congenital heart diseases, fetal ductus venosus flow, and so on.

DA Callagan et al detected fetal heart beat with ultrasonic Doppler method, 1964.

K Maeda introduced Smith-Kline Doptone, the Doppler fetal heart detector, 1967 (Fig. 16). Fetal Doppler heart beat tone was listened early in 7 weeks of pregnancy, thus, afterwards, many Doppler fetal heart detectors were provided to diagnose fetal life in Japan, where almost all of Japanese obstetricians used Doppler fetal heart detector.

- Maeda recorded world first continuous wave Doppler ultrasound fetal arterial flow wave with frequency demodulation technique, 1969 (Fig. 17).
- D Baker et al proposed pulsed Doppler method, 1967.
- FD McLeod proposed indicated Doppler method, 1967.

Fig. 16: Smith-Kline Doptone was ultrasonic Doppler fetal heart detector, of which Doppler sound detected the fetus in early pregnancy. Fetal Doppler device was distributed in Japan

- E Bishop recorded fetal heart rate with Doppler fetal heart signals, 1968.
- Maeda recorded fetal heart rate with ultrasonic Doppler method 1968.
- R Gramisk reported contrast ultrasound cardiography 1969.

ULTRASOUND CONGRESS

The 1st World Congress of Ultrasound Diagnosis, Vienna, 1969.

- JM Reid reported Doppler angiography, 1972.
- Ultrasound Med Biol (WFUMB) was published, 1972.
- J Ultrasound in Medicine (AIUM) was published, 1973.
- Hitachi provided Doppler flow meter, 1972, 1974.
- Japanese J Med Ultrasonics Society was first published in 1963.
- "J Medical Ultrasound" was first published by Japan Ultrasound Society, 1974.
- Australia Society of Ultrasound, ASUM, established 1971.

The 1st World Congress Ultrasound in Med (FWUMB) at San Francisco, 1976.

"Ultrasound" session was held in the 9th FIGO World Congress of Gynecology and Obstetrics, 1979, chaired by Maeda and Kratochwil, and A Kurjak was an invited speaker, which was the first visit to Japan (Fig. 18).

The 2nd World Congress Ultrasound in Medicine was held at Miyazaki, Japan, 1979, July, where Kurjak and Maeda attended.

The 3rd World Congress Medical Ultrasound, Brighton, 1982.

The 4th World Congress Ultrasound in Medicine, 1986 Sydney, where Kasai reported color-Doppler flow mapping (Fig. 19). Many manufacturers added color Doppler function, in 1986.

The 1st Congress of International Society of Ultrasound in Obstetrics and Gynecology (ISUOG), President S Campbell, 1991, London. Maeda organized its 5th Congress in Japan, 1995.

UI OCTOSON

Particular resolution was achieved under special handling using the UI Octoson, 1975, which would be the progress of film echoscopy of G Kossoff, eight focusing transducer moved in the two ton's water tank, covered by plastic film, where the patient or pregnant woman who lied prone attaching her abdomen to the plastic membrane (Fig. 20). Single image photo of the highest resolution was achieved after the scan with eight moving scanner (Fig. 21).

In spite of surprising resolution of Octoson, general trend moved to electronic scan real-time B-mode.

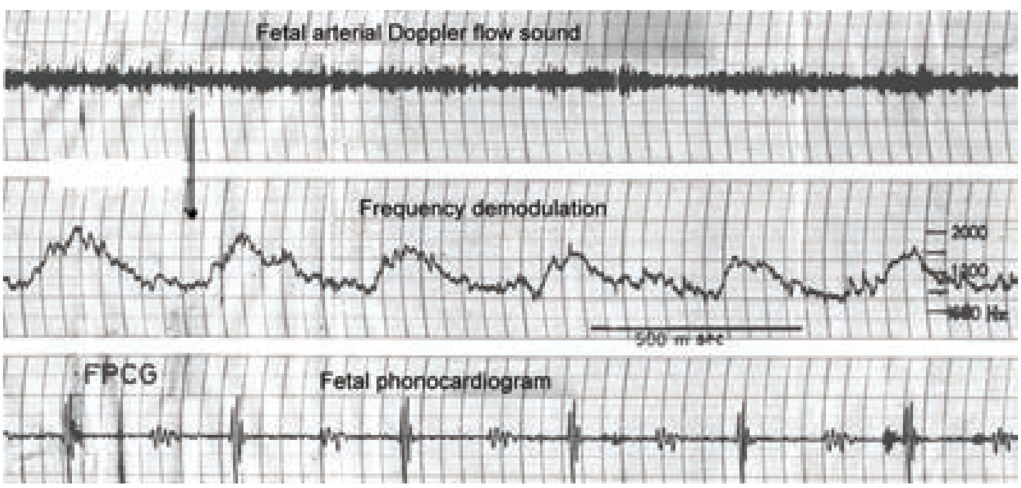

Fig. 17: World first fetal arterial Doppler blood flow wave; 1st line: Doptone sound of fetal arterial blood flow; 2nd line: the CW Doppler fetal arterial blood flow wave, which was obtained by frequency demodulation of the first line signal; 3rd line was I and II fetal heart tones

Fig. 18: "Ultrasound" session was held by the chair of Maeda and Kratochwil, in IX FIGO Congress of Gynecology and Obstetrics, 1979. It was the first visit of Professor Kurjak to Japan. The photo was speaker's dinner in Tokyo

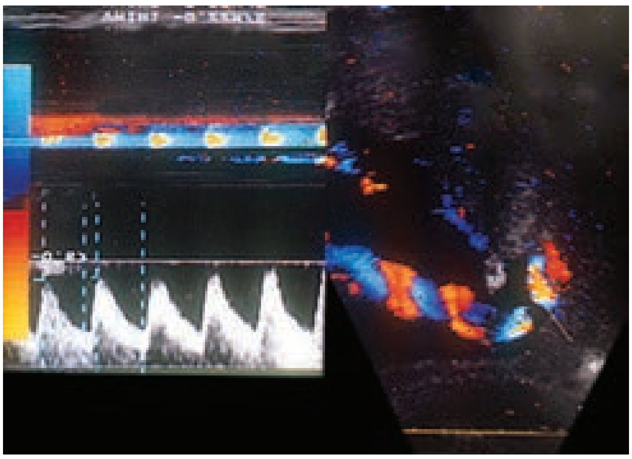

Fig. 19: Pulsed Doppler umbilical arterial blood flow curve and color Doppler flow mapping of umbilical cord

Fig. 20: UI Octoson sonograph in Juntendo University. Eight focused transducers rotated in two tons water, but untouched the body. Kossoff reported it 1977

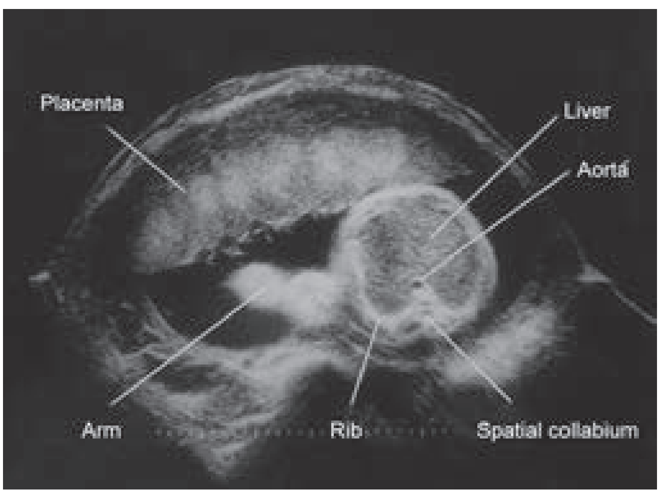

Fig. 21: Transverse scan of a pregnant woman using UI Octoson shown in Fig. 20. Two dimensional B-mode highest resolution was achieved (*Courtesy:* Professor H Takeuchi)

ACTOCARDIOGRAM

K Maeda made actocardiogram (ACG) by his hand in 1984,[4] where ultrasound probe received reflected fetal cardiac Doppler signals (>100 Hz) and fetal chest motion Doppler signals (20–50 Hz), where they were divided into two groups using 20 to 80 Hz band-pass filter. Fetal heart signal was changed to fetal heart rate curve by autocorrelation heart rate meter, and movement signals were changed to spikes, i.e., the ACG is the simultaneous record of fetal heart rate and movement signals. Commercial model added uterine contraction curve, then the record prepared two functions, ACG and cardiotokogram (CTG), where both were utilized for fetal monitoring, namely it can be Actocardiotokogram. The ACG solved the problems of CTG, and also prepared superior fetal analyzing functions (Fig. 22).

ULTRASOUND SAFETY

We had shocking problem in the safety of ultrasound in 1971 to 1976, namely Shimizu et al[8] attached ultrasound generating transducer directly to the abdomen of pregnant mice to expose 100 mW/cm^2 ultrasound for 6 hours,

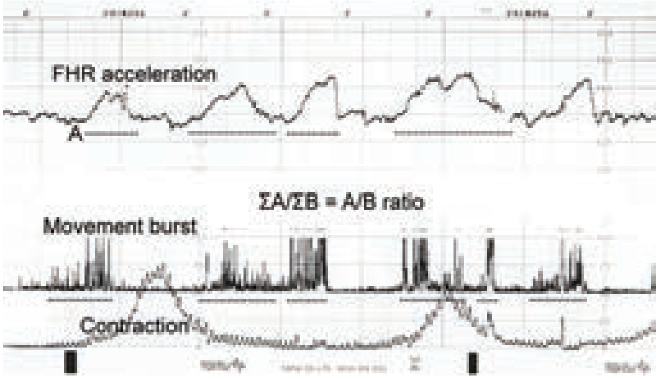

Fig. 22: Actocardiogram in active fetal state. There were FHR accelerations synchronized with fetal movements. "A" was duration of FHR acceleration, and "B" duration of fetal movements. The A/B ratio indicates fetal outcome. Uterine contraction was a diagnostic parameter of "late deceleration" in CTG

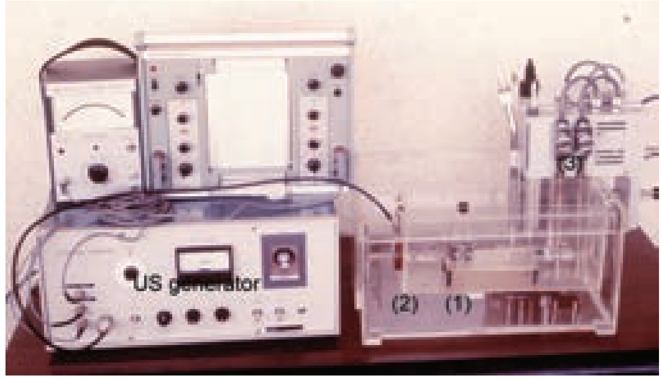

Fig. 23: Ultrasound exposure system utilized in the group study in Japan, where experimental pregnant animal (1) was not heated by ultrasound transducer; (2) inserting stabilized 37°C water (3) between the animal and transducer while ultrasound was fully exposed

then achieved fetal excencephalic anomaly; therefore, the use of ultrasound Doppler fetal heart detector was discarded in early pregnancy, while no ultrasound bioeffect was known among us. Thus, we, obstetric researchers, organized a group to study the ultrasound bioeffects, and it was granted by the Ministry of Health and Welfare of Japan, 1971, where we prepared ultrasound exposure system which cut off the heat of ultrasound transducer inserting 37°C stabilized water between the animal and ultrasound probe (Fig. 23), where Shimizu repeated his animal experiment under no heating of transducer, where no fetal anomaly developed in mice fetuses. Thus, it was concluded in 1976 that the anomaly was caused by the heat of directly attached probe, but not by ultrasound.

Early pregnancy ultrasound was allowed. Tottori university group found that ultrasound had no effect on fetal origin cultured cells, if the output intensity was lower than 240 mW/cm^2, utilizing the special ultrasound exposure system. In addition, Japan Industrial Standard regulated ultrasound device output intensity below 10 mW/cm^2, 1982, then diagnostic ultrasound safety was established in Japan. Afterwards, diagnostic ultrasound was widely distributed, and the member was clearly increased in Japan Society of Ultrasound in Medicine.

ELECTRONIC SCAN REAL-TIME B-MODE

A rapid mechanical scan B-mode machine, Vidson, was created by W Krause, East Germany, 1967 (Fig. 24).

JD Sommer et al proposed the principle of electronic sector scan B-mode, 1967.

N Bom proposed the principle of rapid linear scan, 1967.

M-mode machines were provided by many companies. Digital sonographs was provided by companies in 1972.

The electronic scan real-time B-mode utilizing multiple small transducer units in linear and curved lines producing linear, and sector proves, which were utilized in modern real-time B-mode devices after 1980.

Fig. 24: Rapid mechanical scan B-mode machine, Vidson at Basel university, shown by Prof Hammacher in 1971

Nihon Musen Irigaku demonstrated linear electronic scan B-mode in an Ultrasound Congress to show swimming goldfish in water, where Maeda was impressed by the moving fish images detected by the ultrasound.

Nihon Musen Irigaku provided electronic sector, linear scan real-time sonographs, 1975, of which handling was easy.

Advanced diagnostic research corporation provided linear electronic scan real-time machine. Maeda used its model 2130 which prepared neither interlace nor focusing, 1975 (Fig. 25).

Many electronic scan real-time B-mode devices were provided during the period of 1976 to 1977.

At least 64 small ultrasound units was the base of real-time machine. The units were electronically scanned and manual scan was discarded. The driving time of the units were controlled to form a focus, then repeated in whole units; thus, fine focused image was achieved. Then the

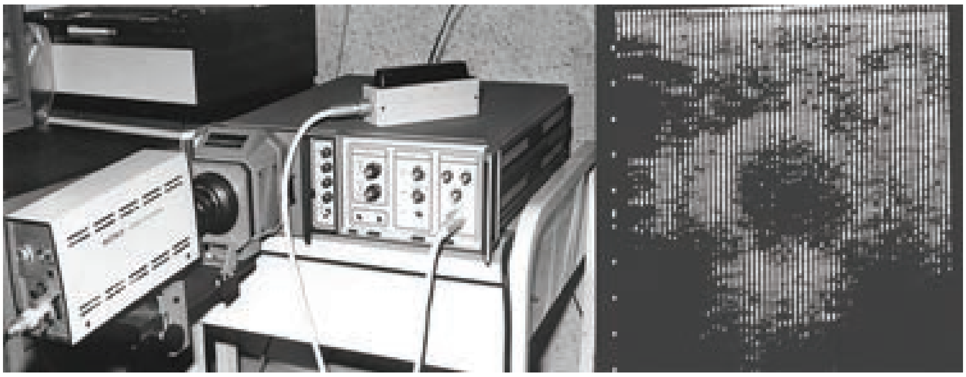

Fig. 25: Early linear electronic scan real-time B-mode, ADR2130, 1975, composed of 64 ultrasound units. It achieved low-grade sonogram, because neither interlace nor focusing was prepared. Sonogram was improved in later machines

focusing is repeated in all depths; thus, generally focused to achieve high-resolution image. Linear or convex scan is adopted for abdominal scan, the sector scan to the heart, and small convex scan to transvaginal scan.

Portable B-mode machines were provided by many companies.

Toshiba, provided ultrasonography-guided puncture transducer, and rectal scan, 1979.

Aloka provided SSD-250 electronic scan sonograph, 1979.

Toshiba provided electronic scan convex transvaginal transducer, 1984.

Hitachi Medico provided finger-tip transducer proposed by H Takeuchi.

It is the most common at present to diagnose the patient and pregnant woman using electronic scan real-time sonograph.

RK Pooh studied fetal brain images through the fetal head fontanel in the cephalic position using transvaginal scan, where various update functions, e.g., blood flow with color Doppler flow mapping and pulsed Doppler ultrasound.

3D–4D ULTRASOUND

K Baba created world first 3D ultrasound machine 1986, which further progressed in Kretztechnik in Vienna, and provided world first 3D ultrasound system.

They provided Combison 330, 1989, then Combison 530, 1993, Voluson 530D was full digital, and interactive real-time 3D-rendering. 4D ultrasound was incorporated in Voluson 730, 1998.

Medison acquired Kretztechnik, 1996.

GE Medical Systems acquired major share of Kretztechnik of Medison, 2001.

Professor Kratochwil advised Kretztechnik on 3D equipment.

Clinical use of 3D ultrasound did start with the first commercial 3D ultrasound unit (Combison 330, Kretztechnik Zipf, Austria) that was introduced in 1989.[11,12] With this unit it became possible for the first time to produce the so-called multiplanar (= triplanar) images.[13]

In a first comparison study of 2D and 3D ultrasound in the fetal face, Merz et al[14] could demonstrate that 3D technology does not only help in appreciating the severity of a fetal defect, but it can also provide more convincing evidence of a normal fetus than conventional 2D sonograms.[14]

Three-dimensional ultrasound has become widely available globally since the first World Congress on 3D ultrasound was initiated and organized by Eberhard Merz (Fig. 26)[13] on September 5 to 6, 1997 in Mainz, Germany.

For an overview on 25 years, 3D ultrasound see the publication of Merz in 2015.[13]

RECENT PROGRESSES

Maeda was honorary professor of Tottori University, 1990

Digital, portable devices or special purpose transducers were provided, 1992 to 1996.

Toshiba HIFU therapy of placental hypertrophy, 1997.

Fig. 26: Announcement of the first World Congress on 3D ultrasound held on September 5 to 6, 1997 in Mainz, Germany

Carl Kretz received Ian Donald Gold medal/ISUOG, 1998. Sonoembryology was reported by R Pooh and H Takeuchi:

Genetic sonography was discussed by R Pooh and A Kurjak: For 13, 18 and 21 trisomies supposed by: FGR, fetal head anomaly, NT, diaphragmatic hernia, umbilical hernia, prune-Belly syndrome, intestinal closure, cystic kidney diseases, renal aplasia, cleft lip, cleft palate, micrognathia, nasal bone defect, low set ear, short extremity, clubfoot, polydactyly, syndctury, single umbilical artery, polycystic placenta, abnormal ductus venosus flow and KANET score, where 3D and 4D ultrasound was very useful to check fetal small parts. The field was progressed by 4D HDlive Silhouette techniques also (RK Pooh and T Hata).

Diagnosis of congenital heart diseases was progressed by 4D ultrasound in fetal echocardiography:

Ring transducer and matrix transducer are update trial.

Strain and shear wave elastography of the uterine cervix were studied in preterm delivery, where the latter may be promising.

Contrast sonography was applied in ultrasonic hysterosalpingography, in obstetrics and gynecology.

CLINICAL TISSUE CHARACTERIZATION

It is gray level histogram width (GLHW), which achieved tissue diagnosis by GLHW obtained by the analysis of gray level histogram of B-mode devices without particular computer or software (Fig. 27).[5]

The GLHW of malignancies in ovary and endometriom was larger than normal tissue, and malignancy GLHW was 50% or more.

The GLHW of placental intervillous fibrin deposit was larger than normal placenta in fetal growth restriction, which was treated by heparin, increasing fetal weight, preventing fetal asphyxia then achieved normal neonate; GLHW was high in fetal brain periventricular echo density predicting preterm neonatal periventricular leukomalacia and cerebral palsy.

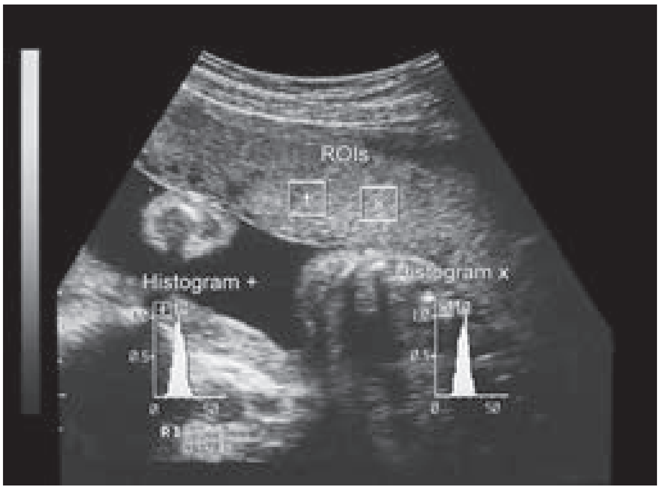

Fig. 27: Gray level histograms of two placental ROIs GLHW values are shown with “%W” index in the legends of histograms

Meconium-stained amniotic fluid GLHW was larger than clear fluid. Fetal asphyxia was diagnosed and predicts meconium aspiration.

Fetal lung immaturity was noninvasively diagnosed, if fetal lung and fetal liver GLHW ratio, multiplied by pregnancy weeks is less than 29.

Adult liver tissue GLHW will be promising to detect liver diseases.

RECENT RESEARCHES

“Fetal Neurology” was studied by Pooh and Kurjak,[6] in Anencephaly, Acrany, Excencephaly, Microcephaly, Corpus callosum defect, Ventriculomegaly, Hydrocephaly, Holoprocencephaly, Porencephaly, Dandy-Walker anomaly, Meningocele, Spina bifida and Chiari-II syndrome (Cranum lemon sign, Cerebelar banana sign, hydrocephaly), Apert syndrome, 2015.

GE 3D ultrasound added HDlive Silhouette functions, 2015.

Biometric measurements of the fetal corpus callosum by three-dimensional Ultrasound was published by Pashaj et al[15] in 2013.

RECENT REPORTS ON POSSIBLE HAZARD CAUSED BY ULTRASOUND IN FETAL ANIMALS

The reports of Ang et al and Ping et al on fetal animal brain damages might be caused by long time direct heating animals by attached ultrasound probe, but not by ultrasound because their output intensity was less than the threshold (240 mW/cm^2). Pellicer’s report on the transient increase of hepatic apoptosis of fetal animal may not be hazardous apoptosis, but it will be prudent to follow ISUOG regulation.

REFERENCES

1. Ichizuka K, Matsuoka R, Aoki H, Hasegawa J, Okai T, Umemura S. Basic study of less invasive high-intensity focused ultrasound (HIFU) in fetal therapy for twin reversed arterial perfusion (TRAP) sequence. J Med Ultrason (2001) 2016 Oct;43(4):487-492.
2. Kretz P. From wired frames to 3D. A short story of Kretztechnik AG, Zipf, Austria. Article by Dr. Joseph Woo.
3. Maeda, K. Ultrasound history. The 8th Ian Donald Course. Marugame: Ian Donald Japanese Branch; 2006.
4. Maeda K. New ultrasonic Doppler fetal actograph and continuous recording of fetal movement. Nihon Sanka Fujinka Gakkai Zasshi 1984 Feb;36(2):280-288.
5. Maeda K, Murao F, Yoshiga T, Yamauchi C, Tsuzaki T. Experimental studies on the suppression of cultured cell growth curves after irradiation with CW and pulsed

ultrasound. IEEE Trans Ultrason Ferroelectr Freq Control 1986;33(2):186-193.
6. Pooh, RK.; Kurjak, A. Fetal neurology. New Delhi: Jaypee Brothers; 2009.
7. Pooh, RK.; Kurjak, A. Donald school atlas of ultrasound in obstetrics and gynecology. New Delhi: Jaypee Brothers; 2016.
8. Shimizu T, Fukushima T, Shoji R. Teratogenesity and ultrasound exposure. Obstet Gynecol 1970;37:1339-1343.
9. Shimizu T, Tanaka K. Basic studies on the bioeffect of pulse wave ultrasound. Special Issue, Studies on the safety of pulse wave ultrasound on the fetus. Ultrasound Med 1981;8:289-292.
10. Woo J. A short history of the development of ultrasound in obstetrics and gynecology.
11. Kirbach D, Whittingham TA. 3D ultrasound – the Kretztechnik Voluson® approach. Eur J Ultrasound 1994;1:85-89.
12. Merz E. Current 3D/4D ultrasound technology in prenatal diagnosis. Eur Clinics Obstet Gynaecol 2005 Dec;1(3):184-193.
13. Merz E. 25 years of 3D ultrasound in prenatal diagnosis (1989–2014). Ultraschall Med 2015 Feb;36(1):3-8.
14. Merz E, Weber G, Bahlmann F, Miric-Tesanic D. Application of transvaginal and abdominal three-dimensional ultrasound for the detection or exclusion of malformations of the fetal face. Ultrasound Obstet Gynecol 1997 Apr;9(4):237-243.
15. Pashaj S, Merz E, Wellek S. Biometry of the fetal corpus callosum by three-dimensional ultrasound. Ultrasound Obstet Gynecol 2013 Dec;42(6):691-698.