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REVIEW ARTICLE

The Safe Use of Diagnostic Ultrasound in Obstetrics and Gynecology

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ABSTRACT

The diagnostic ultrasound was considered safe after the intensity threshold was known and the output intensity (Ispta) was regulated to be less than 10 mW/cm^2 in diagnostic devices in Japan, and diagnostic ultrasound was thought safe in USA when both thermal index (TI) and mechanical index were less than 1.0 in the obstetrical setting. Simple B-mode machine was not concerned from the thermal reason due to its extremely low ultrasound intensity, while the exposure was recommended within 30 minutes. Diagnostic ultrasound should be used after obstetrical setting in fetal study. The TI will be higher in febrile cases than nonfebrile, and the surface temperature of transvaginal scan (TVS) probe should be lower than 41ºC. Simple three-dimensional or four-dimensional ultrasound imaging without pulsed Doppler studies will be as safe as B-mode when the study is within 30 minutes, because they are composed of simple B-mode images. The spectral Doppler study was not routinely used and its exposure should be short in 11 to 13 weeks of pregnancy in the statements of WFUMB and ISUOG, because experimentally early fetal animal tissue was sensitive to the studies. The use of diagnostic ultrasound should be limited for medical purposes, but not for the entertainment or keepsake of pregnancy.

Keywords: Fetus, Early pregnancy, Diagnostic ultrasound safety, B-mode, 3D and 4D ultrasound, Pulsed Doppler ultrasound.

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INTRODUCTION

Although no adverse effect of diagnostic ultrasound has been reported, and the trial study of handedness after prenatal exposure was insignificant,[1] ultrasound bioeffect and the safety of ultrasound diagnosis have been concerned because the embryo and early fetus is diagnosed by ultrasound in the sensitive stages of their tissues to external energies,[2-5] the ultrasound probe is close to the embryo and early fetus in the transvaginal scan (TVS) and it is common to screen the embryo and fetus in the first-trimester of pregnancy to confirm fetal ages with the crown-rump length (CRL), to diagnose fetal life by heart beats, or to detect fetal abnormality or signs to suspect congenital anomalies for the early diagnosis of fetal anomalies, trisomies and fetal central nervous system (CNS) anomalies, for nuchal translucency (NT) or the spectral Doppler studies in fetal ductus venosus and tricuspid valve to assess fetal trisomy, with real-time two-dimensional (2D) B-mode, three-dimensional (3D) and four-dimensional (4D) ultrasound. The diagnosis of fetal intracranial structure through fetal fontanel or sutures in TVS contributed the fetal neurology. In gynecology, uterine anomaly, fibroids, endometrial hypertrophy, polyp, malignancy, trophoblastic diseases, tube patency, hydrosalpinx, polycystic ovary, benign ovarian cysts and malignant masses, endometriosis, ovarian follicle, ovulation, hyperstimulation syndrome and others are diagnosed by 2-4D and Doppler ultrasound, particularly in TVS. No adverse effect of ultrasound had been expected, while the safety was experimentally studied in the wide utility of ultrasound, particularly in prenatal diagnosis.[8-10]

ULTRASONIC BIOEFFECT

As ultrasound is weak in both average and peak intensities, ultrasound bioeffect is not concerned in the continuous wave (CW) ultrasound utilized in Doppler fetal heart detector and monitors of fetal heart rate (FHR) and movement, whereas most imaging ultrasound equipments utilize pulsed wave (PW) ultrasound of which intensity is weak in average but it is as strong as several 10 W/cm^2 in their instantaneous peak intensity, particularly in the spectral pulsed Doppler (Fig. 1). As absorbed ultrasound rises exposed tissue temperature and the heating of fetus with a high temperature is teratogenic in biological experiments,[7] thermal effect of ultrasound produced by its absorption to the tissue was

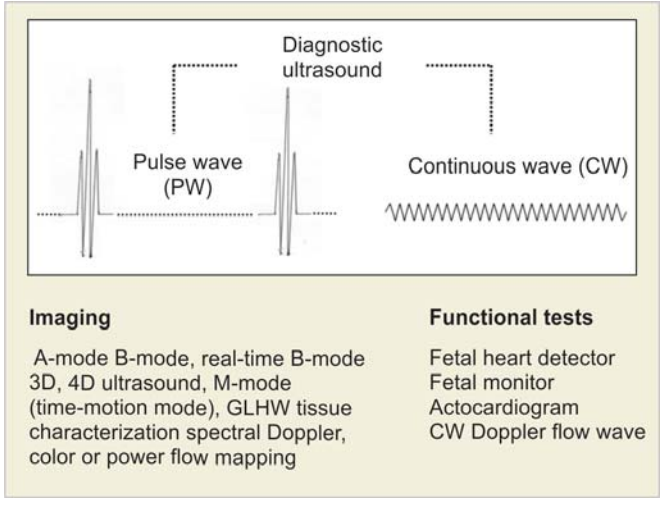

Fig. 1: Two types of ultrasound waves used in the diagnostic equipments

discussed in the average intensity, whereas the high peak intensity of PW may produce tissue changes by such mechanical mechanism as the sonic pressure, micro-streaming, standing wave, particularly by the cavitation and free radical formation at the peak of PW pulse. As the effects are related to the pressure of PW pulse, the mechanical effect is another parameter to assess ultrasound safety.

Heating Effect (Thermal Effect) of Ultrasound

Direct heating of animal fetus produced head and neck anomalies with short heating with high temperature, e.g. 43ºC for 1 minute, but less effect by long exposure to low temperature, in biological experiments.[7]

In case of diagnostic ultrasound, the temperature of exposed biological tissue rises by the absorption of ultrasound, where 1ºC or less temperature rise above 37ºC produces no fetal anomaly in prolonged ultrasound exposure. Therefore, a diagnostic ultrasound is regulated by the temperature rise.

Because of the ultrasound absorption, attenuation of ultrasound during propagation, and the cooling condition by local perfusion are different according to the tissue exposed to ultrasound, the ultrasound which rise temperature for 1ºC above 37ºC in the tissue of a standard condition was defined as 1.0 of thermal index (TI), where actual temperature after rise is 38ºC. The TI is 2 when the temperature rise is 2ºC and actual temperature is 39ºC, and the TI is 6 in case of 6ºC rise and 43ºC.[6]

Since, temperature rise is high in the bone and low in the soft tissue, TI is classified into the bone TI (TIB), soft tissue TI (TIS) and cranial TI (TIC), where bone TI was applied to the fetus after bone production in 10 weeks of pregnancy, soft tissue TI in the embryo before 10 weeks, and cranial TI to the brain examination within the skull.

TI should be one or less in daily clinical practice, screening of the fetus and scientific study. TI should be 1.0 or lower in obstetrical setting. In clinical use of ultrasound devices, output ultrasound TI exposed on monitor screen higher than 1.0 should be lowered by controlling the output power of the device by the user until the TI indicates 1.0 or less.

Other Thermal Issues

The surface of TVS probe should not be heated to 41 or more ºC because of hazardous effect on the vaginal mucosa or the subjects in the pelvis. Caution should be paid on febrile patient whose temperature is higher than 37ºC, i.e. actual TI is higher than nonfebrile condition and, therefore, the exposure time should be shorter in the occasion.

Mechanical Effect of Ultrasound

Most diagnostic ultrasound, except for the continuous wave of fetal heart beat detector or fetal monitor, is pulse wave with short μsec duration containing few ultrasound waves and high peak intensity, i.e. average intensity is milli-W/cm^2 while the peak intensity is several ten W/cm^2. Hence, the mechanical effect is higher than the CW ultrasound, and its mechanical effect is expressed by the mechanical index (MI) that is rarefactional sound pressure (Pr) in Mega-Pascal (MPa) divided by square root of ultrasound frequency (MHz), e.g. MI is 1.0 when Pr is 1 MPa and the ultrasound (US) frequency is 1 MHz (Fig. 2).[6]

The MI indicates nonthermal effect of ultrasound particularly for the cavitation in the presence of gas bubbles in the liquids, because the cavitation may produce local high temperature and strong pressure. The cavitation, however, does not occur within the cell because of high viscosity of cell plasma, and the free radical produced by cavitation in the liquid does not reach the cell due to its short life span. It is, however, recommended that the MI should be less than one in the fetus and neonate. Adverse mechanical effect caused by the standing wave or acoustic streaming has not been reported.

ULTRASOUND SAFETY IN B-MODE

In our experience,[11] cultured cells of amniotic origin floated in culture medium and in ultrasound lucent container was exposed to pulsed ultrasound for 20 to 30 minutes insulating the heat of the transducer by the thermostatic water (Fig. 3), where the cell growth curve showed no difference to the sham by the pulse wave ultrasound of which intensity was below spatial peak temporal average (SPTA) 240 mW/cm^2. Afterward, Japan Industrial Standard (JIS) regulated the output intensity of ultrasound B-mode below SPTA 10 mW/cm^2,[12] and ultrasound safety was established in Japan. According to WFUMB safety committee, there was no

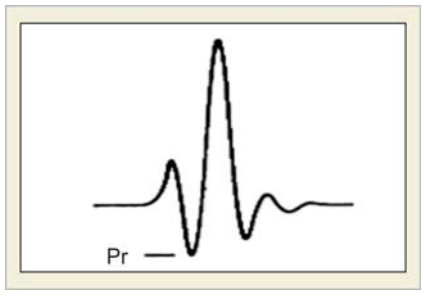

Fig. 2: Typical pulse wave of B-mode ultrasound: Mechanical index (MI) = Pr (mega-pascal)/ $\sqrt{\text{frequency (MHz)}}$, Pr = rarefactional pressure (negative pressure), mechanical effect is caused by sound pressure, large mechanical effect of spectral Doppler is caused by long pulse, high pressure and high repeated frequency, MI should be 1 or less in obstetrics

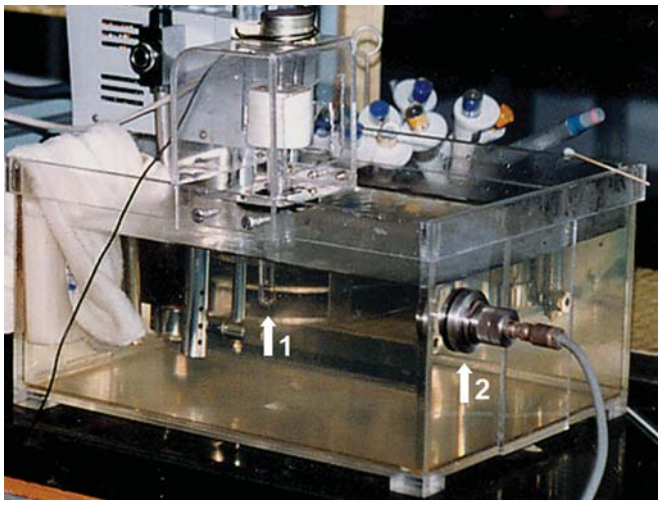

Fig. 3: Cultured cells were exposed experimental ultrasound in the 37°C water insulating the heat of transducer. The arrow 1 is cell container and arrow 2 ultrasound generating transducer. Pregnant animals were also exposed ultrasound in the water tank separating heated transducer, and no anomaly was produced in our group study

thermal reason to concern simple B-mode ultrasound because of its very low output intensity.

Since, TVS sonography is simple B-mode, there is no reason to concern its use by thermal reason when no spectral Doppler is associated. Transvaginal as well as abdominal scan B-mode without Doppler ultrasound user would follow the suggestion of ultrasound organizations that the exposure time would be less than 30 minutes from the concern to the report on the disturbed neuron migration of animal fetus after exposure to common B-mode ultrasound for more than 30 minutes.[8]

The Safety of Doppler Ultrasound: Statements of WFUMB, ISUOG and AIUM on Doppler Ultrasound in Early Pregnancy

The pulsed Doppler flow velocity measurement (or spectral Doppler) required higher intensity of ultrasound than simple B-mode. The ultrasound intensity of color or power flow imaging was less than pulsed Doppler due to scanning of ultrasound beam but needed higher output intensity than simple B-mode. Therefore, Doppler ultrasound TI and MI are requested to be one or less in the obstetrical setting.

Pellice et al[9] studied fetal ductus venosus (DV) flow in 18 days' pregnant rats by a pulsed Doppler ultrasound (5.8 MHz, Ispta 140.6 mW/cm^2, both TI and MI were less than1.0) for 20 to 600 seconds, and found significant linear increase of apoptotic index of fetal rat liver cell at 7 hours after the exposure. The threshold of no damage was 10 seconds exposure. The damage was transient and reversible, i.e. it was not found 12 hours after the ultrasound exposure.

Schneider-Kolsky et al[10] exposed 19 days' fetal chick brain to B-mode ultrasound for 4 and 5 minutes, and to pulsed ultrasound for 1 to 5 minutes *in vivo*. There was no change after B-mode exposure, but significant impairment occurred and an inability to learn was noted after 4 and 5 minutes pulsed ultrasound exposure. Authors concluded that extended exposure to pulsed Doppler ultrasound can adversely affect cognitive function in the chick, while the results can also possibly be due to the heated skulls of fetal chick by the full absorption of ultrasound by mature chick skull bones in the long exposure.

The World Federation for Ultrasound in Medicine and Biology (WFUMB),[13] International Society of Ultrasound in Obstetrics and Gynecology (ISUOG)[14] and American Institute of ultrasound in Medicine (AIUM)[15] approved the following statement on the safe use of Doppler ultrasound during 11 to 13 + 6-week scans (or earlier in pregnancy) in 2011:

1. Pulsed Doppler (spectral, power and color flow imaging) ultrasound should not be used routinely.
2. Pulsed Doppler ultrasound may be used for clinical indications, such as to refine risks for trisomies.
3. When performing Doppler ultrasound, the displayed TI should be less than or equal to 1.0, and exposure time should be kept as short as possible (usually no longer than 5-10 minutes) and not exceed 60 minutes.
4. When using Doppler ultrasound for research, teaching and training purposes, the displayed TI should be less than or equal to 1.0, and exposure time should be kept as short as possible (usually no longer than 5-10 minutes) and not exceed 60 minutes. Informed consent should be obtained.
5. In educational settings, discussion of first-trimester pulsed or color Doppler should be accompanied by information on safety and bioeffects (e.g. TI, exposure times, and how to reduce the output power).
6. When scanning maternal uterine arteries in the first-trimester, there are unlikely to be any fetal safety implications as long as the embryo/fetus lies outside the Doppler ultrasound beam.

We[16,17] also proposed to allow the use of pulsed Doppler flow study within 4 to 5 minutes in particular case.

THE SAFETY OF 3D ULTRASOUND

The 3D ultrasound images are obtained by computer processing of repeated simple B-mode scans in a few seconds where a part of fetus will not be repeatedly exposed to the ultrasound. Since, the use of simple B-mode without spectral Doppler is not concerned by the thermal effect

because of its very low output power,[1] its use is safe if its TI and MI are 1.0 or less. The combination of spectral Doppler, color or power Doppler flow imaging, however, should follow the 2011 WFUMB statement listed in this article.[11]

THE SAFETY OF 4D ULTRASOUND

Since, the 3D ultrasound is repeated with the 10 to 20 per second frame rate in simple 4D ultrasound to analyze the motion of subjects on the screen, the basic imaging is simple B-mode technique and, therefore, basically safe from the thermal effect of ultrasound due to low output intensity of ultrasound probe, and the examination is safe, if the TI and MI are 1.0 or less. The 4D study duration is recommended to be less than 30 minutes according to the opinion of ultrasound organizations on the report of disturbed neuron migration of animal fetus.[10] The combination of pulsed Doppler flow velocity measurement, color or power Doppler flow imaging should follow the 2011 WFUMB statement listed above in this article.[11]

NONMEDICAL USE OF DIAGNOSTIC ULTRASOUND

Although the use of diagnostic ultrasound should be limited for medical purposes and users should be responsible to the safety of ultrasound, i.e. users must keep the knowledge on possible ultrasound bioeffect and use the ultrasound under the ALARA (as low as reasonably achievable) principle, nonmedical ultrasound in entertainment or keepsake ultrasound, fetal portrait studies or prenatal boutiques which record intrauterine fetal 3D/4D ultrasound on DVD are recent problems concerning ultrasound safety.[18-21]

The WFUMB[18] disapproves of the use of ultrasound for the sole purpose of providing souvenir images of the fetus. Because the safety of an ultrasound examination cannot be assured, the use of ultrasound without medical benefit should be avoided. Furtheremore, ultrasound should be employed only by health professionals who are well trained and updated in ultrasound clinical usage and bioeffects. The use of ultrasound to provide keepsake images or video of the fetus may be acceptable, if it is undertaken as part of normal diagnostic ultrasound examination, provided that it does not increase exposure to the fetus. Ultrasound imaging for nonmedical reasons is not recommended unless carried out for education, training or demonstration purposes. Live scanning of pregnant models for equipment exhibition at ultrasound congresses is considered a nonmedical practice that should be prohibited since, it provides no medical benefit and afford potential risk to the fetus.

DISCUSSION

It is important to understand any up-to-date safety statements or new ultrasound bioeffect reports, while the diagnostic ultrasound user has not to be affected by the report of false-positive results in the evaluation of ultrasound safety, which would be sometimes incorrect experimental design, or the exposure subjects heated directly by attached ultrasound radiating units of high temperature but not by ultrasound absorption, or the cell damage caused by the toxic substance developed by the decomposed cell container wall and mixed to the cell floating liquid but not by direct ultrasound effect which actually occurred in the experiment of sister-chromatid exchange, and so on.

Therefore, in our experiments, firstly cultured cell damage was confirmed by the cell-toxic substance mixed to the culture fluid, and the culture fluid in the cell container without culture cell was exposed to ultrasound then culture cells were added the fluid to confirm no cell damage before the experiment of ultrasound effect on cultured cells. Also, ultrasound translucency of cell container was confirmed by the comparison of outputs of tiny ultrasound hydrophone in—and outside of container. Local ultrasound intensity was confirmed by a tiny-steelball placed at the cell container in the water tank. Moving distance of the steel ball by the exposure to experimental ultrasound was measured by a telemicroscope from outside of the water tank. Actual cell exposure was performed in the water tank separating the cell container and ultrasound transducer by at 37ºC—stabilized water.

As ultrasound is a kind of sound, which is mechanical vibration but not an ionizing radiation, therefore, there are thresholds of ultrasound intensity and exposure time in the production of bioeffect under which no bioeffect exists. Therefore, clinical ultrasound should be utilized under the threshold to avoid any bioeffect. There will be no 'risk/benefit' decision but only to seek the threshold in clinical application. To define the threshold and report it to the user will be the important role of medical ultrasound organizations. The threshold is ultrasound intensity or exposure time, i.e. ultrasound intensity will be reduced possibly to enlarge the exposure time, if it is too short to clinical study. The researcher would respond the query of ultrasound users by repeating experiments. That has been done in the history of clinical ultrasound application.

CONCLUSION

Main thermal and mechanical adverse effect of diagnostic ultrasound was effectively prohibited by the introduction of low thermal and mechanical indices in the production of diagnostic ultrasound equipments, and also by the efforts

of medical ultrasound users to keep the ultrasound exposures under the threshold level of ultrasound bioeffect also by the education, leaning and efforts of users. Recent progresses in the recommendations of ultrasound organizations promoted by various up-to-date experiments may further improve the safe use of ultrasound in obstetrics and gynecology.

REFERENCES

1. Heikkila K, Vuoksimaa E, Oksava K, Saari-Kemppainen A, IIvanainen M. Handness in the Helsinki ultrasound trial. Ultrasound Obstet Gynecol 2011;37:638-42.
2. Barnett SB, Kossoff G. WFUMB symposium on safety and standardization in medical ultrasound. Issues and recommendations regarding thermal mechanisms for biological effects of ultrasound. Ultrasound in Med Biol 1992;18:731-810.
3. Barnett SB, ter Haar GR, Ziskin MC, et al. Current status of research on biophysical effects of ultrasound. Ultrasound in Med Biol 1994;20:205-18.
4. Barnett SB, Rott HD, ter Haar GR, et al. The sensitivity of biological tissue to ultrasound. Ultrasound Med Biol 1997;23:805-12.
5. ISUOG bioeffects and safety committee; Safety statement: 2000 (reconfirmed 2002) Ultrasound Obstet Gynecol 2002;19:105.
6. American institute of ultrasound in medicine/National electrical manufacturers association: Standard for real-time display of thermal and mechanical acoustic output indices on diagnostic ultrasound equipment, 1992.
7. National Council on radiation protection and measurements; exposure criteria for medical diagnostic ultrasound: I. criteria based on thermal mechanisms, NCRP report No. 113, 1992.
8. Ang ESBC Jr, Gluncic V, Duque A, Schafer E, Rakic P. Prenatal exposure to ultrasound waves impacts neuronal migration in mice. Proc Nati Aced Sci USA 2006;103:12903-10.
9. Pellice B, Herraiz S, Taboas E, Felipo V, Simon C, Pellice A. Ultrasound bioeffect in rats: Quantification of cellular damage in the fetal liver after pulsed Doppler imaging. Ultrsound Obstet Gynecol 2011;37:643-48.
10. Schneider-Kolsky ME, Ayobi Z, Lombardo P, Brown D, Kedang B, Gibbs ME. Ultrasound exposure of the foetal chick brain; effects on learning and memory. Int J Dev Neurology 2009;27:677-83.
11. Maeda K, Murao F, Yoshiga T, et al. Experimental studies on the suppression of cultured cell growth curves after irradiation with CW and pulsed ultrasound. IEEE Trans Ultrasonics Ferroelectrics and Frequency Control, 1986;33:186-93.
12. Maeda K, Ide M. The limitation of ultrasound intensity for diagnostic devices in the Japanese industrial standards. IEEE Trans Ultrasonics Ferroelectrics and Frequency Control 1986;33:241-44.
13. WFUMB administrative council (January 2011). Safe use of Doppler ultrasound during 11 to 14 weeks scan (or earlier in pregnancy). AIUM Sound Waves Weekly, March 10, 2011.
14. Opinion: Bioeffects and Safety Committee. ISUOG statement on the safe use of Doppler in the 11 to 13+6-week fetal ultrasound examination. Ultrasound Obstet Gynecol 2011;37:625-28.
15. AIUM. Safe use of Doppler ultrasound during 11 to 14 weeks scan (for earlier in pregnancy). AIUM Sound Waves Weekly, March 10, 2011.
16. Maeda K. Safety of ultrasound in obstetrics and gynecology. In Kurjak A, Chervenak FA (Eds). Donald School Textbook of Ultrasound in Obstetrics and Gynecology (3rd ed), New Delhi: Jaypee 2011:pp 3-9.
17. The safety group of the British medical ultrasound society. Guidelines for the safe use of diagnostic ultrasound equipment. BMUS Bulletin 2000;3:29-33.
18. Barnett SB, Abramowicz JS, Ziskin MC, et al. WFUMB symposium on safety of nonmedical use of ultrasound. Ultrasound in Med Biol 2010;36:1209-12.
19. Abramowicz JS. Nonmedical use of ultrasound : Bioeffects and safety risk, Ultrasound in Med Biol 2010;36:1213-20.
20. Phillips RA, Stratmeyer ME, Harris GR. Safety and US regulatory considerations in the nonclinical use of medical ultrasound devices. Ultrasound in Med Biol 2010;36:1224-28.
21. Brezinka C. Nonmedical use of ultrasound in pregnancy: Ethical issues, patients' rights and potential misuse. Ultrasound in Med Biol 2010;36:1233-36.

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