How to keep all this safe?

The inaugural University of Chicago Ob/Gyn ultrasound Symposium
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DISCLOSURE

I have no conflict of interest with respect to any of the material presented in this lecture. I will not discuss off-label or unapproved uses of drugs or devices.

OBJECTIVES

At the end of the presentation, attendants will be able to
1. Define ALARA
2. Discuss two biological effects of ultrasound waves in insonated tissues;
3. Evaluate the potential risks to the fetus during an ultrasound examination;
4. Identify ways to minimize exposure and risks.

Risk means the chance or the possibility of loss or bad consequence

These are the 3 important characteristics of risk: probability of occurring, nature and magnitude of harm

Complicating factor: personal views

RISK ANALYSIS PRINCIPLES (1)

• Risk/Benefit ratio: How much risk is acceptable to obtain a certain benefit
RISK ANALYSIS PRINCIPLES (2)

- Precautionary principle:
  How much harm can you avoid by not performing a certain action/procedure/test
  If a certain action may cause severe damage to the public, in the absence of a scientific consensus that harm would not ensue, the burden of proof falls on those who would advocate taking the action

"When one anticipates a specific benefit from ultrasound examination that cannot be obtained by safer means, he [sic] should do it"

"When one does not anticipate a specific benefit from ultrasound examination, he [sic] should not do it"

David A. Toms, Annals RCPSC, 1984

John Snow, UK, 1842
"Vorsorge" (forecaring), Germany, 1930
Vorsorgeprinzip, W. Germany, 1970's environmental laws
"Better safe than sorry"
"Primum, non nocere"
First do no harm
ALARA
As Low As Reasonably Achievable

"...with the frequency adjusted for resonance, the narrow beam of supersonic waves shot across the tank causing the formation of millions of minute air bubbles and killing small fish which occasionally swam into the beam. If the hand was held in the water near the plate an almost insupportable pain was felt, which gave one the impression that the bones were being heated."

Professor R. W. Wood, an American physicist from Johns Hopkins University, visiting Langevin's lab in Toulon, around 1924.

Why do we speak about it?

What are these?
Che cosa questo?
Was ist das?
Vad är detta?
Qu'est ce que c'est?
O que é isso?

What could ultralow frequency ultrasound do to the children in Afghanistan?

Questions about Prenatal Ultrasound and the Alarming Increase in Autism

Could ultrasound be a cure for interstitial block silver and 3D process?
WHAT IS THE RATE OF EXPOSURE TO ULTRASOUND?

Estimates:
- “1 out of every 2 children born in the USA has been exposed" (1984)
- 80-90% of 4 million infants born in the USA (2000-2002)
- Close to 100% in some European, Asian, South American countries
- ART: every patient, multiple times
WSJ. 7/17/2015

The Wall Street Journal
Pregnant Women Get More Ultrasounds, Without Clear Medical Need

Experts say frequent fetal scans in low-risk pregnancies aren’t medically justified
WSJ. 7/17/2015

…some pregnant women receive 12-14 scans during their apparently uncomplicated pregnancies…

YES, REALLY, WHY EVEN SPEAK ABOUT IT?

We all know ultrasound is safe
Ultrasound is not Thalidomide
Ultrasound is not X-Rays
“Show us the dead babies!”

Ultrasound= Energy
Ultrasound=waveform with positive and negative pressures

THERMAL EFFECTS (INDIRECT)

Acoustic energy is transformed into heat
NON-THERMAL EFFECTS (DIRECT)

Positive pressure
- Radiation stress
- Acoustic streaming
- Nerve ending stimulation
- ?Release of free radicals

Negative pressure
- (mostly) can cause cavitation
  - Inertial (a.k.a. transient): growth and violent collapse of the bubble
  - Non-inertial: back and forth motion of bubbles

So, ultrasound going through living tissues causes effects (bioeffects)...

...but there are no epidemiological studies demonstrating harmful bioeffects in humans

All epidemiological studies are about exposure before 1992

In 1992, maximal acoustic outputs for fetal applications were allowed to be increased by a factor of 8 (from 94mW/cm² to 720mW/cm², ISPTA)

FDA mandated (together with AIUM, NEMA, public representatives): the Output Display Standard (ODS)

Manufacturers may increase maximal output (up to 720mw/cm² for fetal use) on the condition that two indices appear on-screen:
- Thermal index (TI) for thermal effects
- Mechanical index (MI) for non-thermal (a.k.a. mechanical) effects
- AND: a particular effort is to be made to educate the end-users about bioeffects, safety and TI and MI

THERMAL INDEX (TI)

Uniless estimate of possible tissue temperature rise in °C under "reasonable worst-case conditions"

TI = \frac{\text{total acoustic power}}{\text{acoustic power needed to raise temperature by 1 °C}}

Predicts potential for temperature increase
Not a real temperature measurement
No time (duration of exposure) information

THERMAL INDEX

\[ T_{1_{\text{soft tissues}}}, T_{1_{\text{bones}}}, T_{1_{\text{obstetrics}}}, T_{1_{\text{cranium}}} \]

MECHANICAL INDEX (MI)

MI expresses potential to induce inertial cavitation: bubbles must be present

No bubbles in fetal lungs or bowels
Hence, mechanical risk appears to be low
But what do end-users know about these indices?

Manufacturers must display TI and MI on screen

About 25% of end-users know what TI and MI stand for and indicate

About 2/3 do not know that these indices appear on-screen during the examination

Marsal K, UOG 2006

How about residents and fellows?

.87% of residents and 80% of MFM fellows did not know how to find or use the output display standard (ODS).
.89% of residents and 77% of fellows reported they did not use the ODS during ultrasound scanning.
.37% to 46% of residents and fellows reported no limitations to the use of obstetric ultrasound.
.22% to 39% reported no limitations to the use of Doppler ultrasound in the first, second, and third trimesters.


There is a low level of bioeffects knowledge...no relationship was found between knowledge ...and years of practice

HEAT IS TERATOLOGICAL

Animal experiments (Edwards, Barnett)
Maternal fever in early pregnancy*
External factors (e.g. sauna, hot bath)

But how can it get?

Maximum recommended exposure times for embryo/fetus

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So what?
I use an FDA approved machine

Output is mode dependent (Doppler, B-mode, M-mode, TV probe, Color Doppler, Spectral Doppler)
Output is under examiner control but is altered by manipulating gain controls, apparently not related (focus, gate sample etc)
Every machine behaves differently
Is early pregnancy worse?

- Full bladder (rare in 2017)
- Closer to sonicated tissues (TV ultrasound)
- Transducer face heating

Worst effect at bone-tissue interface

- Very little bone in 1st trimester fetus (none in the embryo or the ovum)
- Heat dissipating capacity??
- Repeat exposure??
- Cumulative effect??

Full bladder (rare in 2017)

Critical Periods of Development

Weeks gestation from LMP 4 5 6 7 8 9 10 11 12

"The critical period for structural teratogen sensitivity, about the 3rd through the 8th post-fertilization week*, is the period of embryogenesis or organogenesis..."

- Central Nervous System
- Heart
- Arms
- Eyes
- Legs
- Teeth
- Palate
- External genitalia
- Ears

Missed Period

Mean Entry into Prenatal Care

Major morphological manifestations

Minor/Functional signs

REI/ART scans

First trimester ultrasound

"The critical period for structural teratogen sensitivity, about the 3rd through the 8th post-fertilization week*, is the period of embryogenesis or organogenesis..."

CONCLUSIONS:
The results indicate that diagnostic ultrasound can induce harmful effects on mouse growth and development when given at certain critical periods of gestation.

"...no epidemiological or other evidence was then [in the early 90's] or is now available to support the assertion of safety at these high exposures"

FIRST-TRIMESTER SONOGRAPHY: IS THE FETUS EXPOSED TO HIGH LEVELS OF ACOUSTIC ENERGY?

Conclusions: First trimester examinations* are associated with a negligible rise in TI


What about the oocyte, the ovary and the very early gestation?


Abstract
We have studied the effects of ultrasound on the female rat fertility. When utilized at similar power than for human beings, the echography reduces significantly the number of foetuses counted at the 15th day of the gestation. A direct action of the ultrasound on the mechanisms of the ovulation is to be considered.


Abstract
Fifty women who were subfertile received artificial insemination from donors (A.I.D.) with ultrasound monitoring of ovulation. They were compared with an identical number of women who were inseminated without ultrasound control. The series side by side showed that there was a lower fertilisation rate in those who were monitored with ultrasound (4.2% compared with 6.2%) per month on average over six months as compared with those who were not monitored by ultrasound, and those who were monitored took significantly longer to become pregnant than those who were not monitored. Because of these results the authors wonder whether ultrasounds are harmful for ovulation.


Whereas follicle rupture never occurred before the 37th hour after an ovulatory stimulus (either the onset of the LH surge or hCG administration) in control patients, ovulation was observed at 26 to 36 h in women submitted to ultrasonography during the late follicular phase. Premature ovulation was observed in 5 out of 23 and 8 out of 19 cycles when ultrasonography occurred during the 3 days preceding or in the 36 h following ovulatory stimulus. This as yet unexplained observation leads us to reconsider the advisability of ovarian scan during the late follicular phase of the menstrual cycle.
...exposure of human oocytes to ultrasonic waves, either during the different phases of meiosis or after the completion of meiosis, did not significantly influence the developmental potential of the in vitro fertilized embryos.

Doppler of the ductus venosus
Transvalvular blood flow, in particular tricuspid valve
Cardiac anatomy and function

THE PUBLISHING OF PAPERS ON 1ST TRIMESTER DOPPLER

Campbell and Platt
Ultrasound Obstet Gynecol, 2000

RESEARCH ON THE FETUS USING DOPPLER ULTRASOUND IN THE 1ST TRIMESTER: GUIDING ETHICAL CONSIDERATIONS.

Chervenak and McCullough
Ultrasound Obstet Gynecol, 2000


- Exposed the brains of chicks on day 19 of a 21 day incubation period to 5 or 10 min of B-mode, or to 1, 2, 3, 4 or 5 min of pulsed Doppler ultrasound in ovo.
- Learning and memory function were assessed at day 2 post-hatch.
- B-mode exposure does not affect memory function.
- Following 4 and 5 min of pulsed Doppler exposure, 2h after training, significant memory impairment occurred.
- In separate groups of chicks, short-, intermediate- and long-term memory was equally impaired suggesting an inability to learn.
- Further, the chicks were still unable to learn with a second training session 5 min after completion of the initial testing.

Abbi M et al.: Mice exposed to diagnostic ultrasound in utero are less social and more active in social situations relative to controls. Autism Research, 2013
Jack Rabin, MD: “Ultrasound & Autism: what every pregnant woman should know” (self-published)
Back cover of the book: “Expectant parents are not informed of the risks of prenatal ultrasound. Ultrasound can raise the temperature of fetal brain tissue to dangerous levels. Current safety controls are inadequate. Your baby’s brain may be permanently injured. This book proves that excessive fetal imaging is the cause of the epidemic of autism spectrum disorder”


http://www.aium.org/soundWaves/article.aspx?aId=965&iId=20160907


Ultrasound and Autism
Association, Link, or Coincidence?
Jacques S. Alpern, MD

There is no independently confirmed peer-reviewed published evidence that a cause-effect relationship exists between in utero exposure to clinical ultrasound and development of ASDs in childhood

Can we calculate how much energy is applied to the fetus?
NO!!
Let's assume 2 minutes each to obtain the BPD, HC, AC, FL.

Total energy is (remember: 34 mW/cm² for B-mode)

\[(34 \times 2) \times 4 = 272 \text{ mW/cm}^2\]

Let's now assume 5 minutes each to find the ductus venosus and the tricuspid.

Total energy is (remember: 1180 mW/cm² for pulsed Doppler)

\[(1180 \times 5) \times 4 = 11800 \text{ mW/cm}^2\]

### Recommended Scanning Time Limits

- **TIb**: 0.5 or 0.1
- **TI**: 1

**Conclusion**: Reliable first-trimester Doppler data can be obtained with output energy reduced to a TIb of 0.5 or 0.1.

**AIUM Statement (2011)**

The use of Doppler Ultrasound during the first trimester is currently being promoted as a valuable diagnostic aid for screening for and diagnosis of some congenital abnormalities. The procedure requires considerable skill, and subjects the fetus to extended periods of relatively high ultrasound exposure levels. Due to the increased risk of harm, the use of spectral Doppler ultrasound with high TI in the first trimester should be viewed with great caution. Spectral Doppler should only be employed when there is a clear benefit/risk advantage and both TI and examination duration are kept low. Protocols that typically involve values of TI lower than 1.0 reflect minimal risk.
WFUMB/ISUOG Statement on the Safe Use of Doppler Ultrasound During 11-14 week scans (or earlier in pregnancy)

Approved by WFUMB Administrative Council, January 27, 2011. (This text is identical to that in the statement published by AFSUMB, AIUM, BMUS, EFSUMB and ISUMB)

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 Thermal Index (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.

Statement on Measurement of Fetal Heart Rate

Approved November 5, 2011

When attempting to obtain FHR with a diagnostic ultrasound system, AIUM recommends using M-mode at first, because the time-averaged acoustic intensity delivered to the fetus is lower with M-mode than with spectral Doppler. If this is unsuccessful, spectral Doppler ultrasound may be used with the following guidelines: use spectral Doppler only briefly (e.g. 4-5 heart beats) and keep the thermal index (TIS for soft tissues in the first trimester, TIB for bones in second and third trimesters) as low as possible, preferably below 1 in accordance with the ALARA principle.

Perform exam if indicated
Keep output as low as possible
Keep exam as short as possible
Compatible with accurate diagnosis
Watch TI (MI) and keep <1

Keep output as low as possible
Keep exam as short as possible
Compatible with accurate diagnosis

I WANT YOU TO THINK ABOUT MI AND TI


Christoph Brezinka